Energy efficiency investments in residential buildings: Does personality matter?

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Abstract

In recent years, energy efficiency in the built environment has been attracting considerable interest to mitigate energy consumption. A number of scientific studies indicate that rising air pollution, decreasing biodiversity, ocean acidification and other adverse effects on humans and the environment in recent decades are due to greenhouse gas emissions, and a substantial share of the emissions can be attributed to energy usage in residential buildings. Investments in energy-efficient technologies have been made to alleviate such human induced causes contributing to the emissions, but they are still far from widespread, calling for a thorough understanding of individuals' decision-making processes to promote further adoption of energy efficiency investments. Although personality has been widely recognised as an explanatory factor of behaviour, a rigorous discussion of it in the context of energy efficiency investments is missing. As such, to understand the role of personality traits in making high-cost energy efficiency investments in residential buildings, this research applies a multidisciplinary approach to derive theoretical models that are evaluated in subsequent empirical investigations using quantitative methods and data from the UK and Germany. The findings suggest three ways through which personality can influence energy efficiency investments. The first is an indirect impact of personality traits through risk preferences, in which the significance of the personality effects depends on the financial subsidy context. The second is an indirect effect of personality traits through environmental concern. The third way suggests an impact of personality traits through their importance for individuals' capability and willingness to consider peer behaviour.

I would like to dedicate this thesis to my family.

Preface

The following material from the research conducted for this thesis has been published:

Parts of Chapter 4:

Busic-Sontic A., Czap N. V., & Fuerst F. (2017). The role of personality traits in green decision-making. *Journal of Economic Psychology*, *62*, 313–328.

Parts of Chapters 5 and 7:

Busic-Sontic A. & Brick C. (2018). Personality trait effects on green household installations. *Collabra: Psychology*, *4*(1): 8.

Parts of Chapter 6:

Busic-Sontic A. & Fuerst F. (2018). Does your personality shape your reaction to your neighbours' behaviour? A spatial study of the diffusion of solar panels. *Energy and Buildings*, *158*, 1275–1285.

Declaration

This dissertation is the result of my own work and includes nothing which is the outcome of work done in collaboration except as declared in the Preface and specified in the text.

It is not substantially the same as any that I have submitted, or, is being concurrently submitted for a degree or diploma or other qualification at the University of Cambridge or any other University or similar institution except as declared in the Preface and specified in the text.

It does not exceed the regulation length of 80,000 words, including footnotes, references and appendices but excluding bibliographies.

Ante Busic-Sontic

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Nomenclature

Acronyms / Abbreviations

ABC	Attitude-behaviour-external conditions theory
APEE	Anreizprogramm Energieeffizienz (Energy Efficiency Incentive Programme)
BAFA	Bundesamt für Wirtschaft und Ausfuhrkontrolle (Federal Office of Economics and Export Control)
BMWi	Bundesministerium für Wirtschaft und Energie (Federal Ministry of Economic Affairs and Energy)
DoI	Diffusion of innovation theory
EE	Energy efficiency
EEG	Erneuerbare-Energien-Gesetz (Renewable Energy Source Act)
EEWärmeG	Erneuerbare-Energien-Wärmegesetz (Renewable Energy Heat Act)
EnEV	Energieeinsparverordnung (Energy Saving Ordinance)
EPC	Energy Performance Contracting
EU	European Union
FIT	Feed-in tariff

IEA	International Energy Agency
IRR	Internal rate of return
KfW	Kreditanstalt für Wiederaufbau (German Development Bank)
MAP	Marktanreizprogramm (Market Incentive Programme)
MBTI	Myers-Briggs Type Indicator
PEB	Pro-environmental behaviour
PV	Photovoltaic
TPB	Theory of planned behaviour
VBN	Value-belief-norm theory

Chapter 1

Introduction

In the current and 20th century, humanity has experienced an increasing pace of self-caused changes that contrasts with the slow speed of biological evolution. This imbalance has brought about a number of problems for the environment and humans, such as pollution, deforestation, diminishing biodiversity and scarcity of natural resources. A sound body of research suggests that the matters in question are produced or aggravated by the extensive use of fossil fuels across the energy system. Whilst there are existing solutions for the reduction or substitution of fossil fuels, they are far from being widely adopted and traditional motivations seem to fall short of their promises (Ramos et al., 2015a). Financial incentives and information provisions attempt to encourage investments in energy efficiency,[1] yet, the uptake of energy-efficient technologies remains moderate in spite of their environmental, social and economic benefits (IEA, 2014a). Closing the gap between potential and realised energy efficiency measures ("energy efficiency gap") requires an understanding of the decision process of energy stakeholders beyond the assumption of rational economic decision-making (Stern et al., 2016a).

[1]According to the International Energy Agency (IEA), "Energy efficiency is a way of managing and restraining the growth in energy consumption. Something is more energy efficient if it delivers more services for the same energy input, or the same services for less energy input" (IEA, 2016).

Independent of the energy resource topic, there is a growing recognition of the explanatory potential of personality traits for economic outcomes (Fletcher, 2013; Rustichini et al., 2016). A systematic understanding of the role of such psychological characteristics in the energy efficiency domain is still lacking. The current thesis aims to reduce this knowledge gap by elaborating on the role of personality traits in residential high-cost energy efficiency investments (e.g. thermal insulation installations). Buildings consume about one-third of the global energy and are responsible for the same share of total carbon emissions; and 75% of the energy consumed can be attributed to the residential sub-sector (IEA, 2013). Enhancing the understanding of households' decisions in this realm may help to achieve energy and greenhouse gas reduction goals.

The thesis begins with a review of the energy efficiency literature, followed by a synthesis of theories from the fields of economics and psychology to derive a novel micro-economic model for energy efficiency investments. The suggested model is evaluated in two empirical cross-sectional analyses. The subsequent chapter proposes an alternative model by nesting personality traits into a diffusion of innovation theory and also tests the model empirically. While the first of the three analyses centres on the role of personality traits for energy efficiency investments primarily from the individual point of view, the second study elaborates on personality trait effects in the context of financial subsidies. The third analysis shifts the focus to the social context and explores the interplay between personality traits and social norms. Based on the findings, alternative forms of incentives to existing environmental policy programmes are suggested to promote energy efficiency investments.

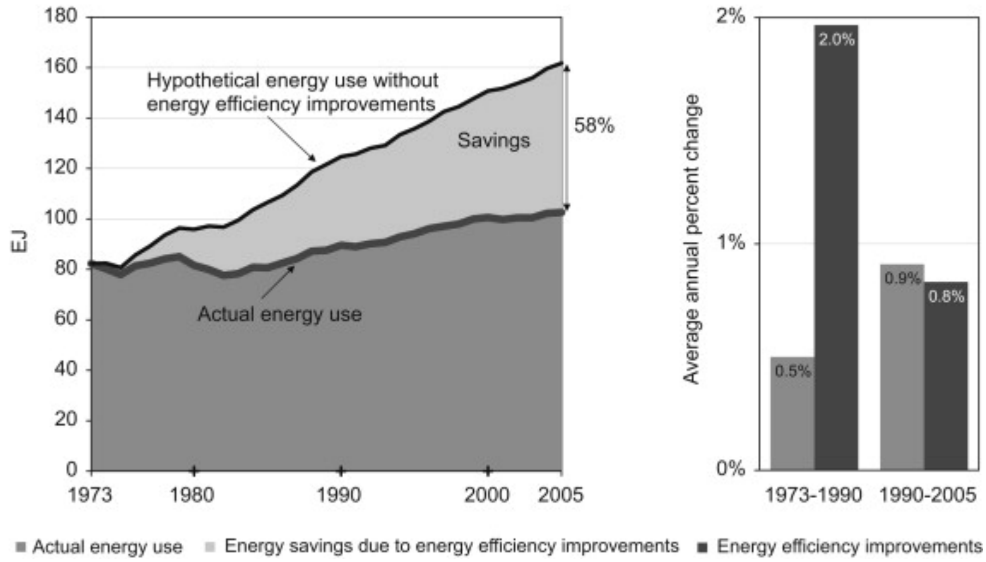
The Introduction outlines the rationale for this thesis. It starts by providing the backdrop to the "energy efficiency gap" and exemplifies a general lack of understanding of how personality traits relate to adoption of energy efficiency measures. Based on these sections, the research questions, scope, design and the contribution of the thesis to knowledge are presented. Next, the term energy efficiency is clarified, energy efficiency as a solution for mitigating the energy use from fossil fuels is discussed and existing policy programmes to increase energy efficiency are summarised. The chapter concludes with the detailed thesis structure.

1.1 The energy efficiency gap

Energy efficiency is considered pivotal in many national policies to tackle carbon emissions from fossil fuels and the scarcity of energy resources (IEA, 2015). Broadly, energy efficiency contributes to solve the "Energy Trilemma" of simultaneously addressing energy security, environmental sustainability and energy equity (accessibility and affordability) (WEC, 2013). The main benefits of energy efficiency include lower energy consumption and costs, reduced greenhouse gas emission and air pollution, lower fossil fuel dependency and investments in energy infrastructure (IEA, 2014a,b; Taylor et al., 2010).

Figure 1.1 illustrates global energy savings from improved energy efficiency levels between 1973 and 2005. The yearly average rate of improvement was positive throughout the period. However, energy efficiency advanced much slower in the period from 1990 to 2005 than before 1990. For the household and service sectors, the lower energy efficiency improvements have led to considerable increases in energy use after 1990 (Taylor et al., 2010). This commonly observed reluctance to make energy efficiency investments, albeit cost effective, is commonly described as the "energy efficiency gap" or "energy efficiency paradox" (Allcott & Greenstone, 2012; Hirst & Brown, 1990; Jaffe & Stavins, 1994).

Traditionally, the explanations of the energy efficiency gap are based on market barrier analyses (Jaffe & Stavins, 1994; Ryan et al., 2012). Imperfect competition and information, capital constraints and hidden transaction costs are commonly identified hindrances that at least partially explain the gap between predicted diffusion of energy efficiency by economic models, and effective energy efficiency adoption (Gerarden et al., 2017). Energy prices usually do not fully internalise environmental costs (e.g. air pollution) and social costs



Source: Adapted from Taylor et al. (2010).

Figure 1.1 Global energy efficiency improvements

(e.g. health costs), which in turn leads to higher energy consumption than what would be optimal (Gillingham et al., 2009). The uptake of energy efficiency measures in the residential markets is additionally impeded by different stakeholder interests. Landlords may have different energy efficiency claims than home builders or renters. For example, a landlord has a lower incentive for energy efficiency upgrades if the renter is paying for the energy bills (Gillingham et al., 2012).

Besides market barriers, behavioural factors started to gain attention in the explanation of the energy efficiency gap. Social norms and personal values among others are found to influence households' decisions related to energy efficiency (Allcott & Rogers, 2014; Crosbie & Baker, 2010). While market barriers have been widely discussed, behavioural factors are still under-emphasised in residential energy efficiency literature and their potential to improve policy-making is poorly understood (Lopes et al., 2012).

1.2 Personality traits and energy efficiency

Personality psychology is the study of characteristics of individuals. The differences in personalities are described with traits which are defined as “consistent patterns of thoughts, feelings, or actions that distinguish people from one another” (Johnson, 1997, p. 74).

Personality traits are found to predict outcomes in different economic contexts, including households’ asset allocation, employment status and entrepreneurial behaviour (Brown & Taylor, 2014; Fletcher, 2013; Obschonka et al., 2015). In the energy conservation realm, the focus has been on the relationship between personality traits and environmental attitudes and habits. Individuals with certain personality traits show similarities in low-cost and frequent pro-environmental behaviour (PEB), such as recycling and using public transportation (Brick & Lewis, 2016; Czap et al., 2012). Creative individuals, for instance, are on average more motivated to solve environmental problems, resulting in more frequent PEB (Markowitz et al., 2012).

While a number of studies describe the link between personality traits and PEB, there is a considerable lack of investigations on the role of personality traits for the adoption of energy efficiency measures. Searches reveal there is no research that elaborates on personality traits in the context of residential high-cost energy efficiency investments (see Chapter 2). Different to PEB, energy efficiency investments are usually not habits and entail a significant financial component. They are possibly triggered by distinct decision mechanisms because they require more cognitive effort and are rather made conscientiously (Barr et al., 2005; Nair et al., 2010).

1.3 Research aims

Increasing service demand during the last decades suggests that energy consumption will grow in the future. The energy use in the building sector (e.g. space heating, lighting) is expected to further increase considering factors such as population growth and economic development (GIA, 2012; IEA, 2015).

In order to mitigate adverse impacts on the environment and humans, efforts are needed to find better ways of directing decisions towards energy efficiency. As outlined in Section 1.1, despite energy efficiency being an effective solution for deflating future increases in energy use, investments into energy-efficient technology are moderate. In the built environment, it is estimated that in 2015, only 2% of the total costs in construction were allocated to energy efficiency (GIA, 2012). Particularly for residential buildings, which account for about 75% of the energy use in the buildings sector (IEA, 2013), investments into energy efficiency will be crucial.

Efforts to promote energy efficiency are usually centred around financial and informational measures that presume households are deciding on rational cost-benefit analyses (e.g. taxes and energy efficiency labels). Despite their limited success in yielding expected energy savings (Karatas et al., 2016), many policy programmes stick to the assumption of economic rationality and utility maximisation in monetary terms. Behavioural impacts are often disregarded, although researchers highlight the need to consider psychological factors in energy efficiency decisions (von Borgstede et al., 2013; Stern et al., 2016a). Thus, it is surprising how little effort has been made to elaborate on the role of personality traits in the energy efficiency domain (see Section 2.4), since they depict a cornerstone of individuals' behaviour (Allport & Odbert, 1936; Cervone & Pervin, 2016; Johnson, 1997; Matthews et al., 2009).

This thesis takes up the argument that psychological factors need to be considered in energy efficiency decisions and explores the role of personality traits in residential energy efficiency investments. The aim is to disentangle personality-related drivers and hindrances in households' decisions to adopt high-cost energy efficiency measures, such as solar panels and thermal insulations. In doing so, this thesis contributes to the understanding of households' energy efficiency decisions and may provide insights for improvements in the design of environmental policy programmes. To set up an effective research strategy, the following research questions are defined:

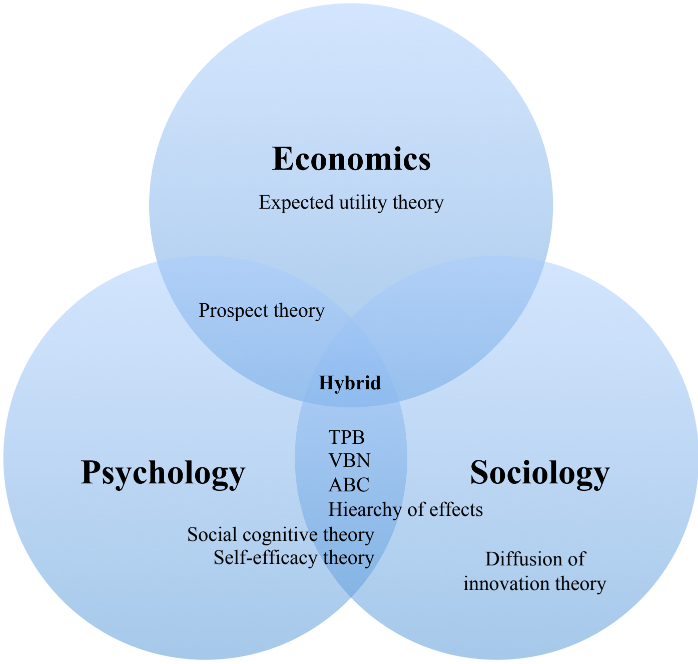
- What are the mechanisms through which personality traits affect decisions of investing in residential energy efficiency?
- Which personality traits catalyse and which curb residential energy efficiency investments?
- Can personality traits be considered in environmental policy programmes and marketing strategies to help overcome obstacles in energy efficiency investments?

1.4 Research scope and design

The research questions are assessed for high-cost energy efficiency investments in residential buildings in the UK and Germany. The energy efficiency measures under review include thermal insulation installations, window modernisations, solar energy systems for heating or electricity purposes and wind turbines for electricity generation.

The research design is guided by the interdisciplinary nature of the research questions. Broadly, an energy efficiency investment can be motivated by financial, pro-environmental or altruistic considerations. For that reason, it is not surprising that the research of energy efficiency has received attention from numerous research areas – including economics, psychology and sociology – and has been assessed by a variety of theoretical models, such as the expected utility theory, theory of planned behaviour or the diffusion of innovation theory (Figure 1.2).[2] A thorough analysis of the research questions therefore requires the assessment of multiple disciplines. The research questions are investigated by three lines of analysis.

[2]The models in Figure 1.2 are discussed in Section 2.5.



Notes:

TPB: Theory of planned behaviour.

VBN: Value-belief-norm theory.

ABC: Attitude-behaviour-external conditions theory.

Figure 1.2 An overview of energy efficiency models sorted by discipline

After a review of the previous research, the role of personality traits in the decision-making process of investing in energy efficiency is first disentangled from a micro-economic point of view. To do so, a theoretical framework for the role of personality traits in the decision-making process is developed based on economic and psychology theory (Chapter 3). The derived model is tested empirically by applying methods of structural equation modelling for a cross-sectional data set in the UK (Chapter 4).

Using the same theoretical model and methodology, the second line of analysis examines the role of personality traits in a context of long-standing financial subsidies. Based on a cross-sectional data set in Germany, the effects of personality traits for significantly subsidised pro-environmental investments are compared to personality effects in investments for which the provision of financial incentives has been more restrictive due to more stringent and complex regulations (Chapter 5).

Different to the first two perspectives, which reflect the decision-making from the individual point of view, the third view focuses on social context by analysing the relationship between personality traits and social norms. The aim of this approach is to investigate personality-related differences in reactions to peer pressure to adopt energy efficiency measures. Based on a UK data set, a first-difference model is run to test the presumed relationships empirically. A second main difference to the first two approaches is that the empirical analysis is run at geographically aggregated levels of personality traits, whereas the first two approaches are conducted at the individual level (Chapter 6).

The findings from the three approaches are summarised by referring to the research questions, followed by suggestions of how they can be used to improve environmental policy-making (Chapter 7).

1.5 Contributions

The research in this thesis makes several original theoretical and empirical contributions to the literature. Chapter 3 makes a theoretical contribution by suggesting a novel model that elaborates on the mechanism through which personality traits may influence high-cost energy efficiency investments in residential buildings. The theoretical contribution is followed by an empirical investigation of the suggested model in Chapter 4. To the extent of my knowledge, this is the first empirical study on the link between personality traits and high-cost energy efficiency investments. Chapter 5 expands the empirical research and provides one of the first examinations on the relationship between personality traits and high-cost energy efficiency measures in a context of long-standing financial subsidies. Chapter 6 turns the focus to the social context and analyses how geographical concentrations of personality traits influence peer pressure to invest in energy efficiency. To the best of my knowledge, this is the first study that (1) investigates the link between spatial concentrations of personality traits and peer effects and (2) rigorously models the impact of spatial concentrations of personality traits on an economic outcome (i.e. energy efficiency investments).

Four types of stakeholders are identified that could benefit from this research. First, it could assist energy efficiency scholars in the explanation of the energy efficiency gap. The interdisciplinary approach of this research aims to provide new perspectives for the reasons of the slow diffusion of energy-efficient technologies in the residential sector. Second, it could support governmental organisations responsible for energy policies in elaborating to which extent financial or informational incentives may be expected to influence households' willingness to invest in energy-efficient technology. Untangling behavioural from economic reasons by understanding the impact of personality traits could help to induce better-fitted policy measures than using general subsidies, which could help to accomplish CO_2 targets. Third, if stimulating and curbing personality traits for energy efficiency investments are known, pro-environmental agencies and organisations could design their programmes in a way that address specifically pro-environmental personality traits. Likewise, producers of energy-efficient technologies may benefit by tailoring their marketing strategies to the relevant traits. This might lead to more energy efficiency investments in residential buildings. Finally, it may also contribute to the well-being of households. Energy efficiency measures can save energy costs and increase living comfort (Allcott & Greenstone, 2012).

1.6 What is energy efficiency?

Although it is widely recognised that energy efficiency can contribute to mitigate harmful effects of using fossil fuels across the energy system, there is less consent with the definition of energy efficiency. Since the term is being applied in a broad range of disciplines, including economics, engineering and psychology, a variety of understandings exists and their meaning is sometimes vague (Pérez-Lombard et al., 2013). Great efforts are put into place to measure energy efficiency and to evaluate its impact on energy consumption and sustainability, and, because these and other terms in the energy efficiency realm are closely related to each other, they are often confused and misunderstood (Karlin et al., 2014; Pérez-Lombard et al., 2013). To avoid such confusion, the subsequent sections aim to clarify the concept of energy efficiency by highlighting the differences and relationships between energy efficiency, energy conservation and sustainability. By doing so, the focus shall also be placed on the relevant research field that this work is contributing to.

1.6.1 Energy efficiency, energy saving and energy conservation

Though energy efficiency and energy saving are related terms and are being widely referenced to describe behaviour of general energy reduction, distinctions prevail. International organisations such as the IEA or the European Union (EU) usually describe "**energy efficiency**" as the **ratio** of output (performance, service, goods, energy) to input of energy (De T'Serclaes, 2010; EU, 2012). Keywords related to energy efficiency include equipment, purchase-related, technology, non-repetitive, investment and durable (Karlin et al., 2014). "**Energy saving**", on the other hand, is not a relative amount (output vs energy input) but describes an **absolute reduction** of an energy resource (Pérez-Lombard et al., 2013), i.e. a decrease in energy consumption. Although the difference between energy efficiency and energy saving might seem obvious, the two terms are often used interchangeably (Karlin et al., 2014; Pérez-Lombard et al., 2013). The confusion arises by inaccurately assuming that energy efficiency inevitably reduces energy consumption, which is not always the case. For instance, consider a household that adopts an improved heating system and increases the indoor temperature at the same time, so that the energy consumption stays the same (rebound effect). The household has a more efficient heating system since it requires less energy for the same amount of service. Is it logical to assume that the household is consequently saving energy? The answer is no, because energy consumption is broadly influenced by two components: service demand and energy efficiency. Thus, considering that energy intensity defines the energy input for one unit of service, energy consumption can be written as (Pérez-Lombard et al., 2013):

$$
\begin{aligned}
Energy\ consumption &= Service\ demand \times Energy\ intensity && (1.1)\\
&= \frac{Service\ demand}{Energy\ efficiency} && (1.2)
\end{aligned}
$$

where energy efficiency is the ratio of service output to energy input (reciprocal of energy intensity). Equation (1.2) illustrates that energy can be saved by either decreasing service demand or increasing energy efficiency, or both. Any reduction in energy consumption that is associated with a **decrease in service demand** is considered as **energy conservation**. Typical energy conservation measures are reducing indoor temperature, turning off lights or cycling instead of using a car. The equation also makes clear that an increase in energy efficiency only saves energy if the service demand remains constant. Separating energy efficiency into service output and energy input shows that increased energy efficiency can be achieved by either increasing service output and holding energy input constant, or decreasing energy input and holding service output constant. For illustration purposes, the rebound effect describes the scenario when the service demand increases at the same or higher rate than the service output per energy input, which improves energy efficiency, but keeps energy consumption constant or results in an increase of energy consumption.

The central interest of this thesis is energy efficiency improvements, whereas energy conservation measures are used for extended comparison purposes only. It focuses on infrequent installations that require a significant financial outlay and can lead to structural and long-term reductions in energy consumption.

1.6.2 Energy efficiency, sustainability and renewable energy

Reducing energy consumption with energy efficiency contributes to sustainable development, which is development "that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). Energy efficiency helps to satisfy present services without using more energy; thus, it preserves energy that can be used by future generations and contributes to better future health conditions by mitigating increases in greenhouse gas emissions.

Another important contributor to energy sustainability is renewable energy. It includes solar, wind, water, geothermal, and other non-fossil energy resources (EU, 2009). Different to fossil energy sources, renewable energy is inexhaustible and continuously replenished, mitigating the risk of energy shortages for future generations. Greenhouse gas emissions of renewable energy generation systems are considerably lower for most of the renewable resources, compared to conventional systems (Amponsah et al., 2014) and therefore considered effective to mitigate human-caused warming of the climatic system.

Renewable energy systems can be divided into technologies that source from "**on-site**" or "**off-site**" renewable resources (Pérez-Lombard et al., 2013). "On-site" renewables are sourced directly from the environment, reducing energy dependence from the supply side. Examples include solar panels and wind turbines for electricity generation at building sites that reduce the electricity consumption from the grid. Such systems are considered as energy efficiency improvements because they decrease energy consumption from the supply side while keeping services constant. Indeed, the EU regards renewable sources as an energy efficiency measure in the residential sector by including them in the list of energy efficiency improvements: "(g) domestic generation of renewable energy sources, whereby the amount of purchased energy is reduced (e.g. solar thermal applications, domestic hot water, solar-assisted space heating and cooling)" (Energy Service Directive (ESD), Annex III, EU, 2006). Additionally, policies for renewable energy often require minimum standards of energy efficiency, thus fostering energy efficiency and renewables simultaneously. For instance, the feed-in tariff scheme in the UK requires buildings to have a minimum Energy Performance Certificate rating "D" in order to qualify for a higher tariff rate for electricity generation from solar panels (OFGEM, 2016).

"Off-site" renewables, on the other hand, are not regarded as energy-efficient since they are delivered via energy carriers, thereby not reducing energy consumption from the supply side. The energy resource needs to be transported to the building first (in the form of energy carriers such as refined biofuels), before it can be converted to usable energy, i.e. heat or electricity. Typical examples of "off-site" renewable resources include green electricity or biofuels.

Another distinction between renewable energies concerns the question whether the applied system is **active** or **passive**. Broadly, active systems of renewable technologies use electrical or mechanical applications for generating or utilising energy from renewable resources (e.g. solar panels, solar thermal collectors, wind turbines), whereas passive renewable systems do not transform energy but use it in its primary form (Chan et al., 2010). Passive renewable systems include building orientation/daylighting design, natural ventilation, free-cooling, passive cooling and heating etc. (Pérez-Lombard et al., 2013).

As is the case for conventional passive energy-efficient technology, such as insulation (cavity, solid wall, loft) or window glazing, passive renewable systems can be clearly considered as energy efficiency improvements because they increase the service but do not require more energy input (e.g. cooler room temperature by better building orientation). However, it is not obvious whether active renewable technologies are energy-efficient. "On-site" and "off-site" generated renewable energy can be considered active since for both forms transformation equipment is used. Therefore it is not possible to say whether the energy from the supply side is reduced, i.e. whether energy generated or used by active energy systems is energy-efficient. For example, solar energy generated at the site ("on-site") and biofuels ("off-site") are both active forms of energy, but the former reduces energy use from the supply side (energy-efficient) whereas the latter does not. EU legislation indicates that active and passive forms of renewable systems are energy-efficient because both forms are listed as energy efficiency improvement measures in the ESD of the EU (EU, 2006).

In other contexts, "on-site" thermal or electric energy generation from solar, wind or water is regarded as active, and all other technologies as passive (Perez-Lombard et al., 2011). This yields yet another different categorisation of renewable technologies that are energy-efficient. Under this definition, passive systems could not be summarised to be energy-efficient (as under the first categorisation of active and passive systems). Biofuels, for example, would also belong to the passive group but are generated "off-site" which is not considered energy-efficient.

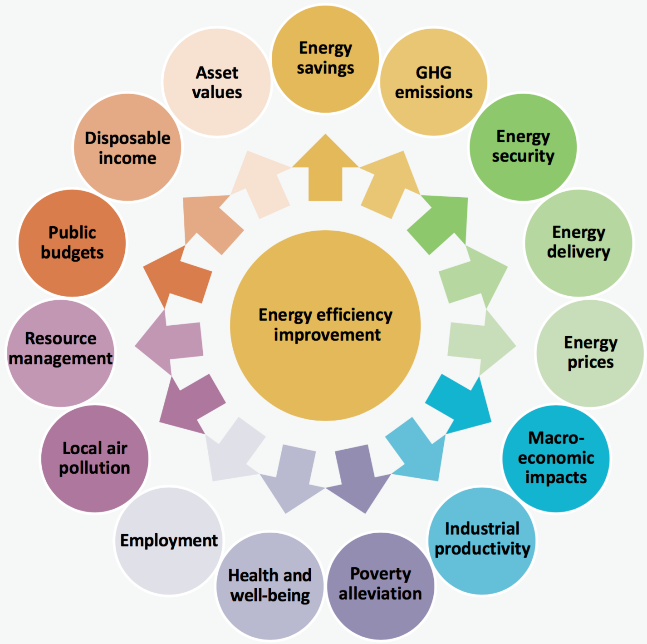
From the engineering point of view, energy efficiency of renewable energy systems is approached by assessing energy conversion, i.e. how much of the energy input (e.g. solar, geothermal energy) can be converted to final energy use (e.g. electricity) (Goswami & Kreith, 2007). For example, a heat pump system requires about ten times less energy input to produce the same heat comfort as a gas-fired heating system (BZE, 2013, p. 84), clearly being more energy-efficient. On the other hand, with a maximal conversion of about 45% of solar light into electrical energy (Dimroth et al., 2014), potential solar electricity efficiency is about equal to the average energy efficiency of fossil fuels of 40% (Harmsen et al., 2011).

In sum, this discussion shows that no general agreement exists on whether renewables can be considered energy-efficient. It depends on the categorisation of renewable energy ("on-site" vs "off-site", active vs passive) and on the research discipline. For the present investigation, energy from renewable resources that is generated "on-site", and that simultaneously reduces energy input from purchased energy, is regarded as energy-efficient. This approach is also in line with EU and most country-level legislation. As such, adoptions of any kind of building insulations and window glazings are considered energy-efficient, as well as "on-site" solar and thermal panels, ground-source heat pumps and wind turbines, and from the technological point of view energy-efficient HVAC (heating, ventilating, air-conditioning) systems.

1.7 Tackling human-caused climate warming with energy efficiency improvements in buildings

Energy conservation and energy efficiency can both contribute to reduce energy consumption and greenhouse gas emissions. Energy policy programmes have predominantly focused on energy efficiency (Bertoldi et al., 2013; Moezzi, 1998). One of the key advantages of energy efficiency to energy conservation is that it allows to reduce energy consumption by keeping quality or quantity of the service constant, whereas energy conservation is unavoidably associated with a loss in the quality or quantity in the service output (see Equation (1.2)). Therefore, energy efficiency can improve economic growth without compromising the goals to curb greenhouse gas emissions and mitigate human-caused climate warming. The IEA estimates that realising economically feasible energy efficiency investments could raise global economic output by USD 18 trillion by 2035 (IEA, 2014a). Besides stimulating economic progress, energy efficiency can also enhance the energy system security and environmental sustainability, foster social development and increase prosperity. Figure 1.3 illustrates the indirect benefits of energy efficiency beyond the well-established benefits of reduced energy consumption and greenhouse gas emissions. The broader benefit areas can be summarised into five categories (each category is represented by a separate colour group in Figure 1.3):

- *Energy system security*
  Reduced energy demand through energy efficiency can contribute to **energy security** by decreasing the risk of shortages in energy availability (physical supply) and unaffordable and/or volatile energy prices. Lower energy demand can also benefit energy producers through energy generation cost savings, deferments of costly distribution



Notes: GHG = greenhouse gas. This list is not exhaustive, but represents some of the most prominent benefits of energy efficiency identified to date.
Source: Unless otherwise noted, all material in figures and tables in this chapter derives from IEA data and analysis.

Source: Adapted from IEA (2014a).

Figure 1.3 Multiple benefits of energy efficiency

system upgrades and reduced line losses,[3] therefore mitigating risks in the **energy delivery** process. Lower energy demand should further result in reduced **energy prices**, all else being equal.

- *Economic development*

  Energy efficiency can have **macroeconomic impacts** by increasing Gross Domestic Product (GDP) through investments in energy-efficient technology, higher employment rates, and increased consumer spending due to reduced expenditures on energy usage. **Industrial productivity** can be enhanced by lower operational costs and reduced pollution, among other factors, creating value for the industrial firms.

[3]Line losses describe the energy waste resulting from the transmission of energy across power lines. The losses grow exponentially with the system load (IEA, 2014a).

- *Social development*

  Social development covers **poverty alleviation**, **health and well-being** and **employment**. Energy efficiency can contribute in reducing households' energy bills, making energy better affordable to poorer people. By improving the quality of indoor environments (e.g. wall insulation) and mitigating outdoor air pollution, it can improve people's health conditions and well-being. Research, production and deployment of energy-efficient technology can further increase employment rates.

- *Environmental sustainability*

  Lower energy consumption by increased energy efficiency can reduce local and regional air pollutants (**local air pollution**), decrease pressure on scarce and non-renewable natural resources and alleviate water and land pollution issues related to emissions (**resource management**).

- *Increasing prosperity*

  Benefits for **public budgets** include lower governmental energy expenditures and higher tax incomes due to increased economic activity and spending on energy efficiency related products. Reduced energy bills due to energy efficiency can increase households' and firms' **disposable income**. Studies further show that people are willing to pay a rental or sales premium for improved energy efficiency in the built environment (Fuerst & Shimizu, 2016; Szumilo & Fuerst, 2015), thereby increasing **asset values**.

In the residential sector, the rising energy consumption of households constitutes a main challenge to achieve energy saving targets (IEEP, 2013). Residential buildings require significant amounts of energy for heating, hot water, and cooling and are responsible for two-thirds of the total greenhouse gas emissions of buildings (IEA, 2013). Energy efficiency is a suitable solution to tackle these issues since it reduces energy usage and can simultaneously satisfy the growing energy needs of households. In addition to the benefits of energy efficiency that are common in all sectors (industrial, transport, residential), some benefits in the building sector (either residential or industrial) are more pronounced. Compared to other sectors, the building sector is highly local, less exposed to global competition, and jobs cannot be easily exported (IEEP, 2013). Considering that adjustments in buildings are labour intensive, any improvements of energy efficiency in the building sector also generate above average indirect benefits by additional jobs, social contributions and tax incomes (IEEP, 2013; Ürge Vorsatz et al., 2010). These contributions and the increased economic activity in the related building branches can offset the higher upfront costs for energy-efficient infrastructure compared to conventional technology. As an example, the Home Energy Saving scheme in Ireland supported energy efficiency upgrades in homes and generated a net benefit of five Euros for every Euro invested through energy, CO_2 and other pollutant savings (SEAI, 2013).

Some studies critique the emphasis on energy efficiency by highlighting its negative side-effects and call for programmes that target energy conservation instead (van den Bergh, 2011; Herring, 2006; Moezzi, 1998; Shove, 2017). A vastly cited adverse effect is the rebound effect which may trigger more energy consumption over time (Achtnicht, 2016; Sorrell et al., 2009) because energy efficiency makes energy prices implicitly cheaper (Herring, 2006). The estimated magnitude of the rebound effects varies significantly across studies, ranging from 5% to 300% across sectors (Chitnis et al., 2013). In the residential realm, the effects are at the lower end of 0%–123% (Chitnis et al., 2014). In a review of studies which account for all of the income and substitution effects,[4] Gillingham et al. (2016) evidence rebound figures in the range from 20% to 40%. Estimations of the rebound effects, however, might be misleading because they are expressed in relative terms but are not compared against absolute energy consumption and greenhouse gas emissions of sectors (Galvin, 2015). Sectors with

[4]The substitution effect accounts for the substitution toward the relatively cheaper energy-efficient product and away from the relatively more expensive other goods, whereas the income effect describes the increased consumption of the energy-efficient product and other goods due to consumers' higher purchasing power. Most studies typically consider the income effects and the substitution effect towards the cheaper energy-efficient product but they disregard the substitution effect on other goods (Gillingham et al., 2016).

the highest rebound effects are not necessarily those that consume most of the energy and therefore their adverse impact on energy savings might be overestimated.

A successful energy reduction by energy efficiency further presupposes that energy use for the production, operation and disposal of energy-efficient products does not exceed the energy savings throughout their life cycle. The existing body of research suggests a net benefit in total life cycle energy demand for energy-efficient buildings using either passive and/or active technologies (e.g. thermal insulation, heat pump) (Ramesh et al., 2010; Sartori & Hestnes, 2007). For residential buildings, studies find that active and passive energy-efficient features can reduce total life cycle energy up to 50% (Chastas et al., 2016). The energy savings are mainly generated throughout the operation phase of the energy-efficient product. Higher savings in operating energy, however, require more complex and energy intensive technical installations, so that excessive use of passive and active energy efficiency features may increase overall energy use again (Ramesh et al., 2010).

Although energy efficiency does not inevitably induce energy savings as energy conservation, relying only on the latter would impede the exploitation of the full potential of reducing fossil fuel consumption, but also the prospects for further economic development because energy conservation goes along with service reduction (see also Section 1.6.1). Therefore, besides energy conservation measures, energy efficiency improvements should be considered as an important factor towards the goal of reducing the energy demand side. It should be also acknowledged that the potential of energy efficiency envisaged in this thesis relies on suggestions by the majority of previous studies that energy efficiency improvements in buildings bring about net benefits in overall energy savings.

1.8 Incentives for energy efficiency adoption

Financing and informing (e.g. eco-labels) are considered appropriate measures for reducing greenhouse gas emissions. The Paris Agreement on Climate Change of 2015 targets net zero greenhouse gas emissions in the second half of the 21st century and includes "Finance" and "Transparency mechanism" as one of the key factors in combating climate warming (UNFCCC, 2015). From 2020 to 2025, USD 100 billion should be provided for adaptation measures and emission mitigations annually.

Among the market barriers for energy efficiency, lack of access to capital receives most attention by policy-makers. Consumers often face projects with high up-front costs and delayed energy savings, posing initial financial hindrances. A wide range of financing mechanisms in different energy efficiency contexts, including direct subsidies, rebate programmes, tax incentives and loan subsidies, are suggested to tackle the financial barriers (Shah & Phadke, 2011). Such programmes have been heavily applied by many countries at different scales, varying in type of frameworks and institutions used for implementation.

Besides financial hindrances, informational barriers as a consequence of high transaction costs for obtaining and processing information have been heavily addressed. For high-cost energy efficiency products, which are rarely adopted, transaction costs can be high (Jollands et al., 2010). Further, non-standardised assessments and uniqueness of projects make comparisons of peer projects difficult and information rare. The primary goal of informational-based policies is to reduce these transaction costs and informational uncertainties. They can be applied in the form of support services, technical assistance, education or information sharing (EPA, 2015). Specifically for buildings, certification standards (eco-labels) are frequently suggested (Ramos et al., 2015a).

The financial and informational programmes can be offered on a standalone basis, but can also be bundled in packages. Designers of such programmes often use programme theory to determine the best mix of incentives, which they assess according to customer segment (e.g. commercial vs residential), key stakeholders (e.g. homeowners, contractors, distributors etc.) and kind of barriers (e.g. high initial costs, lack of information) (EPA, 2015). The identified hindrances in the majority of current programme theories are financial and informational market barriers.[5]

However, financial and informational programmes for energy efficiency show limitations. Effects of financial rewards may be of short-term nature only and knowing about energy efficiency does not necessarily change behaviour (Abrahamse et al., 2005). The key assumptions for the success of these programmes is embraced in the economic framework of utility maximisation: agents will opt for energy efficiency if access to funding and information is provided since they remove the above outlined barriers for cost-benefit analyses of the investments. But, besides being a financial investment, energy efficiency measures may also relate to environmental considerations, such as environmental beliefs, values and norms (Stern et al., 1999). Therefore, environmental policies designed under purely economic frameworks might be too narrowly conceived for energy efficiency decisions.

By investigating the role of personality traits in energy efficiency decisions, this thesis might disentangle motivators and hindrances for energy efficiency that are beyond the standard economic assumption of financial utility maximisation. The findings might help to make energy efficiency programmes more effective.

1.9 Thesis structure

The overall structure of the thesis takes the form of seven chapters.

Chapter 1 sets out the context of the research thesis, the knowledge gap, research questions, contribution of the thesis and specifies the term energy efficiency.

Chapter 2 reviews the literature on the energy efficiency gap, assesses decision-making models for energy efficiency from different research disciplines and summarises existing policy programmes to foster energy efficiency.

[5] See, for example, "National Action Plan for Energy Efficiency in the US" (EPA, 2006).

Chapter 3 synthesises strands of environmental economics and psychology to, firstly, propose arguments why personality traits may matter for energy efficiency investments and, secondly, derive a micro-economic model that integrates personality traits into the decision-making process of investing in energy efficiency.

Chapter 4 evaluates the model suggested in Chapter 3 in a cross-sectional empirical analysis in the UK.

Chapter 5 applies the model suggested in Chapter 3 to subsidised pro-environmental investments in Germany and compares the findings to estimates of the same model for investments for which the provision of financial incentives has been more restrictive.

Chapter 6 elaborates on the relationship between personality traits and social norms, which different to the preceding chapters centres on the role of personality traits related to the social context.

Chapter 7 summarises the key results and suggests improvements in energy efficiency policy-making based on the findings. It concludes with the contribution to research and proposals for future research.

Chapter 2

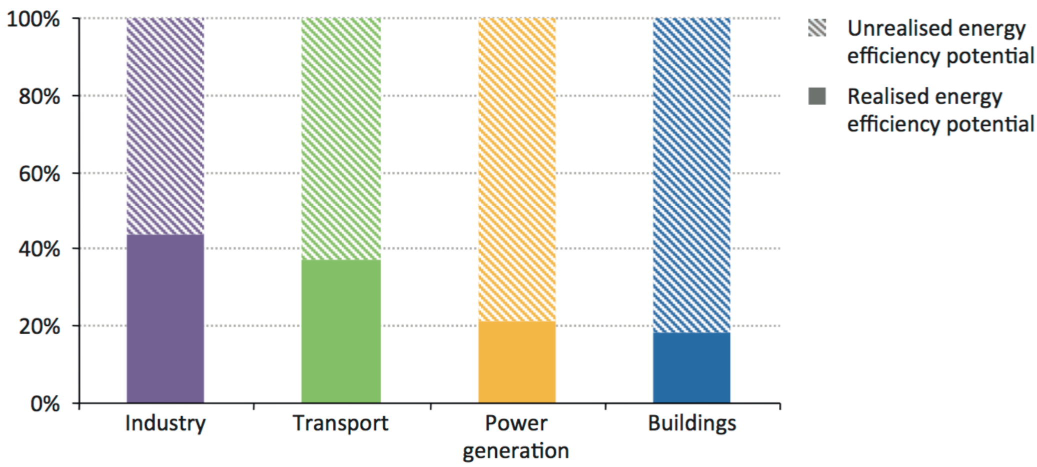
Research Background

This chapter establishes the research background by systematically reviewing the literature related to residential energy efficiency investments. The purpose of the review is to gain an understanding of what is already known about the research topic and to identify the knowledge gap.

The first part discusses the reluctance to invest in energy efficiency in the context of utilitarianism and ties together explanations for its existence from various research strands. The second part discusses the underlying theoretical models for energy efficiency investment decisions. The third part summarises common policy measures aiming to close the observed energy efficiency gap. The research review identifies a knowledge gap for, firstly, multidisciplinary theoretical models that consider economic and personality-related factors in energy efficiency investment decisions and, secondly, empirical investigations on the role of personality traits in energy efficiency investments.

2.1 Energy efficiency investments from the monetary and psychic points of view

Increased greenhouse gas emissions, air pollution, climate warming and the scarcity of fossil energy sources are the consequences of rising global energy consumption. Energy efficiency can help tackle these challenges (see Section 1.7). However, numerous studies find that investments in energy efficiency fail to be undertaken even if standard economic valuations show that they are financially profitable (DeCanio, 1993; Gellings et al., 1991; Horowitz, 1989; Jaffe & Stavins, 1994; Kaur et al., 1991; Tasdemiroglu et al., 1991). Estimates of the IEA for the building sector suggest that under the existing policies more than 80% of the economic energy efficiency potential from 2011 to 2035 will remain untapped (Figure 2.1).



Source: Adapted from IEA (2012).

Figure 2.1 Untapped economic energy efficiency potential from 2011 to 2035

From the neoclassical economics point of view and considering energy efficiency investments only in monetary terms, this energy efficiency gap looks like a paradox (Jaffe & Stavins, 1994): the investments are expected to increase investors' economic benefits, at least in the long-term, so that individuals – described in neoclassical economics as rational and selfish utility maximisers – should exploit the full economic potential of energy efficiency. Against this backdrop, efforts to explain the energy efficiency gap mainly revolve around (1) malfunctions of markets, such as unpriced environmental and social costs (see Section 2.3.1) and (2) the option value of deferring an energy efficiency investment in expectation of lower future energy prices or costs of energy-efficient products (see paragraph "Risk" in Section 2.3.2).

However, energy efficiency investments can also have a biospheric and altruistic component (e.g. reduced pollution), so that the discussion of the energy efficiency gap through the maximisation of the economic benefit might be too narrowly conceived. "Biospheric values reflect a concern with the quality of nature and the environment", whereby altruistic values "reflect a concern with the welfare of other human beings" (Steg et al., 2014). Standard economic theory does not specify how to measure utility. As put by Simon (1982), "the postulates of neoclassical theory say absolutely nothing about what values the utility function contains."

Altruistic and biospheric values can be implemented into the framework of utility maximisation if utility is considered as "psychic income" (e.g. good feelings, prestige, social approval, achievement). Under this setting, altruistic and biospheric actions can drive one's own pleasure. Donations to charity, for example, can be considered as self-interested attempts to purchase "warm glow", increasing one's utility (Andreoni, 1990). On the other hand, "psychic costs" (e.g. discomfort, effort, displeasure) may hold back people from performing altruistic and biospheric actions because they may reduce their utility. For instance, people may prefer travelling by car to public transportation because they perceive driving as more comfortable (Bamberg & Schmidt, 2003).

As long as an action is not completely independent of one's self-interest, biospheric and altruistic behaviour is not prevented from being framed under the principle of selfish behaviour and rational choice. Several studies indeed try to quantify psychic benefits and costs by replacing the purely self-oriented monetary utility function with functions including altruistic and moral preferences (Alger & Weibull, 2013; Andreoni, 1990; Clavien & Chapuisat, 2016).

Because the postulation of underinvestment in energy efficiency originates under the neoclassical model of utility maximisation considering primarily the monetary side of the investments, psychic income and costs should be included in the discussion of the observed reluctance (see behavioural explanations for the energy efficiency gap in Section 2.4). Such an approach suggests that the energy efficiency gap, which at first glance looks like a paradox of rational behaviour, may nevertheless go hand in hand with rationality if psychic cost-benefit analyses are included in the framework of selfish utility maximisation.

Quantifying the overall impact of behavioural variables on the outcome of energy efficiency is a relatively more difficult task to undertake than if only the monetary side is considered because (1) of the difficulty to measure psychological variables (relative to economic variables) and (2) individual behaviour is driven by subjective utility maximisation influenced by the decision-maker's characteristics, while the valuation of an energy efficiency investment under the pure investment point of view is driven by some objective payoff considerations. In this context, by elaborating on the role of personality traits for energy efficiency investments, this thesis can be assigned to the subjective utility maximisation, which besides monetary factors considers individuals' psychic income and costs.

2.2 Neoclassical versus behavioural school of economics

Psychological factors are the centre of focus of the behavioural school of economics. Different to the neoclassical school of economics, which assumes people always behave rationally and in a selfish way, the behavioural school tries to model human behaviour as it actually is. In the energy efficiency realm, this approach puts forth a number of so called "behavioural failures" which contradict the neoclassical assumption of perfect human rationality. For instance, it is found that by using rules of thumb (heuristics), people tend to underestimate the energy use of household appliances (Attari et al., 2010).[1]

The shortcoming of the behavioural school is that its findings represent a collection of special cases which can hardly be put into a unified theory comparable to the neoclassical model. As one economist puts it, in behavioural economics "there is a tendency to propose some new theory to explain each new fact" (Harford, 2014). Without a general theory, any predictions on policy implementations are difficult to make. By modelling realism rather than "perfect" behaviour, the behavioural school loses the merit of the neoclassical school in quantifying market reactions, which is made possible by its assumption of self-seeking and rational individuals.

The neoclassical approach, on the other hand, has its limitation by designing policies based on how people should behave on average and disregarding heterogeneous behaviour. This has frequently unintended consequences. The US, for example, used a variety of financial subsidies to decrease the price of gas-electric hybrid vehicles, expecting an increase in demand for such products. Surprisingly, the sales of the brand Toyota Prius picked up after the tax benefits were removed, possibly because the cheaper price undermined the reputational utility for some buyers who use public green products to signal biospheric and altruistic values (Griskevicius et al., 2010).

Against this background, by the use of personality traits, this thesis identifies potential to release the tension between describing actual heterogeneous behaviour and at the same time placing such behaviour under a general theoretical framework. Models of personality traits distinguish patterns of people's behaviour (Cervone & Pervin, 2016), so that they may be well suited to capture heterogeneity in economic decisions. At the same time, as outlined in the previous section, taking into consideration psychological variables, such as personality

[1]For other examples of behavioural failures, see Section 2.4.1.

traits, can be compatible with the overarching utilitarian principle of the neoclassical school of economics.

By reviewing the reasoning of previous literature for the energy efficiency gap, the next two sections elaborate on what is known about the research topic. The first section of the energy efficiency gap explanations operates in the context of the neoclassical definition of economics, which assumes rational people and ignores psychological factors. The second section is set in the domain of the behavioural school of economics, which describes human actual behaviour by considering psychological variables.

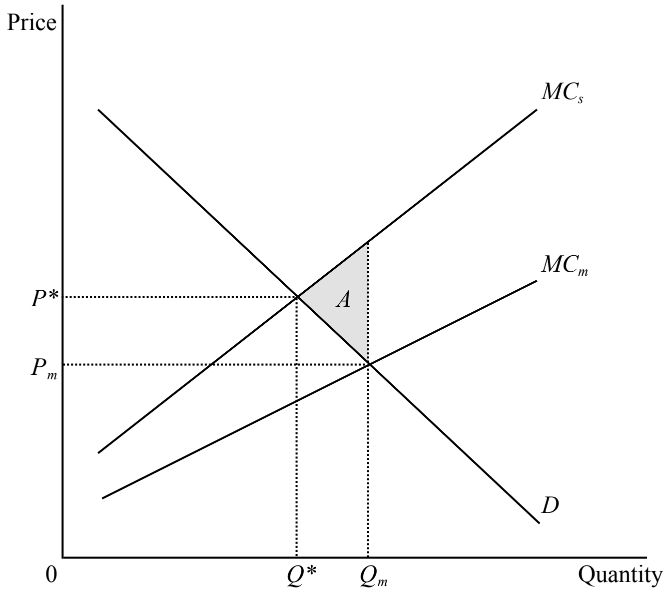
2.3 Economic explanations for the energy efficiency gap

2.3.1 Market failures

Many studies discuss the energy efficiency gap against the backdrop of market failures. Market failures occur when agents in a market cannot allocate resources efficiently because the requirements for doing so are violated, which happens under conditions of incomplete markets, imperfect competition and imperfect information. The literature on energy efficiency commonly identifies such market failures as the main causes for the energy efficiency gap (Bardhan et al., 2014; Gerarden et al., 2017).

Incomplete markets

Incomplete markets might be an issue if property rights are not completely exclusive. Agents should accrue all their benefits and costs of their decisions. If this principle of exclusivity is violated, externalities are formed. That is, actions of an agent affect not only his or her welfare but also those of some other agents (Tietenberg & Lynne, 2014). In the case of fossil energy consumption, negative environmental externalities such as greenhouse gases and adverse human health effects are the consequences. Often, environmental and social externalities related to the use of energy are not fully internalised in energy prices. It follows that an agent consumes more than the optimal amount of energy. Figure 2.2 illustrates the resulting welfare loss to society in the case of fossil energy consumption. D is the demand of fossil energy and MC_m is the marginal cost of generating energy exclusive environmental and social costs. MC_s includes both the production costs and externalities (environmental and social costs). As can be seen, the internalisation of the externalities reduces the equilibrium consumption of energy from Q_m to Q^*. The triangle A shows the welfare loss to society without the internalisation, caused by the excess amount of energy usage, for which the marginal cost MC_s is above consumers' willingness-to-pay for energy, D.



Notes:

MC_s: Marginal cost of energy production including externalities.

MC_m: Marginal cost of energy production excluding externalities.

D: Energy demand.

A: Welfare loss due to unpriced externalities.

Figure 2.2 Unpriced externalities in fossil energy consumption

Empirical research shows unpriced externalities in several domains including the transportation and the electricity sector. Parry et al. (2007) identify that besides the local and global pollution externalities, the use of automobiles also produces externalities in the form of traffic congestion and accidents. The National Research Council (2010) estimates that damages from coal-powered electricity can cost society up to six times more than gas-powered electricity. Researchers agree that unpriced externalities can create a serious barrier on the way to energy efficiency (Allcott & Greenstone, 2012; Gerarden et al., 2017; Ramos et al., 2015a).

Another commonly identified reason is capital market imperfection. It may cause significant investment constraints for many potential energy-efficient adopters who are willing to invest but lack the access to capital (Ryan et al., 2012). Prospective investors in energy efficiency may have difficulties in convincing prospective lenders of the financial profitability of their projects if the energy savings are costly to evaluate for the lenders. As such, the implicit discount rates may be estimated to be above the typical market interest rates because of perceived uncertainty, leading to rejections of energy investments, although their returns are often higher compared to those of the capital markets (Gerarden et al., 2017). For instance, a study by Rhodium Group (2013) in the US estimates that a 30% improvement of energy efficiency in residential buildings (including the commercial sector) would provide an internal rate of return (IRR) of nearly 30% which is well above the average rate of return for corporate bonds or equities. Another reason for the lack of capital market access can be adverse selection. Potential borrowers might possess private information of their energy efficiency investments that they are not willing to disclose to lenders.[2] Lenders increase the loan costs to account for this uncertainty which in turn can deter borrowers from taking the loan or it can attract loan applicants with lower creditworthiness (Sorrell et al., 2000). Some researchers identify restricted capital market access rather as a barrier but do not see it as capital market failure. They argue that markets are working efficiently when capital

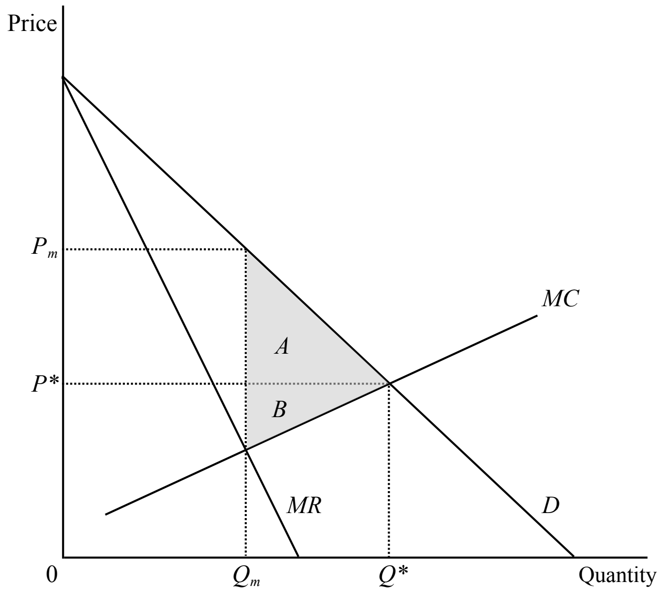
[2] Adverse selection is a consequence of asymmetrical information. Other market failures due to informational issues are discussed in Section 2.3.1 in the paragraph “Imperfect information”.

is declined to some groups of consumers, such as low-income and high-risk borrowers Sutherland (1996).

Imperfect competition

In order to allocate resources efficiently, consumers and producers are expected to behave competitively. If some participants in the markets can exercise excessive power over the exchange of their property rights, the efficient allocation of resources can be impeded (Tietenberg & Lynne, 2014). For instance, the cartel of oil-exporting countries allows oil producers to charge prices higher than at their marginal costs. Figure 2.3 illustrates the inefficiency for fossil energy consumption, whereby a monopoly produces and supplies quantity Q_m, for which marginal revenue MR equals marginal cost MC, and charges price P_m. Consumers incur a welfare loss by paying a higher price than at the optimal level P^*. The total welfare surplus to society is reduced by triangle AB, caused by the undersupply of energy for which the marginal cost MC is below consumers' willingness-to-pay for energy (D). The loss of surplus might be offset to some degree by reduced energy demand and pollution due to the higher price of energy.

In markets with heterogeneous consumers, market power gives suppliers an incentive to under-provide energy goods to consumers who, on average, value it less than others, but also to over-provide energy to consumers who on average value it more than others (Fischer, 2010), which in turn may lead to suboptimal adoption decisions of energy efficiency measures. Policy-makers use liberalisation and economic market power regulations to address the welfare losses due to imperfect competition.



Notes:

MC: Marginal cost of energy production.

MR: Marginal revenue of energy production.

D: Energy demand.

A, B: Welfare loss due to monopoly.

Figure 2.3 Monopoly in fossil energy production

Imperfect information

Another condition for efficient allocation of resources is that agents have the same amount of information available. In the case of imperfect information, some agents have access to more information than others. The uneven distribution of information or asymmetric information can lead to several market failures. A number of investigations ascribe the causes of the energy efficiency gap to lack of information, informational asymmetries and several principal–agent problems.

If potential investors lack information about energy-efficient technology, they might invest less than they would do otherwise. The study by Rhodium Group (2013) posits that unawareness of information is the most important barrier for the adoption of energy efficiency measures in buildings. Studies demonstrate that the provision of energy usage information results in immediate or permanent energy reductions (Allcott & Rogers, 2014; Costa & Kahn, 2013). Governmental policies and private companies apply eco-labelling and energy certificate programmes that inform consumers about the energy efficiency of products. For household appliances or buildings, for example, scales and numbers with differently coloured bars are used to indicate their level of energy efficiency. Several studies investigate the effectiveness of these programmes by assessing the willingness-to-pay of consumers. In the building sector, the majority of research evidence indicates that energy-efficient buildings with energy certificates attain higher rents or selling prices including in the commercial and residential sectors (Eichholtz et al., 2013; Fuerst et al., 2016; Fuerst & Shimizu, 2016; Hyland et al., 2013). For the Dutch residential sector, for example, Brounen et al. (2012) estimate a premium of more than 20% for buildings that are labelled in the highest energy efficiency category compared to those in the lowest category.

Another reason for underinvestment in energy efficiency is asymmetric information, where information between two agents is unevenly distributed (Howarth & Sanstad, 1995). A study in New Zealand by Phillips (2012) finds that tenants' willingness to pay higher rents for energy efficiency improved dwellings would be high enough to increase landlords' economic profitability. However, tenants often lack the information about the energy efficiency improvements and, therefore, landlords have difficulties to capitalise their energy efficiency investments. Similarly, an investigation in the US shows that if tenants are not aware about the energy savings in an energy-efficient dwelling, they are not willing to pay a higher rent, disincentivising landlords to adopt energy efficiency measures (Myers, 2014).

Some studies observe principal–agent problems as a consequence of asymmetric information, including split incentives, moral hazard and adverse selection. Split incentives can be manifested by landlords' reluctance to adopt energy efficiency measures if they are not paying for the energy bills (Bird & Hernández, 2012). Renters, on the other hand, may be unwilling to invest in energy efficiency because they might leave the dwelling in the future and not accrue the savings. The issue of split incentives is supported by the significantly lower number of energy efficiency measures for rented than for owner-occupied buildings (Davis, 2011). In a field survey in California, for example, Gillingham et al. (2012) find that compared to rental properties, owner-occupied dwellings are 20% more likely to have a ceiling insulation. A case study in the Netherlands estimates that split incentives account for about 40% of the heating energy in the residential sector (IEA, 2007).

Asymmetric information can also result in moral hazard. Moral hazard actions not only cause an inefficient overall outcome but also harm the other agent. Giraudet and Houde (2013) posit that due to lack of technical knowledge, homeowners often do not observe how well a job is done by contractors installing an energy efficiency measure. Contractors may exploit this inexperience by completing their jobs with the lowest possible quality to save costs. This may detract homeowners from further energy efficiency improvements. Subcontractors of main contractor companies may have similar incentives to use lower-quality materials in order to improve profitability (Sorrell et al., 2000).

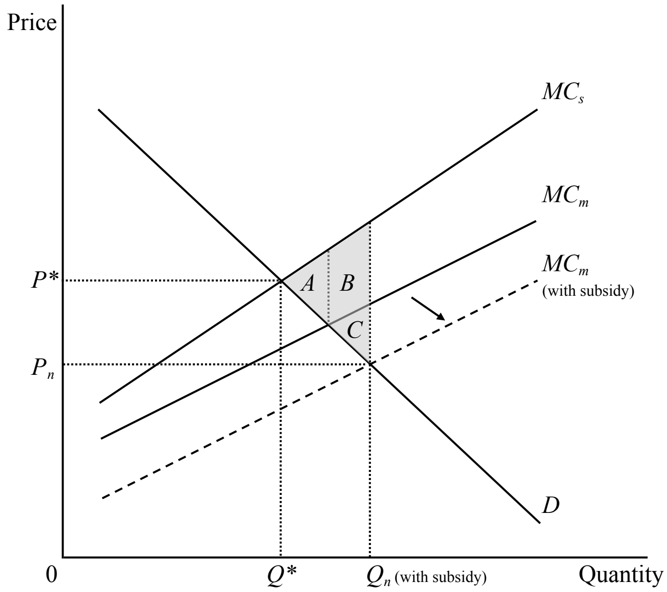
Finally, asymmetric information can cause adverse selection. Because one of the parties to a transaction may have more or less information, it may apply a premium or discount to a good. For instance, if buyers of dwellings do not observe the energy efficiency measures, they might be willing to pay only a price with a discount to the justified price. Constructors, on the other hand, are well aware of the values of the implemented energy-efficient technologies (e.g. heating, insulation, ventilation) and, because they can have difficulties to capitalise the technologies due to the discount applied by the buyers, they may refrain from placing energy-efficient buildings into the market. Especially in the secondary market, it may be difficult for buyers to value the energy efficiency measures because it may depend on very detailed specifications of the energy-efficient technology used. An important difference between adverse selection and split incentives and moral hazard, respectively, is that the former takes place before agents conclude a contract. Although adverse selection as a concept is widely accepted (Akerlof, 1970; Howarth & Sanstad, 1995), little empirical research exists because it is a precontractual matter and, therefore, cannot be observed in empirical transactions.

2.3.2 Market barriers

"Market barriers" and "market failures" are often used interchangeably. Some researchers point out that, different to market failures, market barriers are only "benign characteristics of well-functioning markets" (Sutherland, 1996). For example, transaction costs are frequently disregarded in economic models although they also exist in efficient markets. Therefore, underinvestment in energy-efficient technology due to high transaction costs should be considered as a market barrier, rather than a market failure. Opinions on what constitutes a market barrier or failure differ across studies. Hence, the review of market barriers may to some degree overlap with the assessment of market failures. The following review traces the widespread definition of market barriers in the realm of neoclassical economics. It includes low energy prices, financial constraints, hidden and transactional costs, and risk.

Energy prices

Similar to unpriced externalities, subsidies can generate lower than optimal energy prices and disincentivise investments in energy efficiency. The electricity and natural gas markets are frequently cited examples where regulated energy prices can fall below actual marginal costs (De T'Serclaes, 2010; Jaffe & Stavins, 1994). Figure 2.4 illustrates how the equilibrium price and quantity for energy change if governments subsidise energy producers. A subsidy causes the producer's marginal cost to decrease by shifting MC_m (unpriced externalities) further to the downside. At the new equilibrium, the subsidised producer generates more energy (Q_n) at the lower price of P_n. The total welfare loss increases from A (unpriced externalities) to the triangle *ABC* and the lower energy price may further discourage consumers to adopt energy efficiency measures.



Notes:

MC_s: Marginal cost of energy production including externalities.

MC_m: Marginal cost of energy production excluding externalities.

D: Energy demand.

A, B, C: Welfare loss due to unpriced externalities and subsidies.

Source: Adapted from Tietenberg and Lynne (2014).

Figure 2.4 Governmental subsidies for energy producers

Another explanation for low energy prices and the consequent disinterest in energy efficiency investments is the presence of average cost pricing (Gerarden et al., 2017; Jaffe & Stavins, 1994). An example is the issue related to the lack of time-varying pricing (Gerarden et al., 2017). During peak times of energy use, marginal costs for generating energy are higher and average energy prices are comparatively too low. Because the additional marginal costs are not reflected in the prices, an inefficient utilisation of energy occurs (i.e. overconsumption). On the other hand, utility providers may set marginal prices above marginal costs to recover fixed costs. A study for the natural gas sector, for instance, finds prices above marginal costs of up to 40% in the commercial and residential sectors (Davis & Muehlegger, 2010).

Financial constraints

A number of studies consider financial constraints as one of the most important market barriers for energy efficiency investments (Blumstein et al., 1980; De T'Serclaes, 2010; Hirst & Brown, 1990; Shah & Phadke, 2011). Well-functioning markets should finance profitable investments. For energy efficiency investments, however, individuals and institutions tend to overestimate the risks and underestimate the benefits of the investments, detracting potential energy efficiency adopters from investing and finance suppliers (e.g. banks) from providing financial resources (Blumstein et al., 1980). It is posited that the inability to obtain financing may explain the difference between the high implicit discount rates in energy efficiency investments and the lower observed market interest rates (Gerarden et al., 2017). Although studies identify financial constraints as an important explanation for the energy efficiency gap, empirical evidence has yet to be established (Gerarden et al., 2017; Gillingham et al., 2009).

Transaction and hidden costs

Hidden costs and benefits of energy efficiency investments make exact estimations of the energy efficiency gap difficult. Studies suggest that analysts tend to omit or underestimate transaction costs of energy efficiency measures, thus overestimating the magnitude of the energy efficiency gap (Ramos et al., 2015a). The process of evaluating an energy efficiency investment can be a time-consuming and tedious process. During the initial phase, potential investors spend a lot of time on finding out about existing energy-efficient technologies and deciding which product and supplier to choose (Ostertag, 1999). Learning about energy-efficient technologies is thus a costly process that should be accounted for in the price of energy-efficient technology (Jaffe & Stavins, 1994). Web-based resources decrease information-searching costs to some extent.

The product choice is followed by organising home energy audits, searching for and agreeing appointments with contractors including follow-ups and paperwork (Allcott & Greenstone, 2012). Once a potential supplier or contractor is found, the exact terms of the contract are to be negotiated. During the installation phase, the progress of the project is to be monitored and verified. Other transaction costs include governmental approval, insurance and unforeseen follow-up costs (Sathaye & Murtishaw, 2004).

Hidden costs may also cover less desirable features of energy-efficient technologies compared to standard products. Scholars often cite the hue difference between fluorescent and standard light bulbs and their longer switch-on time (see, for example, Jaffe et al., 2004).

Taken together, transaction and hidden costs are rarely included in cost-benefit analyses of energy efficiency investments, possibly resulting in an overestimation of the energy efficiency gap.

Risk

Energy efficiency investments are usually irreversible (Linares & Labandeira, 2010). Once an energy-efficient technology is adopted, it may be difficult to redeem it if it turns out unprofitable, especially if an investment is capital-intensive and long-term. Hence, investors might be better off to wait until the costs of energy-efficient technology decline. Also, energy prices could decrease in the future, lowering the profitability of an energy efficiency investment. Keeping the existing conventional energy system might be more profitable in such cases (Hassett & Metcalf, 1993; Metcalf & Rosenthal, 1995). By simulating sunk costs and uncertain energy prices, Hassett and Metcalf (1993) find a four times higher hurdle rate to invest. Findings by Rapson (2014) show that the timing to purchase air-conditioners depends on consumers' expectations about the their future efficiency developments. In a survey of the

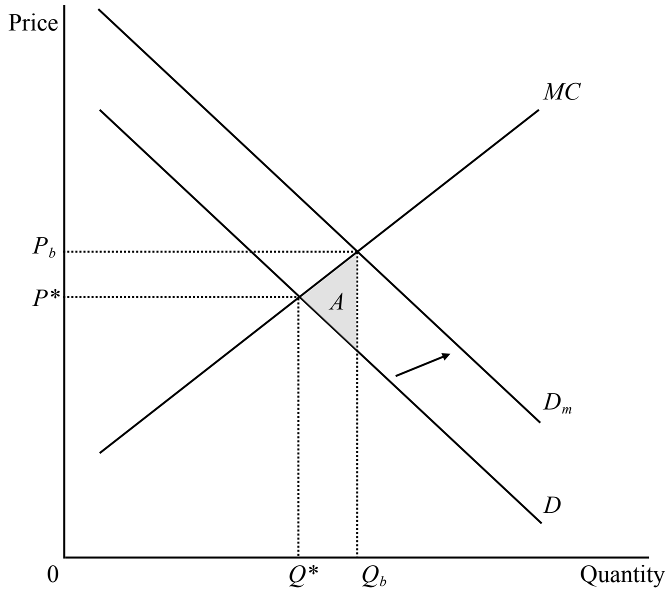
Swiss residential market, Alberini et al. (2013) find a higher likelihood to postpone energy efficiency refurbishments with a higher uncertainty of future energy price developments. Residents who expect future energy price increases are more likely to refurbish.

Framing these observations into option theory suggests that the volatility of energy prices and the uncertainty about future technology changes give consumers an option to wait. The value of the option might justify abandoning an energy efficiency investment, contributing to the energy efficiency gap (Ansar & Sparks, 2009; Van Soest & Bulte, 2001). By using simulations scenarios for photovoltaic systems, Ansar and Sparks (2009) demonstrate that abandoning an energy efficiency adoption also allows households and companies to cash in on future experience effects. Firms may have an incentive to hold back research and development investments if the resulting innovation might benefit other companies. The issue might be especially pronounced in the early stage of research, when knowledge protection such as patents are not yet established (Nordhaus, 2011).

All else being equal, financial constraints, transaction costs or risk can hold back or abandon energy efficiency improvements, which results in higher energy demand, increasing the equilibrium energy price and quantity to P_b and Q_b, respectively, resulting in a welfare loss of the triangle A (Figure 2.5).

In sum, previous literature identifies market failures and barriers as important explanations for the energy efficiency gap, out of which the most cited explanations relate to informational issues. A variety of other explanations are discussed, but in some instances empirical studies are hard to establish because of the difficulty extracting the relevant variables out of the interconnected and complex markets.

Scholars claim that market failures and barriers might lead to exorbitantly high discount rates that are observed implicitly in markets by assuming decision-makers applying standard valuation models, such as the net present value methodology (Giraudet & Houde, 2013; Sutherland, 1991). However, the unrealistically high rates cause doubts on the appropriate-ness of standard economic valuation models to describe the shortage of energy efficiency investments. Since such models under the postulation of rationality do not reveal satisfying results, a number of studies supplement the standard economic models with behavioural frameworks from the fields of psychology to explain the energy efficiency gap.



Notes:

MC: Marginal cost of energy production.

D: Energy demand inclusive energy efficiency realisations.

D_m: Energy demand exclusive energy efficiency realisations.

A: Welfare loss caused by unrealised energy efficiency measures due to financial constraints, transaction and hidden costs, and risk.

Figure 2.5 Increased energy demand caused by unrealised energy efficiency measures

2.4 Behavioural explanations for the energy efficiency gap

2.4.1 Behavioural failures

The behavioural school of economics challenges the assumption of neoclassical economics that people are always self-seeking and rational individuals. Theories from the fields of psychology are used to explain deviations of actual from predicted rational behaviour, often called “behavioural failures” (see, for example, Kahneman & Tversky, 1979). It is argued that bounded rationality, a central concept of the behavioural school that criticises the neoclassical school for assuming people have unlimited capabilities to process information (Simon, 1983), may distort cost-benefit calculations when investing in energy efficiency (Gillingham et al., 2009; Ramos et al., 2015a). Table 2.1 lists the most commonly identified behavioural failures that may contribute to the energy efficiency gap (McFadden, 1999; Shogren & Taylor, 2008). Although behavioural failures receive broad attention, empirical research in the domain of energy efficiency decisions is limited because they are influenced by numerous factors and extracting less tangible behavioural components can be difficult (Ramos et al., 2015a).

Table 2.1 Behavioural failures

Behavioural failure	Description
Reference point dependence	Choices are evaluated relative to a reference point (e.g. status quo).
Anchoring	Judgements are biased towards initially presented values.
Status quo bias	Current status is preferred to unexperienced alternatives.
Loss aversion	Risk averse behaviour for potential gains but risk seeking behaviour for potential losses.
Framing effect	Same alternatives presented differently are evaluated differently.
Self-control bias	Failure to pursuit long-term goals due to lack of self discipline.
Time inconsistency	Preferences change as decisions come closer.
Sunk cost fallacy	Sunk costs are considered in decisions although they should be disregarded.
Disregarded opportunity cost	Opportunity costs are disregarded in decisions although they should be considered.
Irrelevant alternative	Irrelevant alternatives are considered in decisions.

The next paragraphs present the most relevant behavioural failures related to the research on energy efficiency. Scholars usually differentiate between behavioural and market failures. Some researchers, however, posit that market failures (e.g. lack of information) can lead to behavioural failures. A study for the residential building sector in Sweden, for example, finds that lower perceived costs of energy had a negative effect on the likelihood to adopt energy efficiency measures (Nair et al., 2010). Informing households about the true energy costs might therefore increase adoption of energy-efficient products. Due to the interconnectedness of market and behavioural failures, the following discussion of behavioural failures might overlap to some extent with Section 2.3.1.

Heuristic decision-making

Neoclassical economics centres upon developing a universal decision-making model that prescribes which option in a decision should be chosen under conditions of rationality. The process is based on logic and maximization of one's expected utility. Contrary to this normative framework, experimental studies show that people often make decisions according to heuristics instead of using probabilities, weightings and utilities (see, for example, Katsikopoulos, 2011; Todd et al., 2012). By applying heuristics, people make simplified decisions without considering the whole universe of options. According to Todd et al. (2012) a heuristic "is a strategy that ignores available information. It focuses on just a few key pieces of data to make a decision". It is argued that compared to traditional models of rationality, heuristics can lead to the same reasonable decisions, even in a faster and more frugal way (Gigerenzer et al., 1999).

The decision of investing in energy-efficient technology involves many complex choices. For example, a decision-maker has to consider the applicability of an energy-efficient technology, the kind of energy efficiency measure, financing, initial costs, future savings and potential suppliers of the technology among others (see also "Transaction and hidden costs" in Section 2.3.2). The volatility of future energy prices and uncertainty about the energy efficiency fulfilment further add to the complexity.

If investors would behave rationally, they would consider every single attribute of an investment, assign a value to each, aggregate the values, compare it with the costs and decide based on this assessment whether to invest. A decision-maker may lack the time and the skills to evaluate all the attributes properly which may lead to an immediate rejection of an energy efficiency investment, or a decision-maker might use simplified valuation methods and focus on the most salient or familiar factors only, which may bias the cost-benefit analysis (Allcott & Mullainathan, 2010; Gillingham et al., 2009). For example, by dividing initial costs by expected savings, consumers often evaluate the payback time of energy efficiency investments, instead of calculating their profitability. Kempton and Montgomery (1982) find that consumers derive expected energy savings on actual rather than expected energy prices, therefore disregarding potential energy price changes. A study in the US finds that consumers systematically miscalculate the payback time of energy-efficient air-conditioners, leading to underinvestment in such equipment (Kempton et al., 1992). Attari et al. (2010) find that consumers overly focus on energy curtailments rather than on energy efficiency investments to save energy because of more effort involved in the investments. A second observation is that consumers tend to heavily underestimate energy usage for high-energy activities, whereas they only lightly overestimate energy usage for low-energy activities, further detracting consumers from investing in energy efficiency. An explanation for this misperception is heuristics where consumers take the first best information that comes to their mind to estimate the unknown.

Another heuristic that is considered important in energy efficiency decisions is anchoring, a direct consequence when agents decide with respect to a specific reference point.

Reference point dependence

Behavioural economists often build their research on prospect theory, which in contrast to the neoclassical utility approach proposes that the value of an outcome depends on a decision-maker's status quo or reference point (Kahneman & Tversky, 1979). An example is that decision-makers are expected to assign values to outcomes with respect to changes in wealth and not to final wealth. Often observed consequences of reference points are anchoring, status quo bias and loss aversion.

Anchoring describes the observation that people's judgements are biased towards initially presented values, which can make them "stick" to the status quo or prefer default options. Leaving the status quo requires physical or mental effort and might be tedious (Attari et al., 2010). Consumers may therefore prefer options which do not require active choice (default option). It is further shown that consumers implicitly assume that the default option is preselected as the best available one by the choice providers (Dinner et al., 2011). Investing in energy efficiency means to actively choose energy-efficient equipment, so that the status quo of holding inefficient equipment might defer energy efficiency adoption. An experimental choice study shows that setting the default option of replacing standard light bulbs with energy-efficient fluorescent ones increases the number of subjects choosing the fluorescent bulbs (Dinner et al., 2011). A study on building renovations finds that homeowners are more likely to stay with the stauts quo in uncertain settings (Alberini et al., 2013). It is shown that if homeowners do not have expectations on future energy price developments, they are less prone to invest in energy-efficient features, such as roof and wall insulations.

A second consequence of people deciding to reference points is loss aversion. Individuals tend to use separate mental accounts when dealing with positive or negative frames. Loss aversion describes the phenomenon that a gain increases individuals' utility less than an equivalent loss decreases their utility (Kahneman et al., 1982). A consequence of loss aversion is that people prefer risky to non-risky options in the loss setting (risk seeking), and safe options to risky ones in the gain setting (risk averse). When deciding to buy energy-efficient cars, for example, consumers are uncertain about future fuel prices and how much and for how long a car will be driven (Greene, 2011). If the consumers are loss averse, they may dislike the negative outcomes of the described uncertainties more than the potential gains, possibly explaining the undervaluation of future fuel savings of energy-efficient vehicles and reluctance for adoption (Greene et al., 2013). Loss aversion suggests that if energy-efficient equipment is presented in a frame of avoiding losses, such as spikes in energy bills, rather than in a frame of generating gains, households might be more prone to invest in energy-efficient technology (Organ et al., 2013).

Inattention to non-salient costs

Consumers tend to neglect non-salient costs. In the energy efficiency domain, households might pay less attention to energy costs because they might consider their proportion to overall household expenditures as low. In 2012, for instance, UK households spent on average about 5% of their income on energy (ONS, 2014). When deciding whether to invest in energy efficiency, households might therefore rather focus on the purchase price of the energy-efficient technology than on the energy costs. Allcott and Wozny (2013) illustrate that consumers value the present value of future gasoline costs only 76% as much as they value the purchase price. From a rational point of view, however, both costs should be valued equivalently. On the other hand, Sallee (2014) posits that the inattention to some costs can be rational when the cognitive costs of acquiring information are higher than the expected utility of the gains.

2.4.2 Heterogeneous consumers

There is a growing body of literature that recognises the importance of households' heterogeneity in assessing the energy efficiency gap (Allcott & Greenstone, 2012; Allcott et al., 2014; Ramos et al., 2015a). Heterogeneous usage of home appliances, and different consumers' beliefs, and cultural and ideological factors may influence energy efficiency investment decisions. If the impact of heterogeneity is systematic, the estimated energy efficiency gap might be overstated (Gerarden et al., 2017). For example, if future investors in energy efficiency are systematically different to former investors, which the calculations of the energy efficiency gap are based on, the potential energy savings through energy efficiency upgrades might be biased. Considering that energy efficiency adopters have the incentive to select projects with higher returns first, calculations for future energy savings could be overestimated.

Several studies in the residential sector suggest that heterogeneous environmental attitudes and behaviours are important variables in households' decisions related to energy use and energy efficiency. Ramos et al. (2015a,b) find in a survey of Spanish households that eco-friendly behaviour (e.g. recycling, collaboration with environmental protection organisation) is associated with higher energy efficiency investments. Lange et al. (2014) evidence a positive relationship between a set of pro-environmental behaviour, such as wearing a jumper instead of increasing the indoor temperature, and heating expenditures in the UK. An experimental investigation on the effectiveness of eco-labels for residential energy efficiency investments finds differences in the discounting and valuation of information, possibly caused by differences in taste, ability to pay and process information labels, or plans to move out of a building (Newell & Siikamäki, 2014).

Socio-demographic heterogeneity

Much of the literature on heterogeneity reveals socio-demographic factors to explain differences in energy efficiency adoption. The below studies give a small sample of many investigations including socio-demographic variables as either main or control variables in the analyses. In an evaluation of 10 EU countries, Mills and Schleich (2012) find that households with young children and higher levels of education are more likely to buy energy-efficient technology. Using data on the Spanish residential sector, Ramos et al. (2015b) show that income and education are positively linked to energy efficiency investments (e.g. energy-efficient washing machine, double glazing), while age has a negative impact. In contrast, a study in the UK reveals that age is positively associated with energy efficiency measures, such as cavity wall insulation, loft insulation and glazing, while income shows a negative impact (Hamilton et al., 2014).

Norms and values

Research into heterogeneity further explores the impact of social and personal norms and values. In a field study in the US, Allcott and Rogers (2014) show that information about peer energy consumption reduces households' energy usage. The reduction is explained with consumers' moral obligation to comply with social norms of energy conservation (Allcott, 2011; Costa & Kahn, 2013). In a study on the purchases of alternative fuel cars in Sweden, Jansson et al. (2010) report that apart from impacts of income, education and living status (single or cohabiting), the willingness to adopt environmentally friendly cars is positively correlated with biospheric values and personal norms. Individuals who care about biospheric values are those who make decisions by evaluating the consequences for the ecosystem and biosphere as a whole, and personal norms are expressed as feelings of moral obligation to act. Steg et al. (2014) find that besides egoistic, biospheric and altruistic values, consumers' hedonic values play an important role for pro-environmental behaviour. Hedonic values define the "pain" and "pleasure" associated with an action. When acting pro-environmentally requires effort and reduces comfort, the "pain" may discourage individuals from an action. For example, turning down the air-conditioner benefits the environment, but may reduce comfort in the summer. Based on data of an online household study, Abrahamse and Steg (2009) find that socio-demographic factors dominantly influence the level of energy use, whereas psychological variables drive energy savings. Personal norms, awareness of consequences and ascription of responsibility are the most significant psychological variables. In an examination of 14 countries, Schultz and Zelezny (1999) measure personal values using Schwartz's approach (Schwartz, 1994) and attitudes towards nature using the scores of the New Environment Paradigm (NEP) (Dunlap & Van Liere, 1978). They find significant correlations between the personal values and the attitudes towards nature. For example, ecocentric attitudes are associated with a higher degree of universalism but lower score of power-striving. Several other investigations relate Schwartz's values to environmental attitudes or behaviour. The relationships are, in most cases, significant but the specific values that are found to have an impact differ across studies (Mirosa et al., 2013; Stern & Dietz, 1994; Stern et al., 1995).

Personality traits

Apart from frameworks of personal values and norms, psychologists have developed sound theoretical constructs for the analyses of personality traits. Yet, despite their application in various research areas – including employment status, entrepreneurship rates and households' asset allocation (Brown & Taylor, 2014; Fletcher, 2013; Gherzi et al., 2014; Obschonka et al., 2015) – few studies address the role of personality traits in pro-environmental decisions.

One of the studies reports significant influence of trust and empathy on environmental beliefs (Czap & Czap, 2010). Another study demonstrates that openness, conscientiousness, and extraversion influence environmental attitudes (Brick & Lewis, 2016). Both studies further examine how environmental beliefs/attitudes in turn affect environmental behaviour. Whereas Czap and Czap (2010) find significant impact of attitudes on environmental donations in a game experiment, Brick and Lewis (2016) reveal a significant influence on a wide range of pro-environmental real-world practices.

In a study of choice preferences of different power generation programmes for wind farms in Spain, Khashe et al. (2016) report that the choices correlate significantly with individuals' personality facets. However, a drawback of the study is that it fails to offer individuals a clear environmentally preferable option in the suggested programmes, i.e. all of the suggested wind power generation programmes could be considered pro-environmental. While these studies indicate that personality traits can affect individuals' low-cost pro-environmental behaviour, no single study was found which elaborates on the impact of personality traits on energy efficiency investments.

In conclusion, the preceding two sections suggest that the explanations for the energy efficiency gap can be broadly classified into two groups. It is now well established from a variety of studies that economic reasons such as market imperfections contribute to the explanation of the energy efficiency gap, while research also started to examine the role of behavioural factors in this context. Some studies investigate how norms and values, such as environmental attitudes, affect energy conservation behaviour, while only a few focus on the impact of personality traits. Surprisingly, previous studies fail to elaborate on the role of personality traits in high-cost energy efficiency investments, despite their apparent impact on individuals' behaviour.

2.5 Energy efficiency models

Understanding the process of how energy efficiency decisions are made is important for scholars and policy designers. Theoretical models describe the way in which a decision-making process or system works. The following section reviews theoretical decision-making models that can be applied to the energy efficiency context. It summarises the key features of each model and describes its strengths and weaknesses. The goal is to compare models across different research disciplines and decide which ones are most appropriate for the research questions of this work. The models all aim to explain the process of decision-making but each from a different perspective. They can be broadly categorised into economic and behavioural economic, technological, social psychology and hybrid groups, whereby the latter group incorporates aspects from multiple disciplines.

2.5.1 Economic and behavioural economic decision models

In the domain of economics, it was not until the mid 20th century that one of the first extensive decision theories evolved. Von Neumann and Morgenstern (1947) proposed the expected utility theory which is a comprehensive normative decision model that is based on the assumption of agents following a set of axioms of preferences which include *completeness*, *transitivity*, *independence* and *continuity*. According to von Neumann and Morgenstern (1947), this results in decision-makers choosing the option with the highest expected utility. The expected utility of an option is the sum of the values of each possible consequence, weighted by its probability:

$$EU_i = \sum_{j=1}^{N} p_{ij} u_{ij}, \tag{2.1}$$

where EU_i is the expected utility of option i, index j represents the consequences of option i from $j = 1...N$, p_{ij} is the probability and u_{ij} the utility of consequence j for option i.

The framework is widely applied to model economic decisions, including consumer choices between conventional and energy-efficient technologies. One application of the expected utility theory is the net present value method to calculate the profitability of energy efficiency investments. Although studies reveal higher net present values for energy-efficient than for conventional technologies, many investments are not undertaken (see, for example, Jaffe & Stavins, 1994). For household appliances, researchers estimate an implicit discount rate of 5% to 40% that would justify the rejections (Train, 1985). Taking further into consideration that the implicit discount rates are significantly higher than the observed market interest rates, questions on the reliability of the theoretical model are posed.

Some scholars find violations of the rationality assumptions. It is found, for instance, that by presenting energy efficiency labels in different metrics (consumption vs cost) and scales (100 miles vs 15,000 miles vs 100,000 miles), consumers show different preferences in choosing fuel-efficient vehicles (Camilleri & Larrick, 2014). According to the invariance principle, the description of an option should be irrelevant for the decision outcome. Many other findings challenge one or more of the assumptions for rational decision-making, including heuristic decision-making, reference point dependence and inattention to non-salient costs (see Section 2.4.1). The normative theory of utility maximisation fails to incorporate such behavioural factors and, therefore, might be less appropriate to describe actual behaviour. Nevertheless, the expected utility theory provides a sound base to the strands of behavioural economics which extends the prescriptive theory to more descriptive frameworks.

Behavioural economics integrates psychological matters into the rational decision-making process of utility maximisation by considering violations of the axioms in the neoclassical economic model. A key extension to the expected utility theory is the prospect theory by Kahneman and Tversky (1979), which based on observed rationality violations defines a value function with three main features. First, different to the expected utility theory, values (utilities) are measured relative to a reference point (gains vs losses) rather than in absolute terms (e.g. wealth). Second, the prospect theory assumes that people are risk averse in the gain domain (concave value function) but risk seeking in the loss domain (convex value function). For example, a guaranteed payout of GBP 100 is often preferred to a gamble with an expected value of GBP 100 (e.g. 50% probability to win GBP 200 or nothing), but an expected loss of GBP 100 (e.g. 50% probability to loose GBP 200 or nothing) is often preferred to a certain loss of GBP 100. Third, it assumes that people are loss averse, i.e. that losses harm more than gains benefit (steeper value function in the loss domain).

Formally, the value function can be expressed as follows (Jungermann et al., 2005):

$$v(\Delta x) = \begin{cases} (\Delta x)^{\alpha} & \text{if } \Delta x > 0 \\ -\lambda(-\Delta x)^{\beta} & \text{if } \Delta x < 0, \end{cases} \tag{2.2}$$

where Δx is a change in value relative to a reference point, α and β describe the risk aversion in the gain and loss domain, respectively, and λ represents the loss aversion.

Despite strong advances and frequent applications of prospect theory in other decision domains, the framework is less used in the realm of energy efficiency (Gerarden et al., 2017). Energy efficiency scholars find some manifestations of the prospect theory by investigations of loss aversion and reference point dependence (see "Reference point dependence" in Section 2.4.1). Prospect theory helps to explain the decision-making of agents. However, its general nature shows difficulties to capture some specificities in the energy efficiency context, such as asymmetric information between landlord and renters (see "Imperfect information" in Section 2.3.1). Therefore, theoretical models with a specific focus on energy efficiency characteristics might provide a better fit to describe individuals' decision-making.

2.5.2 Technology adoption models

Technology adoption models elaborate on the process of why technology innovation develops, how it gets used and how it is disseminated in the markets (Wilson & Dowlatabadi, 2007). One of the most widely applied technology adoption frameworks is the diffusion of innovation (DoI) theory by Rogers (2003), which can be considered as a collection of theoretical perspectives on the diffusion process of a product, rather than one overarching unified theory. It is mostly applicable in situations where social networks and technological attributes are important. Specifically, the theory addresses how the communication process among persons and media channels influence an individual's decision to adopt technological innovations. Among other perspectives, the theory describes the decision-making process with five stages that start with the decision-maker's knowledge about the innovation and ends with the confirmation of the decision:

1. *Knowledge*
   The first stage, "Knowledge", describes the process when individuals get aware of an innovation and gain some understanding of how an innovation works. The process is triggered by prior conditions. This might be a perceived need to solve a problem,

a social norm to follow or previous or existing practices. For instance, a household would like to save heating costs and gathers information on alternative heating solutions such as solar-based energy systems. The way decision-makers acquire information depends on their socio-economic status, personality and communication behaviour. For example, a very open character who is in frequent exchange of information with his social surroundings might get to know sooner about an innovation than others. These attributes therefore influence how early one gets in touch with an innovation.

2. *Persuasion*

At the second stage, "Persuasion", individuals form either favourable or unfavourable attitudes towards an innovation. Rogers (2003) argues that, different to the "Knowledge" stage, at which the mental activity was mainly cognitive, the main thinking type at "Persuasion" stage is affective. Besides the decision-makers' characteristics, attributes of an innovation affect how attitudes and perceptions towards an innovation are formed.

For the adoption of energy-efficient products, scholars identify relative advantage to conventional products, compatibility, complexity, trialability and observability to be important explanatory factors. The relative advantage of refurbishing a building, for example, can include cost savings and increased comfort (Allcott & Greenstone, 2012). An innovation needs not only to be technically compatible with an existing setting, but also may need to conform to social norms. If saving energy is not considered appropriate among peers, it might be unattractive (Ferraro et al., 2011). Capacity, skills and effort contribute to the complexity of energy efficiency investments (see also "Transaction and hidden costs" in Section 2.3.2). Trialibilty refers to whether decision-makers have the possibility to test an innovation before it is adopted. For instance, the effective energy savings might be only known once an energy-efficient technology is installed. Finally, observable innovations such as solar panels might have a greater normative appeal than non-observable ones (Archer et al., 1987).

3. *Decision*

   At the "Decision" stage, individuals decide whether to adopt or reject an innovation according to their formed attitudes.

4. *Implementation*

   Whereas individuals decide at the "Decision" stage mentally whether to adopt an innovation, they put it into use at the "Implementation" stage only. This implies that an idea to adopt does not necessarily translate into actual adoption. Issues such as unforeseen costs may arise which may lead someone to abandon the implementation.

5. *Confirmation*

   At the "Confirmation" stage, decision-makers seek to reinforce their decisions. In the case of conflicting messages arising about a decision, possibilities of reversing the initial decision may exist. An internal conflict, also called dissonance, is an unpleasant state for individuals and they may want to reduce it by changing knowledge, attitudes or actions. Deciding not to invest in energy efficiency in an environment where most people do so, for example, might cause a state of dissonance. This can be reduced by adapting attitudes (e.g. reduce inner conviction to follow social norms) or changing action (e.g. adopt energy-efficient technology). On the other hand, in the case of an adoption of energy-efficient technology that is followed by regret, a reversion might be difficult because of technical or financial reasons (e.g. thermal insulation, bank loan). Under such circumstances, individuals often try to avoid states of dissonance by seeking only information that supports their decision, commonly called selective exposure.

Different to the outlined economic theory, the decision process suggested by the DoI theory does not assume a-priori given preferences. It allows decision-makers to form attitudes and preferences according to their characteristics and the attributes of an innovation. A drawback of this approach is that it centres on attitudes formation, assuming that technologies are adopted only through awareness and favourable attitudes. However, difficulties of translating attitudes into actions are disregarded (e.g. lack of financial resources), although such contextual factors are of importance for the decision outcome (Dolan et al., 2012).

A model that focuses on attitudes and behaviour, but also considers the decision context, is the theory of planned behaviour (TPB). The TPB assumes that individuals' attitudes, subjective norms and perceived behavioural control define an intention to perform a specific behaviour, which in turn predicts behaviour (Ajzen, 1991). Attitudes are formed by weighing benefits and costs of the possible outcomes. This includes assessing financial and time costs among others. Subjective norm refers to individuals' internal pressure to conform with the expectations of society. To account for factors that individuals are exposed to but cannot fully control (context), the model includes a variable for perceived behavioural control. It is an individual's perception of how easy or difficult it is to perform a behaviour. Recycling, for example, can be considered as an easier pro-environmental action than adopting solar panels.

The social cognitive theory and self-efficacy theory deepen the analysis of perceived behavioural control. They include perceptions of individuals for how well they can act to deal with prospective situations. Self-efficacy influences the attempt and persistence of performing a task, depending on individuals' former experiences, perceived skills and examples of others (Bandura, 1991). Reinforcing self-efficacy by setting achievable goals or providing feedback from peers are found to increase energy conservation behaviour (Abrahamse et al., 2007; Allcott & Mullainathan, 2010).

Another model that focuses on context is the hierarchy of effects model which assesses decisions from the social communication and feedback point of view. It examines how communication channels such as mass media or interpersonal communication can influence the decision-making process at its different layers of hierarchy: information, knowledge, attitude, intention and behaviour (Lavidge & Steiner, 1961). The model is applied to study consumer reactions to marketing initiatives, for example.

2.5.3 Social psychology models

Different to the economic models, theoretical models in psychology and sociology supplement pure cost-benefit analyses with psychological frameworks of environmental concern that centre on individuals' values, attitudes and norms. One of the most prominent models explaining the relationship between values and behaviour is the value-belief-norm (VBN) theory of environmentalism by Stern et al. (1999). The theory suggests a causal chain from general personal **values** (e.g. altruism, biosphere, self-enhancement, duty, family, loyalty) to more specific **beliefs** about the consequences of human behaviour (see left-hand side in Figure 2.6). Beliefs that the consequences of human behaviour pose a threat to personal values (e.g. biospheric values), and that actions can help mitigate the threat, activate personal **norms** that obligate individuals to act in a way that reimposes their personal values. Wilson and Dowlatabadi (2007) translate the process into the figurative sentence of "I ought to do X to prevent Y from adversely impacting Z, because I value Z". This process forms individuals' **attitudes** to trigger pro-environmental behaviour. Similar to the DoI, the VBN theory predicts well in situations where contextual factors are less relevant. However, financial, time, legal and social circumstances can often either foster or hinder individuals' capabilities to act (see also behavioural control in the TPB). The attitude-behaviour-external conditions (ABC) theory incorporates context by positing that attitudes translate to behaviour only if the boundary conditions allow to do so (Guagnano et al., 1995). For instance, the cost of time, effort and inconvenience associated with recycling can reduce the incentive to do so.

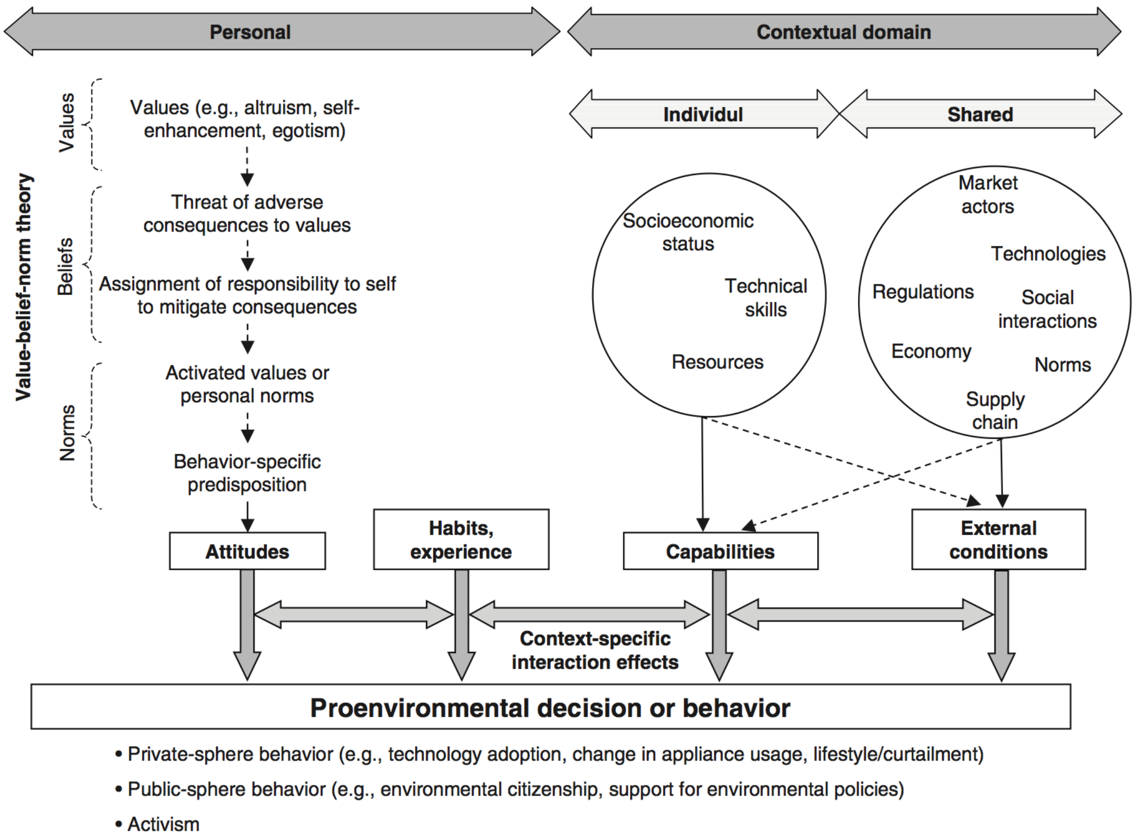


Figure 2.6 An integrated model of pro-environmental behaviour (adapted from Wilson & Dowlatabadi, 2007)

2.5.4 Hybrid models

Wilson and Dowlatabadi (2007) argue that there is an unexplored potential to reconcile theoretical models from different research disciplines: the models often miss some important factors in the decision process and synthesising them into one framework could improve the understanding of decision-making. They propose an integrated model that draws on the VBN framework, ABC theory and other research in social psychology (Figure 2.6). The left-hand side represents the personal-related part which describes the formation of pro-environmental decisions postulated by the VBN framework, whereas the right-hand side illustrates the contextual domain covered by the ABC model. Besides **attitudes**, the personal part covers **habits** and past **experiences** as influencing factors for pro-environmental behaviour. The contextual domain is divided into two parts. The first part describes individual-level variables that may constrain or foster people's **capabilities** to engage in pro-environmental behaviour (e.g technical know-how and skills), while the second part lists aggregate-level variables that are shared by a social system (e.g. economy, regulations, social norms), describing the **external conditions**. The aim of the model is to emphasise the interaction effects between the personal factors (attitudes, habits and experience) and contextual factors (capabilities and external conditions).

Another model that stresses and incorporates the interaction of individual and contextual factors is the energy efficiency model by Allcott and Greenstone (2012). Different to Wilson and Dowlatabadi (2007), who build their model on theories of social psychology, Allcott and Greenstone (2012) found their framework on economics, and include contextual conditions that are found specifically in empirical investigations of energy efficiency, including market failures and barriers (see Section 2.3). According to the model, agents aim to maximise their own utility, as postulated by neoclassical economics. An agent chooses between an energy-efficient and a conventional technology by weighing the future expected energy savings against the additional costs of an energy efficiency investment. If the discounted value of the expected energy savings adjusted by a factor γ exceeds the discounted value of the incremental costs of the investment and the option to wait, the agent chooses the energy-efficient product:

$$PV_{Savings} \times \gamma > PV_{\Delta Costs} + O \tag{2.3}$$

where

- $PV_{Savings} = \frac{P \times u \times \Delta e}{r}$,
- $\gamma = \gamma(\alpha, \varphi,$ info, P–A asymmetries$)$,
- $PV_{\Delta Costs} = PV_{\Delta Costs}(\Delta I, d\%, i)$ and
- $O =$ Option to wait.

The present value of the expected savings $PV_{Savings}$ depends mainly on the price of energy, P, the energy saving intensity Δe and the risk-adjusted discount rate r. The higher the price of energy, and the higher the saving intensity of the energy efficiency investment, the better value the energy-efficient good will be (Allcott & Greenstone, 2012; Bardhan et al., 2014; Jaffe & Stavins, 1994). The risk-adjusted discount rate, r, includes the cost of capital and the opportunity costs that are forgone due to the investment in the energy-efficient project (Gerarden et al., 2017). The variable u depicts the heterogeneity of agents (Bento et al., 2012). For instance, an agent from northern latitudes is assigned a higher u because he or she has a higher preference for heating than an agent from a warmer place.

γ captures the behavioural aspects of energy efficiency. Energy inefficiencies are usually reflected by setting $\gamma < 1$, evoked by several reasons. First, since in the neoclassical framework agents are usually risk averse, the uncertainty of the future benefits of the energy efficiency investments might impede their adoption (Bardhan et al., 2014; Fischbacher et al., 2015). A lower α indicates a lower willingness to take risk and uncertainty. Second, an agent may not internalise the environmental costs associated with the energy use because they are not captured in the price of energy (Gerarden et al., 2017; Ramos et al., 2015a). Adding φ accounts for these externalities. This means that in the case of $\varphi = 0$ an agent tends to under-invest in energy efficiency. Third, an agent may under-invest because he or she lacks the information (info) about energy efficiency measures (Allcott & Rogers, 2014; Costa & Kahn, 2013). Finally, a significant amount of energy efficiency may be lost due to principal–agent (P–A) asymmetries (Bird & Hernández, 2012; Myers, 2014). In the residential markets, for example, landlords omit or tend to buy energy-efficient components at the lowest possible costs because they are not paying fo the energy bills.

An investment in energy efficiency consists of an upfront cost and possible future interest payments caused by debt. The discounted present value $PV_{\Delta Costs}$ depends on the additional capital needed, ΔI, the percentage that is financed by debt ($d\%$) and its interest rate, i (Knittel et al., 2014).

Finally, the volatility of energy prices and uncertainty about future technology changes provide the consumer with an option to wait. Delaying the energy-efficient product might be valuable because energy prices and the costs for the energy-efficient technology might decline, which can lower the present incentive to invest in energy efficiency (Ansar & Sparks, 2009; Van Soest & Bulte, 2001).

This section attempted to summarise the most important decision-making models from different research disciplines. Figure 1.2 in Chapter 1 (p. 8) gives an overview of the reviewed models and illustrates the research field they belong to. Assessing the models against the backdrop of research questions of this thesis shows that no model includes personality as an integral part for describing individuals' decision-making process. The only model that considers personality is the DoI theory which identifies personality as one of the factors influencing the acquisition of information at the "Knowledge" stage. Personality in the DoI model, however, is expressed in a relatively rudimentary way by variables such as rationality, intelligence and attitudes toward education, but a sophisticated framework for capturing the personality profiles of individuals is missing.

It can be further summarised that by including contextual variables (e.g. informational constraints) the hybrid models depict the most comprehensive theoretical frameworks. In terms of kinds of contextual variables, the model by Allcott and Greenstone (2012) includes factors that are specifically relevant for energy efficiency investments and that are identified in previous empirical studies (e.g. informational asymmetries), whereby the integrated model for pro-environmental behaviour by Wilson and Dowlatabadi (2007) refers to more general and theoretical factors (e.g. socio-economic status).

Taken together, none of the reviewed theoretical frameworks elaborates thoroughly on the impact of personality in energy efficiency investments to allow a straightforward empirical investigation. The existing models, therefore, require further extensions. Given that the model by Allcott and Greenstone (2012) is the most comprehensive and tailor-made decision model for energy efficiency investments, and the DoI theory provides a focal point for expansion to a framework with a more sophisticated personality model, they will be taken as the base models for the extensions in the subsequent chapters.

The next section elaborates on programmes that policy-makers commonly use to foster energy efficiency adoption based on the existing literature on the energy efficiency gap and the outlined theoretical models.

2.6 Traditional energy efficiency programmes

Policy-makers at national-, country- and regional-levels design various programmes to stimulate the uptake of energy efficiency measures. The EU, for example, approved its latest energy efficiency directive in 2012 (EU, 2012) which defines a set of binding measures for their members in order to achieve its energy efficiency target of 20% in 2020. It issues guidance notes for how to transpose the directive's provisions into national law. The directive targets the whole supply chain of energy from its production to consumption, including the public and private sectors.

Policy-makers can draw from a wide range of instruments to achieve their energy efficiency goals. They can be broadly summarised into three main categories (Bremer Energie Institut, 2007):

- Regulatory measures (e.g. directive, laws).
- Financial instruments (e.g. subsidy programmes, tax benefits).
- Information- and motivation-based incentives (e.g. energy audits, commercials).

These standard policy measures are based on economic explanations of the energy efficiency gap. Previous research traditionally ascribed the reluctance to invest in energy efficiency to market imperfections (see Section 2.3). Policy-makers commonly assume agents make rational cost-benefit decisions and expect that if the imperfections, such as lack of information, are removed, agents can appropriately evaluate costs and benefits of the energy efficiency investments. This should trigger more energy efficiency adoptions because the majority of investments is expected to generate positive returns, at least in the long term.

Often, regulations are used to account for the market imperfections. The goal of energy taxes, for example, is to price in externalities of burning fossil fuels (e.g. environmental pollution). Other common regulatory instruments are carbon emission caps and minimum building certifications. Apart from setting binding standards, regulatory measures further encompass monitoring to detect non-compliance, which includes the development of energy efficiency indicators, data collection and the evaluation of indicators among others (WEC, 2013). Regulatory measures are often implemented with financial- or information-based incentives.

Energy efficiency investments require significant financial outlays and are not immediately rewarded. To overcome this barrier, grants for retrofits, "green" loans with lower interest rates or reduced credit constraints are offered (WEC, 2013). Such financial programmes are refinanced by governmental debt, dedicated taxes, banking systems or multinational financing institutions. The energy taxes outlined above are another form of financial instruments. In addition to traditional measures such as direct financial subsidies or taxes, there are meanwhile offered some more innovative financing tools. In a partnership of Energy Performance Contracting (EPC), for instance, an energy service company installs an energy efficiency system and guarantees a minimum of energy savings to the client. The client evades the significant upfront costs by repaying the installation costs later through the savings of energy costs. An advantage from the government point of view is that EPC is self-financed, so that public spendings can be saved. Besides being a financing measure, the advice to clients through experts in EPC also contributes to spreading energy efficiency information.

The underlying notion for financial instruments to be effective is that individuals are rational agents primarily motivated by economic self-interest (Thaler, 2000). By positioning energy efficiency as financially rewarding through the financial incentives, or making conventional energy systems more costly (e.g. taxes), energy efficiency investments get financially more attractive. However, financial benefits are not always required to promote the desired behaviour or can even be counter-productive. Counterintuitively, the sales of the Toyota Prius in the US, for example, started to increase only after the tax credit on hybrid cars was removed (Griskevicius et al., 2010). Handgraaf et al. (2013) show that financial incentives may in fact decrease actions related to energy conservation. It is argued that if a behaviour (e.g. energy saving) is spurred by social norms (e.g. ethics, morals), the inclusion of financial incentives can undermine these normative considerations and discourage the behaviour that actually should be stimulated (Bolderdijk & Steg, 2015). Another explanation is that a financial provision awakens people's attention to cost-benefit comparisons and may reveal that the incentive is not worth the effort (Heyman & Ariely, 2004). Therefore, financial incentives can be effective in situations where agents act purely upon economic self-interest. However, they incorporate the risk of discouraging specific behaviour if economic profit is not the only driver, or if a financial compensation is not sufficient.

Another well-used category of policy programmes promoting energy efficiency involves information- and motivation-based incentives. Disseminating information about energy efficiency via effective information channels is considered crucial. The information can be spread through different institutions and vehicles, ranging from public institutions, private companies and technological appliances, by energy information centres and campaigns, energy consultations and other different means of market communications. Another typical form of information provision is the use of building codes or labellings of appliances, indicating the level of energy efficiency. The treatment of such energy certificates has become an integral part of the EU legislation (EU, 2010). An example is the 2010 Energy

Performance of Buildings Directive which requires the inclusion of energy certificates in all advertisements for the sale or rental of buildings. The certificates aim to remove informational inefficiencies in markets. Although studies show that certificates capitalise in higher rental and sales prices (Eichholtz et al., 2013; Fuerst & Shimizu, 2016), the uptake of energy efficiency labels is surprisingly low in some countries (Brounen & Kok, 2011).

A weakness of providing information is that it can also reveal limitations of the implemented measures as outlined for financial incentives above. Appliances that provide feedback on the financial consequences of specific behaviour (e.g. setting the thermostat lower) may result in consumers becoming aware of how little the benefits are compared to the required effort or inconvenience (Jain et al., 2013). As such, the intended behaviour may be discouraged.

Researchers recognise that socio-economic differences require attention when drafting energy efficiency policies (Brounen et al., 2012). However, traditional financial and informational policy programmes for energy efficiency are usually standardised. Because agents in the market are heterogeneous, the reactions are different and the effectiveness of standard policy measures can be suboptimal (Allcott & Greenstone, 2012). The energy use in the residential sector keeps growing, despite the efforts of EU governments to promote energy efficiency (EU, 2006, 2012; IEEP, 2013). As illustrated in Figure 2.1 at the beginning of this chapter, projections estimate that more than 80% of the economically viable energy efficiency investments in buildings will not be realised if current policy-making prevails (IEA, 2014a). This stresses the need for more effective policy-making in the realm of energy efficiency. Scholars identify potential for improving policy-making by the use of “nudging” and “behavioural insights”.

2.7 Nudging and behavioural insights

There is a growing body of literature that suggests including insights from behavioural sciences, rather than purely relying on economic related incentives to increase the uptake of energy efficiency measures (e.g. price subsidies, informational measures). It is expected that such insights will help to design more targeted and cost-effective policies (Allcott & Mullainathan, 2010; Stern et al., 2016a). The main idea is that findings from behavioural sciences, such as psychology, are used to direct people towards a desired behaviour. The term "nudging" describes the process of changing an aspect of a choice architecture that directs individuals' behaviour in a predictable way. An important feature of nudging is that it changes the framing of choice options but keeps the same set of options to choose from (Thaler & Sunstein, 2008). In contrast, "behavioural insights" encompasses a broader range of features that can be changed than just altering the context (EU, 2016). It is also often combined with traditional policy instruments (i.e. financial and informational measures). For instance, France incorporates the idea of fairness by taxing the most polluting cars and using the generated revenues to subsidise the least polluting ones (EU, 2016).

Different to traditional incentives, nudging and behavioural insights are not based on the assumption of rational decision-making. Hence, they offer a way of approaching behavioural failures, which are seen as deviations from rational decision-making and are identified as factors contributing to the energy efficiency gap (see Section 2.4.1). Changing the context is also a relatively cost-effective alternative to the traditional policy programmes. Scholars identify change of default options, goal-setting (commitment) and feedback combined with behavioural insights to be promising ways of changing people's behaviour (Brown et al., 2013; Ramos et al., 2015a).

Many studies evidence that default options can direct agents toward a certain behaviour by helping to overcome inconsistent preferences. To illustrate, if asked for their preference, many people would agree to opt for "green". However if confronted with real decision options, the outcome is often a different one (Pichert & Katsikopoulos, 2008). It is demonstrated that setting the right default option for decisions related to energy conservation can remove the inconsistent preferences. By switching the default option to green electricity sources, for example, Pichert and Katsikopoulos (2008) find that more consumers chose “green”. In an experiment for thermostat settings, Brown et al. (2013) observe that reducing the default temperature in an office building by 1 °C results in significant lower energy usage.

Goal-setting can be an effective way to keep people committed. Individuals tend to delay decisions that are in their long-term interests. External and self-imposed goal-setting can help following these interests. Several studies find reductions in energy usage by the inclusion of such goals. Winett et al. (1982) ask participants to sign a form with a commitment to reduce energy usage by 15%, and the average energy savings are 17%. Similarly, a study on Dutch households gives participants an energy reduction goal of 10%. Depending on the treatment group (in-home displays, monthly feedback, self-monitoring), energy consumption decreases down to 12% (Van Houwelingen & Van Raaij, 1989). A study for households in New Jersey (US) shows that setting the right target can be critical for the success of such measurements (Seligman et al., 1978). The study finds that setting energy saving targets higher than 20% reduces energy usage significantly, whereas a savings goal of 2% has no effect. Abrahamse et al. (2007) compare individual and group goal settings. One group in the survey receives a combination of tailored information and feedback on the energy usage together with a 5% energy reduction target. The other group receives the same instructions with an additional group reduction target. Energy usage declines for both groups but the group target does not show additional effects.

As outlined above, behavioural insights are often combined with traditional incentives to improve their effectiveness. It is found that energy consumer reactions depend on the way information is provided. In a review of feedback studies, Darby (2006) illustrates that real-time smart meters have a greater effect on energy savings than periodic billing figures.

Ehrhardt-Martinez et al. (2010) find similar results and suggest that policy-makers provide real-time feedback with the help of web-based devices or in-home displays. Besides the provision of information on own energy usage, they propose to combine social comparison and other motivational elements, such as goal-setting and commitment, with information-based policy programmes. Allcott and Mullainathan (2010) reveal that if households' energy consumption is compared to peers of similar characteristics, competition across the households or the desire to fulfil the social norms changes the energy consumption behaviour. They quantify the impact of social comparison on energy savings to be equally high as an electricity price increase of 11%–20%. In a similar approach, Ferraro et al. (2011) investigate water consumption and find that in the short term social comparison yields a water reduction equivalent to a water price increase of 12%–15%.

Despite the evident potential of nudging to tackle behavioural failures, several issues need to be considered. One concern is related to the use of deceptive nudging. In an experiment to initiate pro-environmental behaviour by using social norms, hotel guests are provided with inflated figures of how many people reuse towels (Goldstein et al., 2008). Using false numbers to endorse improved behaviour raises moral issues and concern about the reputation of future policy implementations. Also, the consequences of nudging might be difficult to anticipate, potentially resulting in unintended behaviour. Brown et al. (2013) show that reducing the default temperature of thermostats by 2 °C instead of 1 °C reverses intentions to reduce energy usage: with a 2 °C reduction, individuals actively intervene and increase the temperature to pre-set levels. This shows how sensitive the framing must be to achieve the desired goals. Another unintended effect is the "boomerang effect" which describes the observation that by the use of social messages some households might increase rather than decrease energy consumption if the average energy consumption of their peers is higher (Schultz et al., 2007).

Further discussions revolve around the question whether nudging effects persist throughout time. Long-term evaluations are not yet available to address the question properly. Some studies indicate that nudging could be strongest for inexperienced consumers and fade out once consumers are familiar with the matter. For example, a study on flight bookings observes that defaults for CO_2 offsets do not affect decisions of environmental economists who are possibly more familiar with the issue of environmental pollution than others. Allcott and Rogers (2014) find that first reports on peer electricity consumption reduce energy usage about five times more than later reports do, indicating a fading-out of the effectiveness of the interventions. On the other hand, Ferraro et al. (2011) show that information on peer water consumption has effects on household water usage even two years after. Other studies suggest that the persistence of social norm interventions may rely on continued feedback reports. For instance, Van Houwelingen and Van Raaij (1989) show that households consume significantly less electricity when they are informed by displays about their consumption. However, when removing the displays after 12 months, the savings do not persist. Similarly, in a meta-review of feedback studies, Ehrhardt-Martinez et al. (2010) conclude that some feedback-related energy savings persist only if reports are provided continuously. Allcott (2011) finds that there is some decay in energy savings between quarterly reports on peer energy consumption, but not in the case of monthly reports.

Consumer heterogeneity further increases the difficulty to implement nudging successfully. For instance, Costa and Kahn (2013) find that political liberals are more likely to react to environmental nudging than conservatives, illustrating the importance of understanding the heterogeneity of consumers to improve the design of tailor-made environmental policies.

Taken together, this section shows that nudging and behavioural insights can improve environmental policy-making by considering behavioural failures in the decision-making process which are not accounted for in traditional programmes (regulatory measures, financial and informational incentives). The long-term consequences of nudging and behavioural insights, however, have yet to be studied.

2.8 Chapter summary

The literature review reveals that the gap between potential and realised energy efficiency investments is mainly assessed against the backdrop of economic factors, such as market barriers, while there is an emerging number of studies incorporating behavioural factors into its assessment. The review further shows that the role of personality traits in energy efficiency investment has not yet been systematically investigated, neither theoretically nor empirically, although they are recognised as important decision drivers in other research realms. Finally, it is found that traditional policy programmes for energy efficiency, which are generally designed under the premise of rational cost-benefit evaluations, show limited success in some instances. It is recognised that findings from behavioural sciences can help to improve the effectiveness of the programmes.

The identified knowledge gap is addressed in the subsequent chapters by proposing two models for how personality traits may matter for energy efficiency decisions and examining the presumed hypotheses of the models empirically. The first model is derived in Chapter 3 by focusing on the detailed decision-making process of investing in energy efficiency, followed by its empirical investigations in Chapters 4 and 5. The second model in Chapter 6 centres on the view of social context by elaborating on the link between personality traits and social norms.

Chapter 3

Conceptualising the role of personality traits in making investment decisions: the case of residential energy efficiency

As reported in Chapter 2, the existing literature in the energy efficiency discipline lacks a comprehensive theoretical model that elaborates on personality traits in energy efficiency investments. This chapter develops an interdisciplinary conceptual framework for high-cost energy efficiency investment decisions that includes personality into individuals' decision-making process. To do so, it draws on available theories for energy efficiency and fills the personality gap by synthesising findings from the fields of environmental economics and environmental and personality psychology. The outcome is an adapted model of the utility maximisation framework for energy efficiency by Allcott and Greenstone (2012) (see Equation (2.3) on p. 60). As such, this chapter contributes to the theory of energy efficiency decisions by suggesting a novel theoretical decision framework.

3.1 Why should personality matter?

It is well known that the perception of identical situations differs widely across individuals (Allport & Odbert, 1936; Costa & MacCrae, 1992; McCrae & Costa, 2003; Villanueva, 2010). Personality defines how an individual processes events and drives his or her corresponding characteristic behaviour and decisions. For instance, extraverted people may perceive a crowded location as enjoyable while introverts might feel less comfortable. The extraverts may appreciate the conversation and the exchange of ideas, whereas the introverts may be threatened by such surroundings and would prefer to leave. As in the case of such an everyday example, it may be true that personality drives economic decisions, such as investing in energy-efficient technology. Indeed, researchers show that personality traits affect investors' behaviour and several economic outcomes, including employment status and wages, households' financial asset allocation, and regional entrepreneurship rates (Brown & Taylor, 2014; Fletcher, 2013; Gherzi et al., 2014; Obschonka et al., 2015).

It might seem intuitive that personality traits influence decisions but what are the tangible arguments for that link? More specifically, why should personality have an impact on energy efficiency investments? Four main arguments are developed for why personality should matter in energy efficiency decisions.

3.1.1 Personality and environmental behaviour

First, previous theoretical constructs and empirical investigations demonstrate a link between personality traits and environmental behaviour in general; this suggests that specific decisions, such as energy efficiency investments, are likely to be affected as well.

As described in Section 2.5.3, personal values, beliefs and norms (VBN) can be grouped as attitudinal factors that guide pro-environmental behaviour ranging from energy conservation measures to purchases of energy-efficient products (Stern et al., 1999). VBN theory explains these links through a chain of causal steps (see Figure 2.6 on p. 59). Importantly, the model assumes personal values to be relatively stable and to exert their influence at the beginning of the causal chain.

The chain structure of personal values being one step before attitudes is also proclaimed by personality trait theory. Personality traits define core personal characteristics that are relatively stable and affect how individuals react to stimuli that they encounter (McCrae & Costa Jr, 1999). Attitudes, in turn, are seen as characteristic adaptions that result from a nexus of individual essential personality traits and contextual factors such as the political, social and cultural setting (McCrae & Costa Jr, 1999). Accordingly, it should follow that attitudes related to environmental concern and subsequent environmental action or inaction can be traced back to personality traits.

3.1.2 Personality and economic theory

Second, recent economic theory on personality and economic outcomes also supports the concept that personality traits affect the choice of energy efficiency investments. Researchers are increasingly recognising connections between decision-making theory in economics and personality trait theory in psychology. Both fields address how individuals make decisions and how these lead to specific behaviour outcomes. There is general agreement among economists that they depict two closely-related concepts and that an integration of both could add significant value in explaining economic patterns (Almlund et al., 2011; Borghans et al., 2008; Bucciol & Zarri, 2015; Ferguson et al., 2011; Rustichini et al., 2016). Though researchers agree on the potential value added, clarity needs to be established on how and through which channels personality traits affect economic decisions. Becker et al. (2012) suggest that they exert a direct impact on economic outcomes complementary to economic preferences which include risk, time and social preferences. Bucciol and Zarri (2015) propose that their impact rather is translated through economic preferences. Other researchers suggest that personality traits influence individuals' productivity (Almlund et al., 2011; Borghans et al., 2008). For instance, more conscientious individuals may produce more income, thus, generating higher utilities compared to other individuals, holding other factors constant.

I advocate that the integration of personality and economic theory presaged in these previous studies should be applied to the analysis of energy efficiency investments. By representing an economic outcome, such investments depend on individuals' economic preferences. Although there is no agreement with respect to exactly how personality traits influence economic decisions, economic preferences are an area of focus in a number of studies and they are considered to be one of the most direct ways to introduce psychological factors into economic models (Almlund et al., 2011; Becker et al., 2012; Bucciol & Zarri, 2015). In the first instance, therefore, I hypothesise that, for energy efficiency investments, personality traits are mediated through economic preferences. In the second instance, they are supposed to be mediated through environmental beliefs. The causality for the latter is elaborated in Section 3.1.1 above. Why personality traits should impact energy efficiency investments through economic preferences is presented in the following section.

3.1.3 Personality and risk preferences

Third, energy efficiency investments in residential buildings, as investments, depend on risk and uncertainty preferences and are consequently driven by personality traits.

This third argument is divided into two parts. The first part shows that energy efficiency investments in residential buildings depend on risk preferences, which are core economic preferences. The second part demonstrates that risk preferences are influenced by personality traits. It is concluded that energy efficiency investments in residential buildings depend on personality traits by potentially being mediated through risk preferences.

Before each of the parts is addressed, it is important to remember what is encompassed by the term "energy efficiency investment". The term defines infrequent installations that require a significant financial outlay which can lead to structural and long-term reductions in energy usage (Karlin et al., 2014). Adoptions of energy-efficient HVAC (heating, ventilating, air-conditioning) systems and retrofits such as double-glazed windows, wall insulation, solar panels and other alternative energy installations belong to this category.[1]

The first part of the argument builds on the relationship between energy efficiency investments and risk preferences. Investing in energy-efficient technology is associated with significant ambiguity and risk.

The fact that markets for energy-efficient technology are immature is one of the reasons for this (Ryan et al., 2012). The lack of information and comparable energy efficiency investments, and the resulting shortfall in knowledge about the technology, effectiveness and financial profitability among consumers, create a state of ambiguity and a defensive attitude towards the investments. Specifically in the building sector, builders are found to misinform about the energy savings of energy efficiency improvements that creates additional mistrust (Imam et al., 2017). Furthermore, the profitability of an energy efficiency installation depends on future energy use and price patterns, which are unknown (Epper et al., 2011; Linares & Labandeira, 2010). Investors of energy-efficient technologies, therefore, run various risks, and capabilities for accepting certain amounts of uncertainty are necessary.

The second part demonstrates that an important link exists between personality traits and risk preferences. A sound body of literature in psychology and economics examines the relationships between personality traits and risk-taking. Significant relationship is found in many contexts ranging from taking part in risky sports, to health-, economic- and financial risks (Becker et al., 2012; Borghans et al., 2009; Fogel & Nehmad, 2009; Lee et al., 2008; Magar et al., 2008; Obschonka et al., 2013; Rustichini et al., 2016; Tanaka et al., 2014). Of particular interest for this research are associations between personality traits and risk-taking in investment decisions.

[1] For further clarifications of the term energy efficiency, see Section 1.6.

3.1.4 Personality and investments

Forth, there is a growing body of literature recognising the importance of personality traits for investment decisions. The available literature is mainly concerned with personality effects on risk-taking behaviour in finance.

Carducci and Wong (1998) find that Type A personalities (hard driving, competitive, impatient, tendency for hostility and aggressiveness) have a higher willingness to take risks in financial matters (e.g. automotive insurance, stock and bond investments) compared to Type B personalities, who tend to be more relaxed. They attribute the higher risk-taking of Type A individuals to their ambition for personal achievement, recognition and tendency to have higher income levels than Type B subjects. Mayfield et al. (2008) show that people scoring highly in Neuroticism have lower intentions to invest short-term, whereas extraverted individuals have higher preferences for such investing. They presume that the former effect is due to the higher anxiety of people high on Neuroticism and the latter to the outgoing and optimistic tendency of extraverted people, so that they are more likely to consult a finance advisor or start investing on their own. They further find a positive link between Openness to Experience and long-term investing, which they assign to the tendency of imagination and intellectual expression of individuals who are open to experience.

Several studies suggest that personality traits matter for people's portfolio composition. Extraverts and individuals with a tendency for anger are found to have greater exposure to equity in their financial portfolios, whereas agreeable individuals tend to have less (Durand et al., 2008; Gambetti & Giusberti, 2012). Gambetti and Giusberti (2012) find a positive link between anxiety and savings and low-risk investments (e.g. interest bearing accounts). Durand et al. (2013b) observe that individuals high on Neuroticism tend to avoid small stocks (which are usually riskier than stocks with large market capitalisations) and that investors who are more open to experience have less diversified portfolios.

Other studies report significant associations between personality and investment performance. A study of fund managers finds that investment returns of funds correlate with managers' financial risk attitude, stress tolerance level and skills to solve complex problems (von Weissenberg, 2017). Similarly, Fenton-O'Creevy et al. (2007) show that the investment performance of European investment bankers depends on their risk acceptance level and emotional stability. They further find associations between investment performance and openness to new experiences. Durand et al. (2008) observe that Extraversion and preference for innovation are positively correlated with investment performance, whereas masculinity has a negative relationship.

A few studies relate personality traits to commonly observed investment behaviours that are considered as deviations from rationality in neoclassical economics. Durand et al. (2013b) observe that agreeable and more conscientious individuals have a higher tendency for selling winners too soon and keeping losers too long in their portfolios (disposition effect), and neurotic people have a higher predisposition to rely on information that comes to their mind first when investing (availability heuristics). In a foreign exchange market simulation, Durand et al. (2013a) show that overconfidence and overreaction to unexpected news are correlated with several personality traits.

Taken together, there seems to be evidence that personality traits are associated with investment decisions. The studies suggest, that the effect of personality traits in investments mainly emerges through their importance for risk-taking behaviour. Undoubtedly, personality traits are linked to risk preferences, and since these are central to the decision-making process of investing, it should follow that personality traits are also of importance for energy efficiency investments. However, no study is found that goes beyond the assessment of risk-related factors in the personality-investment relationship, i.e. no analysis includes environmental or altruistic factors, which are key components in energy efficiency investment decisions.

Overall, the arguments for an impact of personality traits on energy efficiency investments are part of two disciplines. On the one hand, environmental concern can be attributed to environmental beliefs, which is incorporated in the VBN theory, thus in the field of social psychology. On the other hand, risk preference is an essential decision driver in economic theory. Hence, a model that considers both aspects is necessary. It is the model by Allcott and Greenstone (2012) that covers both risk preferences and environmental factors in the decision-making process (see Equation (2.3) on p. 60). Accordingly, the model is considered as the most suitable framework to nest personality traits into the decision-making process, so it will serve as the underlying model to include personality traits in the next step.

3.2 Energy efficiency investments in residential buildings: towards a framework on the impact of personality

The following paragraphs derive a conceptual framework that presents a way to integrate personality traits into economic decision-making. To build the framework, the findings of the multidisciplinary literature review in the previous sections are synthesised with the energy efficiency model developed by Allcott and Greenstone (2012). It is built in a three-step approach. In the first step, the core underlying assumptions of the framework are set. The second step incorporates the two channels for the mediation of personality traits through risk preferences and environmental concern. Finally, the translation of risk preferences and environmental concern into a revealed outcome (i.e. whether or not to adopt energy efficiency measures) is discussed.

3.2.1 Underlying assumptions and constructs

To introduce the essence of personality traits, it is assumed that preferences and beliefs are not universal or given a priori. Based on previous literature on environmental behaviour and economic and personality theory (see Sections 3.1.1 to 3.1.4), the model by Allcott and Greenstone (2012) is extended by allowing personality traits to have an impact on the agents' risk preference α and environmental belief φ:

$$PV_{Savings} \times \gamma(\alpha(\Psi), \varphi(\Psi)) > PV_{\Delta Costs} \tag{3.1}$$

This model postulates that an agent invests in energy efficiency if the discounted savings, $PV_{Savings}$, multiplied by a factor γ exceed the discounted additional costs $PV_{\Delta Costs}$. γ is a behavioural factor that adjusts the savings either to the up- or downside, depending on the individual's risk attitudes, α, and externalities φ. α expresses an agent's propensity to take risks, whereas φ describes the degree to which one considers environmental and social costs generated by energy production, such as environmental pollution (i.e. environmental concern). Importantly, the model assumes that risk preferences (α) and externalities (φ) are implicitly a function of personality traits, represented by Ψ.[2]

Before the mediation of the personality traits through risk preferences and environmental concern can be assessed, a clear definition of personality traits is necessary. The next section elaborates on how personality is operationalised in the model through the taxonomy of the so-called "Big Five" personality traits.

3.2.2 The Big Five

The five-factor structure of personality

An abundant variety of theoretical concepts and empirical approaches exist to define personality (Cervone & Pervin, 2016). For a long time, there was no consent among researchers regarding the most accurate assessment of personality, and what descriptive labels should

[2]For a more detailed version of the base model by Allcott and Greenstone (2012), see Equation (2.3) on p. 60.

be used (John & Srivastava, 1999). Often, the same names in the literature have described different concepts, and different names have referred to concepts that were in fact quite similar. During the last decades, however, there has been a developing consensus on a general taxonomy – the Big Five model – which characterises personality using five factors (Costa & MacCrae, 1992; Goldberg, 1992). The model comprises one of the "most generalizable, empirically rooted, and theoretically sound models of personality" (Gill & Hodgkinson, 2007).

The origins of the Big Five taxonomy can be traced back to the work of Allport and Odbert (1936), who collated a huge collection of adjectives as characteristics for describing individuals. This and many other studies are guided by the lexical hypothesis, according to which individuals' core characteristics are expressed in everyday language (John & Srivastava, 1999). Personality traits are extracted by analysing the vocabulary that people use and find important in their daily interactions (Goldberg, 1981). Accordingly, inventories of the main adjectives for describing characteristics (trait adjectives) are constructed and evaluated based on self-ratings, assessments by peers or scholars of psychology. Studies identify strong correlations between specific trait adjectives, and five factor structures turn out to be very similar across different samples, languages and countries (Schmitt et al., 2007). Goldberg (1992) conceptualises these personality clusters in a taxonomy of five main dimensions: Openness to Experience, Conscientiousness, Extraversion, Agreeableness and Neuroticism.

In parallel with the lexical approach, researchers use questionnaires with different scales and measures to attempt to identify broad dimensions of personality through joint factor analyses (Eysenck, 1991). Amid the sheer variety of questionnaires and methodologies, the personality inventory initially converged into only two broad characteristics: Extraversion and Neuroticism. Influenced by the lexical strands, however, Costa and McCrae (1976) began to extend the questionnaire inventories stepwise by including additional scales, i.e. Openness to Experience, Conscientiousness and Agreeableness. Their findings show that the questionnaire-based approach converges very well with the adjective-based dimensions of the Big Five traits (McCrae & Costa, 1985), underpinning the applicability of the Big Five traits for expressing personality, and further paving the way for a widely-accepted taxonomy for personality. The following paragraphs describe each of the five dimensions (Costa & MacCrae, 1992; Goldberg, 1992):

Openness to Experience describes individuals' affinity towards new actions, experiences, mental novelties and different cultures. It also describes the level of openness to arts and unconventional topics. Individuals with a high score in Openness to Experience have usually a high imaginative capability, are often well-educated and tend to question existing norms and values critically. The opposite to Openness to Experience can be described by closed mindedness, low appreciation of art and beauty and low openness to inner feelings and emotions.

Conscientiousness implies a high level of determination, persistence and reliability. It is associated with the ability to control the desire for immediate gratification. This facilitates goal-oriented decision-making, manifested in thorough evaluation of possible options before deciding, self-organisation, planning, prioritisation of tasks, and orderliness. Conscientiousness is also disclosed in the degree of diligence in following guidelines and norms.

Extraversion is characterised by a high degree of sociability, an energetic approach to social activity and talkativeness. Extraverts tend to be assertive, cheerful and tend to experience positive emotions. They prefer social interactions in groups and communities than spending time on their own. On the other hand, introverted persons tend to be reserved, shy, less active and show a lower preference for the company of others.

Agreeableness describes a prosocial attitude that is expressed in friendly, benevolent and helpful behaviour towards others. Typical traits of Agreeableness include tolerance, altruism, modesty and trust. People who score high in Agreeableness are inclined to expect positive and good behaviour from their peers and tend to retreat first in conflicts. People with a low score in Agreeableness are more suspicious, uncooperative and quarrelsome. In addition, they tend to compare themselves with others, leading to rather competitive behaviour.

Neuroticism manifests itself in anxiety, fear, anger, sadness and low emotional stability. Neurotic people are more sensitive and prone to stress and tend to be less self-confident. They are inclined towards negative emotionality, which include nervous, excited, tense and depressive feelings. On the other hand, individuals with a low score of Neuroticism are more emotionally stable, even-tempered and tend to be less susceptible to stress.

Theoretical considerations of the Big Five

A commonly held conception of personality models is that personality traits are organised mental structures which initiate and guide behaviour (Allport & Odbert, 1936). The validity of this notion is supported by studies observing that personality is linked to genetics. Riccelli et al. (2017) find that differences in the brain anatomy, development of which is strongly affected by genetic factors, are related to the Big Five traits. Lo et al. (2017) evidence links between certain genes and specific personality traits. The notion is further supported by the Big Five model and other personality taxonomies in studies showing that these constructs predict a variety of life outcomes, including academic and economic success, Body Mass Index, health, criminality, political orientation and lifespan (Almlund et al., 2011; Block & Block, 2006; Borghans et al., 2008; Rustichini et al., 2016).

However, there are some concerns whether a development of a general scientific theory of personality is possible. One concern refers to the notion that personality traits are mental structures which influence behaviour (Allport & Odbert, 1936). It is argued that the explaining of behaviour depends on different levels of analysis, including genetic, physiological, social and situational factors, so that causal models of personality traits cannot be generalised across all these levels of investigations (Matthews et al., 2009). Further, personality traits are traditionally assumed to relate to fundamental and core characteristics of an individual, possibly driven by genetic factors (Lo et al., 2017; Riccelli et al., 2017). Some studies challenge this view, positing that some traits may be constructed by social dynamics, therefore questioning the causal primacy assumption that the dominant causal direction is from the traits to behaviour. Some researchers also raise the concern that all aspects of personality are unique and idiosyncratic, disabling a theoretical generalisation of personality (Matthews et al., 2009).

Against the backdrop of questioning the theoretical notion of personality effects evolving through mental structures into behaviour, three caveats need to be raised. First, it is important not to treat the Big Five as a model that is intended to describe something that is truly existent. The Big Five traits are not tangible and do not exist in a factual way like physical items, such as a tree or flower, so that they should not be considered as a representational model of the actual world (Galvin, 2013). Nor are the Big Five a device that is expected to be found to exist as such. Instead, the Big Five as other models not representing a fact, or not presuming that the entities the models assess might genuinely exist, should be assigned to the category of heuristic models – methodological guides that allow interpreting complex phenomena of the world (Galvin, 2011; Harré, 2009). The Big Five offer a way of thinking that allows describing certain clusters of human behaviours as specific “personality traits”. The model provides researchers with a framework for how to handle and think of the complex matter of personality. A “personality trait” cannot be found in the real world but is a concept that was developed in personality researchers’ minds and spread to other people through diverse communications channels (e.g. books, internet). Many of the personality researchers agree that thinking in a framework of five “personality traits” is a reasonable heuristic to deliberate people’s heterogeneous behaviour. Although not existing in a factual way, such a concept of personality is considered a “useful imaginative device” (Galvin, 2011, p. 275) in this research to assess whether it helps to explain energy efficiency decisions.

Second, it should be recognised that the Big Five depict a descriptive construct of how people are rather than a firm theory with predefined assumptions. No a priori theoretical reasons were provided for what and how many factors of personality should emerge (Briggs, 1989). Instead, the five-factor structure manifested through the exploratory nature of the lexical approach, and theoretical explanations started to evolve only post hoc (Block, 1995). The Big Five taxonomy was therefore not intended as an explanatory personality theory but to organise the huge amount of personality traits into assessable broad domains by considering the interrelations between traits (Wiggins & Pincus, 1992).

Third, a personality structure is said to dynamically organise an individual's motivations, perceptions, cognitions and behaviours, and to lie within an individual (Block, 1995). Those dynamic processes of a psychological system cannot be directly represented by the Big Five dimensions, which measure the observable outcomes of these processes instead: the use of language in the lexical approach and self-perceptions in questionnaires. Thus, one should be aware that despite assuming an integrative and dynamic nature of the personality functioning, the Big Five constitute a descriptive and static model that tries to address individuals' internal processes indirectly through observed outcomes (Block, 2010; Magnusson & Torestad, 1993).

Alternative personality measures

Other taxonomies organise personality into fewer or more traits, while conceptually being related to the Big Five model. A very popular personality assessment is the Myers-Briggs Type Indicator (MBTI), which suggests types of personalities that are formed by four scales each consisting of two preferences: Extraversion-Introversion (EI), Sensation-Intuition (SN), Thinking-Feeling (TF) and Judging-Perceiving (JP) (Myers & McCaulley, 1985). A dichotomous preference system is used to determine one type for each scale (e.g, either extravert or introvert) but continuous preference scores can be computed to indicate the clarity of a preference. Some studies find that the scores of the EI, SN, TF and JP indices correspond well to those of Extraversion, Openness, Agreeableness and Conscientiousness, respectively, whereas Neuroticism is not associated with any of the indices (Furnham, 1996; McCrae & Costa, 1989). Often cited weaknesses of the MBTI are that it was developed on unproven and empirically untested theories based on Carl Jung's work, it does not properly represent Jung's theory of personality types, its focus on a dichotomous classification system and that its predictive power on behaviour is limited (Gardner & Martinko, 1996; McCrae & Costa, 1989; Pittenger, 2005). Thus, the popularity of the MBTI seems to be due to its publisher's successful marketing campaigns and simple categorisation scheme of individuals (Pittenger, 2005), rather than a consequence of a sound academic construct for describing personality.

Other taxonomies using fewer traits than the Big Five often merge some of the five factors into broader dimensions. In the two-factor model of temperament, for example, the first factor tends to summarise emotional stability (reversed Neuroticism), Conscientiousness, and Agreeableness by capturing attributes such as responsibility, productiveness and good behaviour, whereas the second factor seems to combine characteristics related to Openness to Experience and Extraversion, such as being creative and outgoing (Evans & Rothbart, 2009). Adding dimensions usually results in a narrower reinterpretation of the Big Five traits. The HEXACO model, for example, includes a sixth factor, Honesty-Humility, which describes individuals' sincerity, fairness, greed avoidance and modesty, while Neuroticism is re-labelled and -described with Emotionality (Ashton et al., 2014).

In view of the research goals in this thesis, the Big Five taxonomy is preferred. First, the lack of a dimension equivalent to Neuroticism in the MBTI could be a serious limitation for the research on energy efficiency investments since Neuroticism is regarded as a fundamental dimension of personality (Furnham, 1996; McCrae & Costa, 1989), and previous studies find significant associations between Neuroticism and investment behaviour (Durand et al., 2013b; Fenton-O'Creevy et al., 2007; Gambetti & Giusberti, 2012; Mayfield et al., 2008).

Other severe weaknesses of the MBTI include its dichotomous category system and limited theoretical foundations. Second, the popularity of the Big Five in the academic world is favourable against the backdrop of doing empirical analyses in this research. Apart to their conceptual and academic acceptance, the popularity of the Big Five can be attributed to the preference of large studies for brief personality measures (e.g. 5 to 15-item questions) due to multiple focuses and limited time in the studies (e.g. panel studies), and short inventories of the Big Five show acceptable reliability levels (Gosling et al., 2003). The lower popularity of the HEXACO, two-factor and other personality structures would impede the prospects for finding large empirical data that contain those measures. From these practical points of view, the Big Five model is therefore also favoured. Considering that many of the personality measures overlap with the Big Five, a reinterpretation of the Big Five effects to the other measures could be possible (McCrae & Costa, 1989).

Although the five-factor model is criticised for having been developed based on descriptive approaches, rather than on theories (Block, 1995), scholars are progressing to underpin them with theoretical constructs (Nettle, 2006), and while this process is not yet complete, the Big Five framework represents a considerable step forwards in measuring personality empirically (DeYoung, 2010). Overall, the Big Five taxonomy provides a sophisticated framework to think of people's heterogeneous personality characteristics. The different personality research strands and variety of definitions have converged towards the same five traits in the last few decades and they proved to be replicable and stable across different studies and countries. The Big Five framework is considered as one of the most useful models of personality traits among personality researchers (Matthews et al., 2009). Hence, it is used in the thesis as a heuristic device for exploring how personality traits relate to energy efficiency decisions.

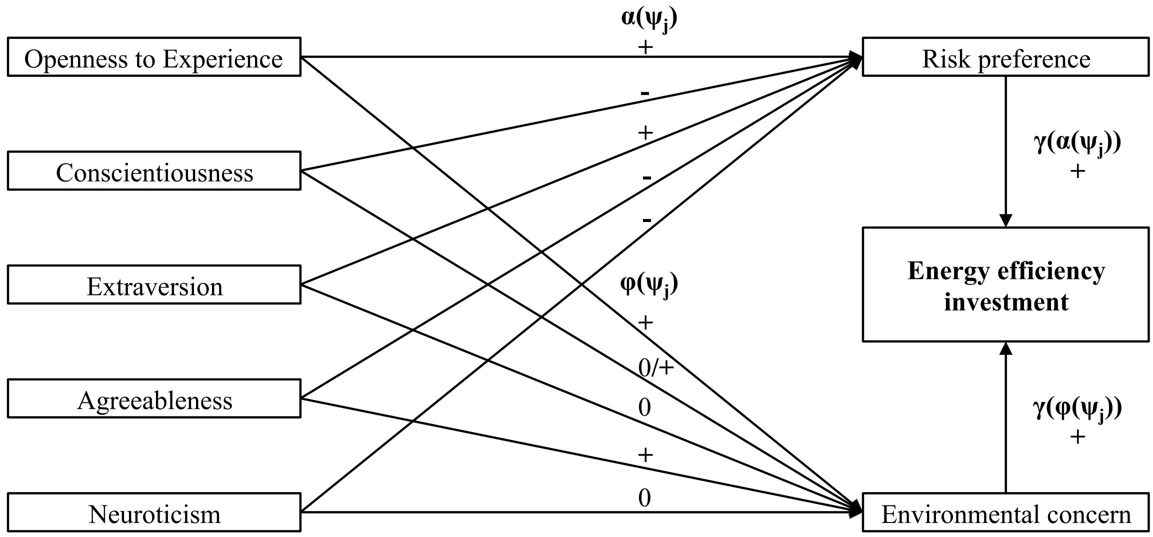
3.2.3 The two channels of mediation: risk preferences and environmental concern

Having determined a sound taxonomy to capture personality traits, their role in the decision-making process in Equation (3.1) can be assessed more thoroughly. Specifically, four functions are defined. The first two specify how the Big Five traits relate to risk preferences and environmental concern: $\alpha(\Psi_j), \varphi(\Psi_j)$, where $j = \{$Openness to Experience, Conscientiousness, Extraversion, Agreeableness, Neuroticism$\}$. The second two define how risk preferences and environmental concern translate to energy efficiency investments: $\gamma(\alpha(\Psi_j), \varphi(\Psi_j))$. Because risk preferences and environmental concern are in the middle of the causal chain, they are called the mediators.

Based on the Big Five taxonomy (Costa & MacCrae, 1992) and findings in the risk preference and environmental attitudes literature, the next paragraphs describe how each of the Big Five traits is expected to affect the mediators ($\alpha(\Psi_j), \varphi(\Psi_j)$), followed by an explanation of how the latter are expected to translate to energy efficiency investments ($\gamma(\alpha(\Psi_j), \varphi(\Psi_j))$). The hypothesised relationships are summarised in Figure 3.1.

Openness to Experience. Openness to Experience (O) is associated with higher openness to undertake new actions, which very often involves a degree of uncertainty. It also means a higher readiness to question one's values and those of the authorities, which requires an ability to confront uncertain situations since the status quo is abandoned. Previous work finds evidence for a positive relationship between O and risk preferences: Lee et al. (2008) and Nicholson et al. (2005) reveal a positive correlation between O and financial risk-taking in lottery questions and real-world practices, respectively, while other studies evidence a positive link to household debt allocations and entrepreneurship rates (Brown & Taylor, 2014; Obschonka et al., 2013).

Studies also support a positive link between O and environmental concern. As stated by Brick and Lewis (2016), flexible and abstract thinking, two main facets of O, are required



Note: +/-/0: Positive/negative/neutral impact.

Figure 3.1 Mediation of personality traits on energy efficiency investment

to anticipate long-term environmental consequences. In addition, the readiness of high-O individuals to question their own values and the status quo goes in line with scrutinising the current situation of adverse climate change. Empirical research shows a positive association between O and environmental concern (Brick & Lewis, 2016; Hilbig et al., 2013; Hirsh & Dolderman, 2007; Markowitz et al., 2012).

Conscientiousness. Conscientiousness (C) means having strong beliefs in one's own competence, being self-disciplined and striving for achievement. High-C individuals tend to be responsible and hardworking. Such achievement, however, is not aimed for under random environments (e.g. gambling) but under controlled conditions. The aversion to uncontrolled or uncertain environments is evident in the analysis by Brown and Taylor (2014), who find that households with a high C level have a lower willingness to acquire debts. Taking on debt depicts a step towards losing financial self-control (compared to equity) which is not desirable for C individuals (Lee et al., 2008). Nicholson et al. (2005) evidence a negative impact of C on general financial risk-taking.

Causality discussions on the link between C and environmental concern bring out arguments both in favour of and against pro-environmental engagement (see, for example, Markowitz et al., 2012). Results from empirical studies evidence a consistent positive relationship, though some show very small influences and minor inconsistencies (Hilbig et al., 2013; Hirsh, 2010; Markowitz et al., 2012; Milfont & Sibley, 2012). Swami et al. (2010) explain the positive impact of C on environmental concern by the need for achievement in pro-environmental values, which is facilitated by facets that work in favour of pro-environmental attitudes such as self-discipline, responsibility and carefulness. Because of minor inconsistencies in previous studies, a positive or neutral influence of C on environmental concern is expected.

Extraversion. Extraversion (E) directs people's interest towards the outer world. Individuals who score highly in E values are assertive, ambitious, energetic and optimistic. These attributes provide a strong basis to deal with uncertain decisions. E is a typical characteristic of entrepreneurship-prone individuals who usually face a significant amount of uncertainty (Caliendo et al., 2014; Zhao et al., 2010). Studies reveal a positive association between E and taking risk and uncertainty, respectively (Becker et al., 2012; Brown & Taylor, 2014; Lee et al., 2008; Nicholson et al., 2005).

Previous analyses find no, or only a very small, impacts of E on pro-environmental attitudes and therefore no relationship is expected between E and environmental concern (Markowitz et al., 2012; Milfont & Sibley, 2012; Nisbet et al., 2009).

Agreeableness. Individuals scoring highly in Agreeableness (A) show a tendency to believe in the sincerity and good intentions of others. They tend to be cooperative and more group- than self-oriented, whereas low-A individuals tend to be antisocial and egocentric. Self-centred individuals are inclined towards over-confidence by overestimating their own abilities and knowledge, which is often manifested in higher propensities to take risks (Chui et al., 2010; Mihet, 2013). Empirical studies in various risk-taking domains therefore find an inverse relationship between A and risk preferences (Borghans et al., 2009; Bucciol & Zarri, 2015; Lee et al., 2008; Nicholson et al., 2005).

Several analyses report a robust and positive impact of A on biospheric concern and pro-environmental goals (Czap & Czap, 2010; Hirsh & Dolderman, 2007; Milfont & Sibley, 2012; Passafaro et al., 2015; Swami et al., 2010). High-A individuals show higher concern for the welfare of others, meaning that they consider the consequences of their actions for others. For example, adopting energy-efficient technology may not only reduce one's own energy usage but can also improve the living conditions of fellow men through reduced carbon emissions. It is therefore expected that A is positively associated with environmental concern.

Neuroticism. Neuroticism (N) is expected to correlate negatively with risk preferences. Neurotic individuals often show a high degree of anxiety and susceptibility to stress. They try to avoid situations where outcomes are uncertain. Individuals scoring low in N, on the other hand, tend to be more confident, resilient, and are able to face stressful situations without becoming anxious or upset. Such attributes facilitate opting for risky alternatives (Becker et al., 2012; Borghans et al., 2009; Lee et al., 2008; Nicholson et al., 2005; Rustichini et al., 2016; Zhao et al., 2010).

Results on the link between N and environmental concern are mixed, ranging from negative, no to positive correlations (Brick & Lewis, 2016; Hirsh, 2010; Markowitz et al., 2012; Wiseman & Bogner, 2003). Hence, no clear association is expected between N and environmental concern.

3.2.4 Translation of risk preferences and environmental concern to energy efficiency investments

After the impact of personality traits on risk preference and environmental concern is addressed, their influence on energy efficiency investments is analysed. The translations of risk preferences and environmental concern to the investments are illustrated in the right-hand side of Figure 3.1.

As elaborated in Section 3.1.3, investing in energy efficiency involves uncertainty and risk. Higher preferences for risk should therefore facilitate investments in energy efficiency. Energy efficiency investments further consist of an environmental component. As shown in Section 3.1.1, pro-environmental attitudes and environmental concern facilitate pro-environmental decisions, which includes decisions of adopting energy-efficient technologies. Therefore, higher risk preferences and environmental concern are likely to increase the probability to invest in energy efficiency.

The final impact of personality traits on energy efficiency investments can be analysed by synthesising the translation of mediators with the associations between personality traits and the two mediators. Since the translation effects are expected to be positive for risk preference and environmental concern, the impact of the Big Five traits on energy efficiency investments should follow the same direction as the impacts of personality traits on the mediators.

3.3 Chapter summary

This chapter discusses causal arguments for a relationship between personality traits and energy efficiency investments. A detailed decision-making model is suggested by elaborating on the theoretical role of personality traits in the decision process of investing in energy efficiency. Personality traits as measured by the Big Five personality traits are found to correlate with risk preferences and environmental concern. Since these attributes depict two main factors for energy efficiency investments, it is argued that the Big Five influence energy efficiency investments indirectly through risk preferences and environmental concern (mediators).

Chapter 4

The role of personality traits in green decision-making

This chapter tests the theoretical model derived in Chapter 3 empirically. Using the data from the Understanding Society UK survey, structural equation modelling is applied to examine if the Big Five personality traits help explain why certain individuals choose to invest in energy efficiency measures while others do not, even under nearly identical financial conditions. The results show that some personality traits affect one-time, high-cost energy efficiency investments indirectly through environmental attitudes and risk preferences.

4.1 Introduction

By signing the Paris Agreement on Climate Change of 2015,[1] the UK along with other countries has agreed to limit the rise in global temperature to well below 2 °C above pre-industrial levels (UNFCCC, 2015). To achieve this goal, the Agreement sets out a target of net zero greenhouse gas emissions in the second half of the 21st century. In 2014, residential

[1] The Paris Agreement was adopted in December 2015 and entered into force in November 2016.

buildings accounted for 22% of total UK greenhouse gas emissions (CCC, 2014). Improving energy efficiency (EE) in homes offers a promising route towards achieving the emissions reduction goals along with smaller and cheaper-to-implement changes such as conserving energy and using public transport.

It has been estimated that by 2020 about 10 million homes in the UK will have solar panels on their roofs (Harvey, 2014). However, the uptake of sustainable and EE measures remains moderate despite their apparent financial profitability and benefits to environment. Stern et al. (2016a) stress the importance of considering behavioural and social factors to close the gap between potential and realised EE measures ("EE gap"). Their suggestion is picked up and it is shown empirically that a homeowner's economic decision to invest in EE can be partially predicted by certain personality traits of the decision-maker. EE investments are also compared to pro-environmental behaviour and similar results are found in terms of personality traits and environmental attitudes. However, risk preferences and household income levels are more important for predicting EE investments, which entail larger financial outlays than pro-environmental behaviour (PEB).

It is well documented that market failures such as imperfect information or unpriced externalities can prevent optimal allocation of resources into EE (Bardhan et al., 2014; Gerarden et al., 2017). More recently, researchers have turned to behavioural approaches for explaining suboptimal EE investment decisions (Allcott & Mullainathan, 2010; Ramos et al., 2015a). Gerarden et al. (2017) point out several behavioural anomalies (e.g. inattention, loss aversion, and myopia) that are responsible for the EE gap. In the residential sector, researchers find that differences in social norms do matter for energy saving behaviour (Allcott & Rogers, 2014). It is also shown that households with pro-environmental habits are more likely to invest in energy-efficient appliances (Ramos et al., 2015b). To my knowledge, this paper presents the first empirical attempt to predict EE investments using data on individual psychological characteristics (personality traits). Specifically, a structural equation model (SEM) is estimated using data on UK homeowners, to predict solar and wind turbine installations for electricity generation and solar water heating. The findings are compared to PEB by applying the same model to environmental habits (e.g. switching off appliances when not in use, carpooling, and using public transport). The results contribute to a better understanding of the EE gap and why providing financial support or information about EE options may not be sufficient for achieving higher levels of EE in the residential sector in line with carbon emissions targets.

4.2 Heterogeneous consumers and the EE gap

A number of studies investigating the microeconomic determinants of EE investments try to explain why some households choose to invest while others do not, even under seemingly identical financial circumstances (Allcott & Greenstone, 2012; Ramos et al., 2015a). Two factors emerge as particularly salient. The EE benefits are uncertain and they will (or not) occur in the future, while costs are certain and occur in the present (Fischbacher et al., 2015). Uncertainty arises from the fluctuation of energy prices as well as from idiosyncratic factors (e.g. household energy demand may fall in the future). In addition, consumers' beliefs as well as cultural and ideological factors may be of importance (Ramos et al., 2015a). If the heterogeneity of energy consumers is ignored, the estimated energy saving potential might be biased upwards and the EE gap may be overstated (Gerarden et al., 2017).

Several empirical studies of the residential sector provide evidence that environmental attitudes, environmental concern, and PEB influence the use of energy and households' EE. Ramos et al. (2015b) find that eco-friendly behaviour (e.g. recycling) among Spanish households is associated with higher investments into energy-efficient appliances, low-consumption bulbs and double glazing of windows. Lange et al. (2014) show the evidence of a positive relationship between a set of PEB, such as wearing a jumper instead of increasing the thermostat settings, and heating expenditures in the UK.

Although researchers observe heterogeneity among energy consumers, little is known about the causes for these differences. One of the possible explanations of heterogeneity is the variation in the individual psychological characteristics, specifically personality traits. Numerous studies show that personality traits affect investor behaviour and certain economic outcomes, including employment status and wages, household financial asset allocation, and regional entrepreneurship rates (Brown & Taylor, 2014; Fletcher, 2013; Gherzi et al., 2014; Obschonka et al., 2015). Other researchers find significant influence of empathy, locus of control, autism, and selfism (Ovchinnikova et al., 2009), trust and empathy (Czap & Czap, 2010), empathy and selfism (Czap et al., 2012) on conservation behaviour in framed laboratory experiments. In the context of self-reported past behaviour, Brick and Lewis (2016), using a large sample of US consumers, demonstrate that Openness to Experience, Conscientiousness and Extraversion are associated with environmental attitudes and emission-reducing activities (e.g. using reusable bags, driving below a certain speed on highways, avoid flying when travelling). By investigating electricity conservation activities from 377 individuals in New Zealand (e.g. turning off electric equipment when not in use, using EE appliances, air-drying clothes instead of using clothes drier), Milfont and Sibley (2012) find strong links between such behaviour and Conscientiousness, Agreeableness, and Neuroticism, respectively, while the links to Extraversion and Openness to Experience are not statistically significant.

Existing studies on personality traits and energy usage focus on energy conservation. Research on personality and EE, however, is remarkably limited. Energy conservation and EE seem to be closely related and previous literature often uses the terms interchangeably, without general agreement on what can be considered energy-efficient.[2] For this research, the approach of Pérez-Lombard et al. (2013) is taken and passive energy technology (e.g. wall insulation), and energy from renewable resources (e.g. solar electricity, geothermal heating)

[2]For a discussion of the terms energy conservation and EE, see Appendix A.1.

that is generated “on-site” (i.e. does not have to be delivered to the consumer) and that simultaneously reduces purchased energy, is regarded to be energy-efficient. This approach is also in line with the EU and most country-level legislation.

4.3 A model for the integration of personality traits into EE decisions

A modified utility maximisation model for EE based on the work of Allcott and Greenstone (2012) is used to test the impact of personality traits on EE investments. Consistent with basic financial mathematics, this model assumes that individuals invest into energy-efficient technology if discounted savings exceed additional discounted costs. However, the relationship between savings and costs is moderated by individual attitudes and general externalities in the following form:

$$PV_{Savings} \times \gamma(\alpha(\Psi_j), \varphi(\Psi_j)) > PV_{\Delta Costs} \tag{4.1}$$

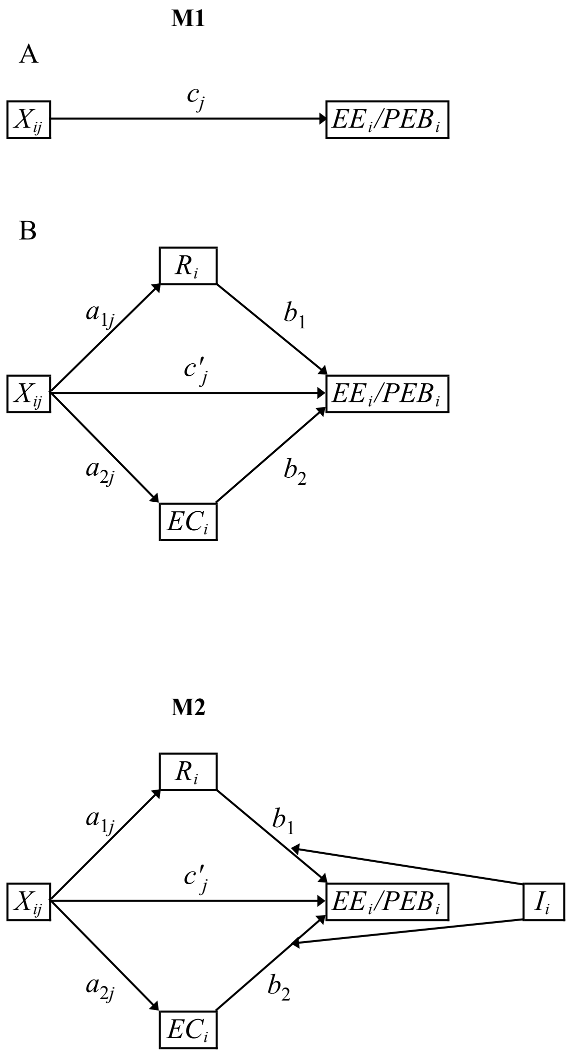
where γ is a factor that adjusts the benefits either up or down, depending on the individual’s risk attitudes, α, and externalities φ. The variable α expresses an individual’s propensity to take risks, whereas φ describes the degree to which an individual considers environmental and social costs generated by energy production. Importantly, the model assumes that risk preferences (α) and externalities (φ), which can be measured with environmental concern, are implicitly a function of personality traits Ψ. Hence, personality traits (Ψ) are mediated through risk preferences (α) and environmental concern (φ) on EE investments. In the same vein, it is assumed that the consumer compares the benefits of PEB, including personal and environmental benefits, with the associated costs, such as effort and time invested (e.g. in recycling) (Young et al., 2010).

The underlying mediation mechanisms for the model are derived from previous research on the links between personality traits on one side and risk preferences and environmental attitudes on the other side. To measure personality traits, the Big Five is used, which is a broadly recognised framework with five core dimensions (Costa & MacCrae, 1992): Openness to Experience, Conscientiousness, Extraversion, Agreeableness and Neuroticism. Researchers have found significant correlations between the Big Five and risk preferences as well as between the Big Five and environmental attitudes. Two mediation models are constructed: M1 and M2 (Figure 4.1). In M1, a direct effect and two indirect effects through risk preferences and environmental concern (mediators) for each personality trait are assumed. In M2, moderated mediation is assumed: the mediators can only be translated to EE investments or PEB (e.g. buying more expensive organic products) if households' income is sufficiently high. That is, the translation of the mediators is modelled conditionally on households' relative income (income per household member).

Significant associations have been also observed between personality traits and a number of socio-demographic variables that are of importance for EE investments or PEB, including links between the Big Five and education and age (Hakimi et al., 2011; Nair et al., 2010; Roberts et al., 2006). These factors could be included as additional mediators in the model but it is refrained from doing so because the theoretical base model by Allcott and Greenstone (2012) does not explicitly account for them. Instead, they are included in the model as control variables (see also Section 4.4.3).

4.4 Methods and derivation of the hypotheses

Based on the existing risk and environmental attitudes literature, hypotheses are derived for how each of the Big Five traits affects EE investments and PEB (Table 4.1). Each of the Big Five personality traits is introduced below and their impact on risk preferences and environmental concern is discussed.



Note: Models of the Big Five traits (X_{ij} with $j = \{$Openness to Experience, Conscientiousness, Extraversion, Agreeableness, Neuroticism$\}$) mediation through risk preferences (R_i) and environmental concern (EC_i) on energy efficiency (EE) investments (EE_i) and pro-environmental behaviour (PEB_i), where i denotes the households and I_i is the income per household member.

Figure 4.1 Mediation model M1 and moderated mediation M2

Openness to Experience. Openness to Experience (O) is associated with higher willingness to undertake new actions, which very often involve uncertainty. Previous work uncovered strong evidence of a positive relationship between O and risk preferences in the

Table 4.1 Mediation hypotheses

	EE investment		PEB	
	R	EC	R	EC
Openness to Experience	+	+	+	+
Conscientiousness	-	0/+	0/-	+
Extraversion	+	0	0	0
Agreeableness	-	+	-	+
Neuroticism	-	0	0	0

Note: This table presents the hypotheses for the mediation of the Big Five traits through risk preferences (R) and environmental concern (EC) on energy efficiency (EE) investment and pro-environmental behaviour (PEB), respectively (+/-/0: positive/negative/neutral relationship).

domains such as household asset allocations and entrepreneurship rates (Brown & Taylor, 2014; Obschonka et al., 2013).

As Brick and Lewis (2016) state, flexible and abstract thinking (two main facets of O) are required to anticipate long-term environmental consequences. Several empirical studies support this causal relationship, reporting a positive correlation between O and environmental concern (Brick & Lewis, 2016; Hilbig et al., 2013; Hirsh, 2010; Hirsh & Dolderman, 2007; Markowitz et al., 2012).

Conscientiousness. Individuals with a high degree of Conscientiousness (C) tend to be responsible and strive for achievement. Such achievement, however, is not aimed at random environments, such as gambling. Rather, the conscientious individuals strive for goal achievement in controlled conditions. This aversion to uncontrollable or uncertain situations is evident in the analysis conducted by Brown and Taylor (2014), who find that households with a high C level have a lower willingness to acquire debts.

Proponents of a causal link between C and environmental concern bring to bear arguments both in favour of and against pro-environmental engagement (Markowitz et al., 2012). Results from empirical studies show an overall consistent positive relationship, though some show very small influences and minor inconsistencies (Hilbig et al., 2013; Hirsh, 2010; Markowitz et al., 2012; Milfont & Sibley, 2012). Swami et al. (2010) argue that the need for achievement in pro-environmental values explains a positive causal pathway from C to pro-environmental action.

Extraversion. Extraversion (E) directs individual's interest towards the outer world. Individuals who score highly in E values are assertive, ambitious, energetic and optimistic. These attributes provide the ability to deal with uncertain decisions. E was found to be a typical characteristic of entrepreneurship-prone individuals, who face a significant level of uncertainty (Caliendo et al., 2014; Zhao et al., 2010). However, previous analyses have found no or only small influence of E on pro-environmental attitudes, and therefore, no sign is hypothesised between E and environmental concern (Hirsh, 2010; Markowitz et al., 2012; Milfont & Sibley, 2012).

Agreeableness. People with a high degree of Agreeableness (A) tend to be cooperative and more group- than self-oriented. Individuals with low A tend to be antisocial and egocentric. Self-centered individuals are often inclined towards over-confidence by overestimating their own abilities and knowledge. This can lead to a higher propensity for risk (Chui et al., 2010; Mihet, 2013). Related to environmental concern, several analyses report a robust and positive impact of A on biospheric concern and pro-environmental goals (Hirsh, 2010; Hirsh & Dolderman, 2007; Milfont & Sibley, 2012; Swami et al., 2010).

Neuroticism. Neurotic people tend to be anxious and susceptible to stress. The literature reports a strong and consistently negative link between Neuroticism (N) and risk-taking (Borghans et al., 2009; Zhao et al., 2010). Thus, it is hypothesised that N will negatively influence risk preferences.

Results on the link between N and environmental beliefs are mixed, ranging between zero, negative, and positive correlations (Brick & Lewis, 2016; Hirsh, 2010; Markowitz et al., 2012). Hence, no sign is hypothesised for the association between N and environmental concern.

4.4.1 EE investment as affected by the Big Five, risk preferences and environmental concern

Because markets for energy-efficient technology are immature, investing in energy-efficient technology is associated with significant ambiguity and risk (Ryan et al., 2012). The lack of information, and the resulting lack in knowledge about the technology effectiveness and financial profitability among consumers, create a defensive attitude towards investments. The expected efficiency benefits may also be uncertain because the technology is new and homeowners' experience from comparable EE projects is limited. Furthermore, the profitability of the investment depends on future energy use and price patterns, which are unknown (Epper et al., 2011; Linares & Labandeira, 2010).

Pro-environmental attitudes and environmental concern, on the other hand, facilitate pro-environmental decisions, including household decisions to adopt energy-efficient technology. Therefore, it is hypothesised that higher risk preferences and environmental concern relate positively to EE investments. Consequently, it is hypothesised that the Big Five personality traits influence EE investments in the same direction as they affect each of the two mediators.

4.4.2 PEB as affected by the Big Five, risk preferences and environmental concern

This research joins Markowitz et al. (2012, p. 83) in uncovering "underlying, situationally stable factors that motivate individuals to perform many different types of PEB" (pro-environmental behaviour). PEB includes a wide range of individual choices and can be grouped into three categories: (1) routine purchases (e.g. locally-sourced goods, organic or green products, recyclable packaging), (2) environmental habits (e.g. switching off the lights, putting on a sweater instead of adjusting the thermostat, recycling, using public transport), and (3) environmental engagement (e.g. eco-activism, voluntarism, involvement in environmental organisations). The previous studies demonstrate significant influence of some Big Five traits on PEB (Fraj & Martinez, 2006b; Markowitz et al., 2012; Milfont & Sibley, 2012; Quintelier, 2014).

For the first category, routine purchases, Quintelier (2014) finds that for young people in Belgium Openness to Experience leads to more political consumer behaviour (i.e. boycotting environmentally-damaging products and buycotting green or fair-trade products); Conscientiousness and Extraversion lead to less, while Agreeableness and Neuroticism do not influence such behaviour. For the second category, in Study 2 of Milfont and Sibley (2012), conducted in New Zealand, C, A and N are positively associated with home electricity conservation, whereas O is not statistically significant. In contrast, Markowitz et al. (2012), using US samples, show that only O and its facets are consistently and positively linked to environmental habits (such as using public transport, carpooling, composting food scraps, recycling, etc.). Regarding the third category, Fraj and Martinez (2006b) use data from Spain and find that C, A and E are positively linked to the actual commitment to environmental engagement (e.g. joining a clean-up drive, attending ecology meetings, and tracking public official voting records on environmental issues).

In this paper, it is concentrated on PEB in the second category that includes energy saving and conservation habits that are relatively cheap to implement and do not require large time commitment. In contrast to the EE investment, environmental habits involve relatively little objective risk. However, depending on the habit, individuals may evaluate the subjective risk differently. The habits such as switching off the lights when not in use and putting on more clothes instead of raising the thermostat setting are low-risk. Other habits can carry higher perceived risk: some individuals consider a personal car to be more reliable than a bus; a sudden change in weather may make a bike ride uncomfortable or even hazardous. As mentioned above, consumers may consider the EE investments (Fischbacher et al., 2015; Qiu et al., 2014) to carry significant risks. Similarly, there is an uncertainty among consumers regarding the PEB benefits, including personal benefits and the impact on the environment. In addition, risk averse individuals prefer to stick to old habits and defaults and judge them as low risk. Based on that, it is hypothesised that risk averse individuals are less likely to engage in PEB (Table 4.1).

PEB is positively linked to environmental concern: individuals making environmentally friendly conservation decisions are more concerned about the environment (Czap & Czap, 2010). Along the same lines, Fraj and Martinez (2006a) find that the individuals following ecological lifestyles score higher on the actual commitment subscale mentioned above. However, while environmental concern leads to a higher intent to behave environmentally-friendly, it does not necessarily translate into an actual pro-environmental consumer behaviour (Quintelier, 2014). One of the reasons for this weak link between attitude and action is that environmental concern affects PEB (such as requesting a green-electricity brochure) indirectly via situation-specific cognitions (Bamberg, 2003). In this paper, the interest is in the role of the relatively stable personality factors in environmental decisions and it is posited that personality traits will be mediated by environmental concern in their influence on PEB (see the second set of hypotheses for PEB in Table 4.1).

4.4.3 Data

To test the hypotheses, data from the yearly Understanding Society survey in the UK are used, the successor of the British Household Panel Survey (BHPS) (University of Essex, 2010, 2014). Since 2009 about 40,000 households and 80,000 individuals have been interviewed. The survey covers all regions of the UK and is nationally representative. The data contain a wide range of variables, ranging from individual attitudes to household socio-economic characteristics. They also cover the variables necessary to test the suggested mediation mechanism of personality traits on EE investments and PEB. The latest information on EE is available in Wave 4 (2012–2013), whereas the data on risk preferences and personality traits were collected in Wave 1 (2009–2010) and Wave 3 (2011–2012), respectively. Because the latter two variables were measured in preceding years, it is tested whether they are time-invariant.[3] Only owner-occupied households are included in the analysis since renters cannot decide on major dwelling adjustments.

EE investments. The data set contains information on whether households installed a solar panel or wind turbine for heating or electricity purposes. Answers from Wave 4 on the question "Have you installed or are you seriously considering any of the following": (1) "solar panels for electricity?", (2) "solar water heating?", (3) "wind turbine to generate electricity?" are used. Each question has the following answers to choose from: "Yes – fitted", "Yes – seriously considering", "Considered in the past and rejected" and "No". Based on the answers, two dependent variables for EE investments are derived.

The first dependent variable allows to distinguish between households that have considered an EE investment and those that have not (EE_C). If a household considered any of the adoptions, EE_C is coded with 1 (for the answers "Yes – fitted", "Yes – seriously considering", "Considered in the past and rejected"), otherwise 0 ("No"). The second dependent variable is conditioned on those households that have considered any of the EE measures and indicates an EE adoption on an ordered categorical scale (EE_A): "Yes – fitted" (2), "Yes – seriously considering" (1) and "Considered in the past and rejected" (0).

Personality traits. Wave 3 includes questions about the Big Five personality factors: Openness to Experience, Conscientiousness, Extraversion, Agreeableness and Neuroticism. Each personality trait is assessed using three questions. For each question, participants were asked to rate themselves from (1) "does not apply to me at all" to (7) "applies to me perfectly". Because personality traits were not measured in Wave 4, EE investment figures were mapped to traits from Wave 3. It was tested for invariance of personality traits and the results show that they can be expected to stay stable over time (Appendix A.2).

[3] For further details, see description of the variables below.

Personality traits are individual characteristics, whereas EE investments are household outcomes. A growing body of evidence suggests that household behaviour not only reflects the attitudes and decisions of a single individual (e.g. household head), but also incorporates the preferences of other household members who participate in the decision-making process (Donni & Chiappori, 2011; Grossbard, 2011; Milfont & Markowitz, 2016). For households with two adults (e.g. couples or a parent living with an adult child), joint decision-making is assumed and their average personality traits and other individual-level characteristics are taken. In case of three or more adults (e.g. multiple-adult households incl./excl. couples, couples with an adult child), the attributes of the homeowner responding to the survey and his/her indicated partner are averaged.[4] If there is no partner or no data available on the partner, only the attributes of the responding homeowner are taken. Since the reviewed EE investments require significant financial outlays, the attributes of the selected adults are additionally weighted by their share of the household income to check for robustness of the results.

Risk preferences. The first channel of the personality traits mediation is risk preference. Wave 1 includes a question that asks for participants' risk attitude. Respondents can choose between answers on an 11-item Likert scale from "I am not prepared to take risks at all" (0) to "I am fully prepared to take risks" (10). Since risk attitudes from Wave 1 are matched with figures from Wave 4, it was tested for invariance of risk attitudes using the data from Wave 1 and BHPS data from 2008 (University of Essex, 2010). The results show that the risk preferences are likely to be stable across a 3–4-year timespan, with some tendency to decline with age (Appendix A.3).

Environmental concern. The second channel of the personality traits mediation is environmental concern. Wave 4 also includes a module related to environmental attitudes.

[4]Partner in this context means the other person in a couple or any other adult indicated by the responding homeowner.

Respondents self-assess their attitudes toward environment on a 5-item Likert scale from "strongly agree" (1) to "strongly disagree" (5):

1. "My behaviour and everyday lifestyle contribute to climate change."
2. "If things continue on their current course, we will soon experience a major environmental disaster."
3. "Climate change is beyond control, it's too late to do anything about it."
4. "The effects of climate change are too far in the future to really worry me."
5. "It's not worth me doing things to help the environment if others don't do the same."
6. "It's not worth the UK trying to combat climate change, because other countries will just cancel out what we do."

A lower score ("strongly agree") for the first two questions means a higher environmental concern, whereas for the remaining four questions there is an inverse relationship. The answers to questions one and two are reversed to create a consistent measure, with higher scores indicating greater environmental concern. Subsequently, the scores to each question are averaged to construct an index of environmental concern, *EC*.

Pro-environmental behaviour (PEB). Wave 4 includes questions about PEB, out of which 8 can be categorised as environmental habits that are relatively cheap to implement. Respondents choose an answer on a 5-item scale ranging from "Always" (1) to "Never" (5). The answers to questions 2 and 4–8 are reversed (see below), so that higher scores on the scale correspond to more engagement in PEB. Subsequently, the PEB index was calculated as an average of the answers to:

1. "Leave your TV on standby for the night."
2. "Switch off lights in rooms that aren't being used."

3. “Keep the tap running while you brush your teeth.”

4. “Put more clothes on when you feel cold rather than putting the heating on or turning it up.”

5. “Take your own shopping bag when shopping.”

6. “Use public transport (e.g. bus, train) rather than travel by car.”

7. “Walk or cycle for short journeys less than 2 or 3 miles.”

8. “Car share with others who need to make a similar journey.”

Control variables. Based on the EE and PEB literature, the following control variables are included into the analyses: income per household member, age, gender, education, and the number of children in a household (Chen et al., 2011; Hamilton et al., 2014; Mills & Schleich, 2012; Nair et al., 2010; Poortinga et al., 2003). It is also accounted for dwelling type (detached/semi-detached/end terrace/terraced house or flat) and different solar irradiance levels, which indicate the yearly average solar irradiance per Government Office Region in the UK.[5]

4.4.4 Data representativeness

Table 4.2 presents the summary statistics of the data containing 6,044 households for the analysis. From initially 31,979 surveyed households in Wave 4, 25,875 returned fully or partially filled questionnaires, giving a response rate of 81%. Keeping only owner-occupied households (including an indication of the owners) in the analysis reduces the number of households by 8,865 to 17,010.

[5]The figures for the irradiance levels are taken from http://contemporaryenergy.co.uk/insolation-map/ for Northern Ireland and from http://www.theecoexperts.co.uk/freebook/appendix-solar-insolation-values-uk for the remaining Government Office Regions (assessed on 3 October, 2016).

Table 4.2 Summary statistics energy efficiency (EE) investments and pro-environmental behaviour (PEB)

	Total sample					Subset 1: Considering EE					Subset 2: PEB				
	N	M[a] / %	SD[b]	Min	Max	*N*	M[a] / %	SD	Min	Max	*N*	M[a] / %	SD	Min	Max
Dependent variables															
EE investment considerations (*EE_C*)	6,044	100.00													
Considered EE	1,581	26.16													
Did not consider EE	4,463	73.84													
EE adoptions (*EE_A*)						1,581	100.00								
Fitted						224	14.17								
Seriously considering						477	30.17								
Considered and rejected						880	55.66								
PEB											3,665	3.11	0.59	1	5
Personality traits															
Openness to Experience	6,044	4.68	1.11	1	7	1,581	4.73	1.06	1	7	3,665	4.72	1.21	1	7
Conscientiousness	6,044	5.57	0.91	2	7	1,581	5.55	0.89	2	7	3,665	5.58	1.01	2	7
Extraversion	6,044	4.58	1.17	1	7	1,581	4.58	1.16	1	7	3,665	4.59	1.32	1	7
Agreeableness	6,044	5.61	0.87	1	7	1,581	5.57	0.85	2	7	3,665	5.57	0.98	2	7
Neuroticism	6,044	3.43	1.22	1	7	1,581	3.42	1.16	1	7	3,665	3.31	1.34	1	7
Mediators															
Risk preference (R)	6,044	5.33	2.18	0	10	1,581	5.43	2.11	0	10	3,665	5.53	2.38	0	10
Environmental concern (EC)	6,044	3.40	0.62	1	5	1,581	3.52	0.61	1	5	3,665	3.41	0.68	1	5
Control variables															
Income[c]	6,044	1.45	1.08	-3.97	20	1,581	1.46	1.05	-0.39	10	3,665	1.52	1.1	-3.97	20
Children	6,044	0.54	0.91	0	6	1,581	0.63	1.00	0	5	3,665	0.54	0.90	0	6
Age	6,044	52.80	13.73	22	94	1,581	52.80	12.95	23	94	3,665	52.38	13.25	22	94
Gender	6,044	0.45	0.38	0	1	1,581	0.47	0.36	0	1	3,665	100.00			
Male											1,576	43.00			
Female											2,089	57.00			
Education	6,044	3.38	1.37	1	5	1,581	3.47	1.32	1	5	3,665	100.00			
Secondary school											342	9.33			
A-level or equivalent											965	26.33			
Higher degree or equivalent											538	14.68			
Diploma of higher education											327	8.92			
1st degree or equivalent											1,493	40.74			
Solar Irradiance[d]	6,044	111.72	6.52	100	123	1,581	112.09	6.48	100	123					
Building type	6,044	100.00				1,581	100.00								
Detached house/bungalow	2,134	35.31				684	43.26								
Semi-detached house/bungalow	2,100	34.75				538	34.03								
End terraced house/bungalow	430	7.11				100	6.33								
Terraced house/bungalow	1,000	16.55				224	14.17								
Purpose built flat/maisonette or equivalent	380	6.29				35	2.21								

Notes: In the total sample and subset 1, the individual-level variables show the average values of households' couples. [a]Mean. [b]Standard deviation. [c]1,000 GBP/month/household member. [d]Relative to the Government Office Region with the lowest solar irradiance level (Scotland=100).

In this sample, 1,046 and 5,012 households could not be matched with the Big Five data from Wave 3 and risk preference data from Wave 1, respectively, because households were no longer surveyed (panel attrition) or new households entered the survey (see Table 4.3). The reason for the considerably higher number of unmatched cases for the risk preference data is mainly due to the inclusion of information from continuing households of the former BHPS from Wave 2 onward, which were not captured in Wave 1. From the matched households, 1,602 are missing data on the Big Five traits and 1,920 on environmental concern mainly because respondents refused to complete the relevant self-completion modules for personality and environmental attitudes, and to a lesser extent due to not responding to at least one question in the modules (see environmental concern questions in Section 4.4.3).

Table 4.3 Missing household observations

	Unmatched households	Non-response	Missing by error or implausible	Proxy respondent	Other	Total missing
Openness to Experience	1,046	1,602	21	776	-	3,445
Conscientiousness	1,046	1,602	21	776	-	3,445
Extraversion	1,046	1,602	21	776	-	3,445
Agreeableness	1,046	1,602	21	776	-	3,445
Neuroticism	1,046	1,602	21	776	-	3,445
Risk preference (R)	5,012	18	1,531	485	-	7,046
Environmental concern (EC)	-	1,920	9	1,043	-	2,972
Education	-	-	1,293	-	5,965	7,258
Building type	-	-	272	-	38	310
EE outcome	-	8	4	-	157	169
Solar Irradiance	-	-	-	-	10	10
Income	-	-	-	-	-	-
Children	-	-	-	-	-	-
Age	-	-	-	-	-	-
Gender	-	-	-	-	-	-

Note: This table shows the number of missing household observations by variable after excluding non-owner-occupied households.

Of the same 17,010 households, 1,531 do not contain data on risk preferences and 1,293 on highest education levels due to processing errors in the panel study or implausible answers. Data on the highest education qualification are not available for additional 5,965 households (see column “Other”) because some respondents were never asked for their highest education level (3,212) or due to participants having opted "none of the above" in the education question (2,753), meaning that these cannot be assigned to an education level. Information on the Big Five, risk preference and environmental concern is further missing due to proxy respondents (e.g. spouse, parent), who provide information on the person about whom information is being sought but are not part of the survey themselves, i.e. the question are not asked of proxy respondents.[6]

The missing data for particularly the outlined variables reduce the sample to the 6,044 households.[7] The final sample for the analysis excludes rented dwellings and is missing data on several variables so that the sample is likely to have different characteristics than the overall UK population represented by the total sample of the Understanding Society data. To quantify selection effects, the participants of the final sample are compared with the total sample of the Understanding Society survey including renters and before data cleansing. The attributes are weighted using sampling weights provided by the Understanding Society survey to adjust for unequal selection probabilities, response rate differences and panel attrition (Knies, 2015). For instance, the weights account for unequal selection probability due to oversampling of certain groups or areas (e.g. ethnic minority groups, Northern Ireland).

[6]Information on the building type was not provided for 310 households and the energy efficiency outcome variable is not available for 169 households. 10 households cannot be assigned to their corresponding Government Office Regions because of missing data on geographical indicators. Any resulting sample bias due to these variables, however, is likely to be small compared to those caused by the variables with considerably more missing observations.

[7]Note that some households are missing multiple variables so that the reductions as outlined above are not cumulative. Because multiple variables are not available for a household, showing a breakdown of missing observations that add up exactly to the difference between the initial 17,010 and final 6,044 households (10,966) would not allow recognising all missing data. This can be easily illustrated with the Big Five: 3,445 households are lost due to missing observations for Openness to Experience, so that 13,565 (17,010-3,445) would remain for the analysis but it would be not known that the same 3,445 households are missing data on the other Big Five too. With such a breakdown, the number of missing observations per variable depends on which variable is taken first, second, third etc. to exclude missing household observations from the data set. In the Big Five example, the missing observations would be 3,445 for Openness to Experience but zero for the other traits. Excluding missing observations for Conscientiousness first, however, would give 3,445 missing observations for that trait but zero for the others. For the sake of completeness, Table A.3 in Appendix A.4 shows the breakdown of missing household observations that add up to the difference between the initial and final available households by excluding missing observations in the order of variables that corresponds to the order used in the data preparation.

Table 4.4 compares the total sample (representing the population) and final sample mean by people's characteristics and suggests that the differences of the means are statistically significant ($p < 0.01$ except for Extraversion with $p < 0.10$). The magnitude of the deviations is assessed by the absolute value of the relative sample bias (Groves & Peytcheva, 2008; Olson, 2006):

$$\text{Sample bias} = 100 \times \left| \frac{\bar{x}_{\text{Final sample}} - \bar{x}_{\text{Total sample}}}{\bar{x}_{\text{Total sample}}} \right| \tag{4.2}$$

where $\bar{x}_{\text{Final sample}}$ denotes the final sample and $\bar{x}_{\text{Total sample}}$ the total sample mean.

The biggest sample bias is observed for income with an overestimation of the population mean by 33.9%, followed by gender, education and age with a 10.4%, 8.7% and 7.8% overestimate. The restriction to owner-occupied dwellings in the analysis is probably one of the main reasons for these overrepresentations because high-income, male, more educated and older participants are more likely to be homeowners (Bramley & Karley, 2007; MHCLG, 2018; Vignoli et al., 2016). The sample biases for the other variables range from 0.4% to 3.5%.

Besides to the restriction of the analysis to owner-occupied households, the differences of the mean of the variables can be attributed to reducing the analysis to observations with valid values for all variables, so that the number of valid observations in the final sample (N_{Final}) is lower for each characteristic than if the variables are assessed separately (N_{Total}). To analyse which variables contribute to the sample bias the most due to missing data, the variables with the most missing household observations (these also include those with the most non-responses as can be seen in Table 4.3) are excluded separately from the data and the sample bias of these adjusted data sets is compared with the bias of the final sample used in the analysis.[8]

[8]Note that the variables with the most missing observations are not necessarily the ones that cause the biggest biases (Groves & Peytcheva, 2008).

Table 4.4 Comparison of total and final sample mean by individual variables in the UK

	Total sample mean	Final sample mean	N_{Total}	N_{Final}	p-value[a]	Sample bias[b]
Openness to Experience	4.51	4.67	35,326	8,562	0.000	3.5%
	(1.34)	(0.84)				
Conscientiousness	5.44	5.56	35,352	8,562	0.000	2.2%
	(1.12)	(0.70)				
Extraversion	4.57	4.55	35,359	8,562	0.095	0.4%
	(1.31)	(0.90)				
Agreeableness	5.60	5.56	35,359	8,562	0.000	0.7%
	(1.06)	(0.67)				
Neuroticism	3.55	3.44	35,359	8,562	0.000	3.1%
	(1.46)	(0.93)				
Risk preference (R)	5.23	5.38	25,055	8,562	0.000	2.9%
	(2.63)	(1.66)				
Environmental concern (EC)	3.29	3.39	38,472	8,562	0.000	3.0%
	(0.66)	(0.46)				
Education	3.09	3.36	28,674	8,562	0.000	8.7%
	(1.52)	(1.01)				
Income	1.44	1.93	47,157	8,562	0.000	33.9%
	(1.33)	(1.09)				
Age	47.76	51.47	47,157	8,562	0.000	7.8%
	(18.96)	(9.84)				
Gender	0.48	0.53	47,157	8,562	0.000	10.4%
	(0.50)	(0.34)				
Mean sample bias						**7.0%**

Notes: Standard deviations are provided in brackets. Note that the differences in N_{Total} across the variables due to non-matched individuals for attributes only available in previous waves (Big Five and risk preferences), non-responses and proxy respondents are accounted for by using weights provided by the Understanding Society survey (longitudinal weights are applied since attributes from different waves are used (Knies, 2015)).

[a] *t*-test on the equality of means. The *t*-test assumes independent samples and thus does not account for the covariance between individuals that are in both samples. Considering that the covariance is positive (same values for matched individuals), a test statistic accounting for the non-independence would generate a lower *p*-value due to a higher test statistic score (see, for example, (Looney & Jones, 2003)). This implies a higher likelihood of rejecting the hypothesis that the means are equivalent compared to assuming independent samples in the *t*-test, which already suggests significant differences for all variables at the 0.10 and lower significance level.

[b] Sample bias$= 100 \times \left| \frac{\bar{x}_{\text{Final sample}} - \bar{x}_{\text{Total sample}}}{\bar{x}_{\text{Total sample}}} \right|$.

Table 4.5 Sample bias of adjusted samples

	Sample bias[a]			
	Excl. Big Five	Excl. risk pref.	Excl. env. concern	Excl. education
Openness to Experience		3.5%	3.1%	1.3%
Conscientiousness		2.2%	2.2%	2.4%
Extraversion		0.4%	0.4%	0.4%
Agreeableness		0.5%	0.5%	0.2%
Neuroticism		3.1%	3.4%	4.2%
Risk preference (R)	2.9%		2.3%	1.0%
Environmental concern (EC)	3.0%	3.0%		1.2%
Education	8.7%	8.7%	8.4%	
Income	33.9%	32.8%	32.7%	24.8%
Age	7.7%	7.4%	8.6%	13.8%
Gender	8.3%	8.3%	8.3%	10.4%
Mean	10.8%	7.0%	7.0%	6.0%
Difference to mean of biases in final sample (7.0%)	3.8 pp	0.0 pp	0.0 pp	-1.0 pp

Notes: This table presents the sample biases by individuals' variables for four different data sets: a sample either excluding the Big Five traits, risk preferences, environmental concern or education. [a]Sample bias= $100 \times \left| \frac{\bar{x}_{\text{Adjusted sample}} - \bar{x}_{\text{Total sample}}}{\bar{x}_{\text{Total sample}}} \right|$.

Table 4.5 presents the sample bias of people's characteristics for each adjusted sample – a sample either excluding the Big Five traits, risk preferences, environmental concern or education (variables with the most missing observations) – and the mean of the biases, including the differences to the mean of biases in the final sample of 7.0%. With 10.8%, the mean of biases of the variables in the sample excluding the Big Five is 3.8 percentage points higher than that of the final sample. A higher sample bias with a removal of the Big Five can be attributed to the relatively low biases of the Big Five compared to the other variables, contributing to a reduction of the overall mean of biases. The mean of biases for the other adjusted data sets is either equal or 1.0 percentage points lower to that of the final sample. The numbers suggest that the contribution of one attribute due to missing data to the average sample bias is relatively small (or even negative for the Big Five). It is rather the joint consideration of those attributes that results in the overall sample bias together with the exclusion of renters. A considerable reduction of the sample bias, therefore, could be hardly achieved by the exclusion of one or a few variables but would require the elimination of multiple variables.

Overall, the sample bias – either being caused by the exclusion of renters and/or missing data – implies that the results of the analysis cannot be generalised to the UK population. This issue is discussed in Section 4.6 after presenting the results.

4.4.5 Estimation

Structural equation modelling (SEM) is used assuming no joint-normality (Byrne, 2013) and the estimated effects are bootstraped following Preacher and Hayes (2008). EE investments EE_i[9] is the dependent variable. Risk preferences (R_i) and environmental concern (EC_i) depict the mediators, and personality traits (X_{ij}) are the independent variables with $j = \{1, \ldots, 5\}$ representing the average score of the household partners for Openness to Expe-

[9] EE_i stands for either considerations of EE investments ($EE_{C,i}$) or EE adoptions ($EE_{A,i}$).

rience, Extraversion, Conscientiousness, Agreeableness and Neuroticism for each household i (Figure 4.1 on p. 101).

Path c_j in Figure 4.1A is the total effect of X_{ij} on EE_i. In Figure 4.1B, it is decomposed into the direct effect c'_j and the indirect effects of X_{ij} on EE_i via the two mediators R_i and EC_i. a_{1j} and a_{2j} depict the effects of X_{ij} on the two mediators, while path b_1 and b_2 represent the effects of the mediators on EE_i. The total indirect effect of X_{ij} on EE_i is the sum of both specific indirect effects $a_{1j}b_1$ and $a_{2j}b_2$.

Two types of models are estimated. The first, Model 1 (M1), assumes that the mediation mechanism of personality traits works equally well across different households. The corresponding equations to estimate the coefficients are:

$$R_i = d_1 + \sum_{j=1}^{5} a_{1j}X_{ij} + \gamma_1 Z_i + \varepsilon_{i1} \tag{4.3}$$

$$EC_i = d_2 + \sum_{j=1}^{5} a_{2j}X_{ij} + \gamma_2 Z_i + \varepsilon_{i2} \tag{4.4}$$

$$EE_i = d_3 + \sum_{j=1}^{5} c'_j X_{ij} + b_1 R_i + b_2 EC_i + \gamma_3 Z_i + \varepsilon_{i3}, \tag{4.5}$$

where $\gamma_k Z_i$ denotes the product of the vector for the control variables, Z_i, with the corresponding coefficient vector γ_k, d_k is the intercept, and ε_{ik} is the error term for the equations $k = \{1, \ldots, 3\}$. The personality traits, mediators and control variables are standardised due to different scales of the observations.

Model 2 (M2) represents an extension of M1 by introducing household income per household member as a moderator on path b_1 and b_2, meaning that coefficients b_1 and b_2 are calculated conditionally on income per member I_i (Figure 4.1). The translation of mediators to a decision to seriously consider or undertake an investment can be expected to be stronger for households with higher income. Formally, Equation (4.5) is adjusted as follows:

$$EE_i = d_3 + \sum_{j=1}^{5} c'_j X_{ij} + b_1 R_i + b_2 EC_i + \gamma_3 Z_i + \beta_I I_i + \beta_{RI} RI_i + \beta_{ECI} ECI_i + \varepsilon_{i3}, \qquad (4.6)$$

where β_I is the coefficient for income, β_{RI} is the coefficient for the product of risk preferences and income, RI_i, and β_{ECI} represents the coefficient for the product of environmental concern and income ECI_i.

To estimate the coefficients, a fitting process of the first and second moments (mean and variance) was implemented by applying maximum-likelihood estimation, conditional on the independent values as given (no joint-normality assumption). The assumption of no joint-normality is necessary because dummy and ordered categorical variables are included in the equation system. This allows to better assess the stability of coefficients in case of non-normal variables.

To test for significance of the estimated coefficients, 95% bias-corrected bootstrapping confidence intervals are used. The advantage of bootstrapping is that it does not impose any specific distribution of the coefficients when testing for significance. The bias-corrected confidence intervals account for any skewness and bias present in the distribution of the estimated coefficients.[10]

The same estimation procedure is applied for PEB, excluding solar irradiance and building type as control variables, which are not relevant for this outcome variable.

4.5 Results

The next two sections describe the results of the mediation models M1 and M2 for EE considerations ($EE_{C,i}$) and EE adoptions ($EE_{A,i}$), followed by the mediation results for PEB.

[10] For further details about bootstrapping, see Preacher and Hayes (2008).

4.5.1 The Big Five and EE investments

First, the estimation results of M1 are discussed. The left-hand part in Table 4.6 summarises the mediation results of M1 comparing households that have considered an EE investment with those that have not. Notably, the Big Five influence the decision to consider investing in EE through environmental concern, but not through risk preferences. Openness to Experience and Agreeableness both have a positive impact, whereas Extraversion shows a negative effect.

To assess which personality traits effectively lead to adoption of EE technology, M1 is estimated only for the households that have considered an investment: (1) the households that adopted EE measures; (2) the households that are currently seriously considering adoption; and (3) the households that considered and rejected (right-hand part Table 4.6).

In contrast to considering an EE investment, an actual investment is influenced by personality traits through the mediation channel of risk preferences. Openness to Experience and Extraversion increase the probability of investing in EE through risk preferences, whereas Agreeableness and Neuroticism have a negative impact, providing support to 4 out of the 5 hypotheses for risk (Table 4.1). The absolute size of the effect is the strongest for Openness to Experience (0.0220) and Neuroticism (-0.0224).

For mediation through environmental concern, Openness to Experience shows a positive statistically significant effect on the probability of investing in EE, whereas Extraversion has a negative effect, providing support for 3 out of the 5 hypotheses (Table 4.1). A possible explanation for an intriguing result that more extraverted individuals are less environmentally concerned is that such individuals are less disturbed by the environmental threats because of their tendency to have positive emotions and an optimistic way of thinking.

Due to the opposing mediation effects through risk preferences and environmental concern, the total indirect effects are not significant with the exception of Openness to Experience.

Overall, it is concluded that: (1) some of the Big Five personality traits indirectly influence consideration of an EE investment through the channel of environmental concern; and (2)

Table 4.6 Mediation effects of the Big Five traits on energy efficiency (EE) investments (M1)

	EE investment considerations[a]					EE adoptions[b]				
	R	EC	R+EC	Direct	Total	R	EC	R+EC	Direct	Total
Openness to Experience	.0071	**.0393***	**.0463***	.0265	**.0729***	**.0220***	**.0334***	**.0554***	-.0424	.0129
	[-.0045, .0188]	[.0281, .0522]	[.0298, .0633]	[-.0381, .0932]	[.0103, .1375]	[.0061, .0444]	[.0136, .0586]	[.0295, .0867]	[-.1569, .0706]	[-.0956, .1204]
Conscientiousness	.0010	-.0064	-.0055	-.0288	-.0343	.0029	-.0070	-.0041	.0235	.0194
	[-.0004, .0040]	[-.0147, .0008]	[-.0139, .0023]	[-.0945, .0328]	[-.0998, .0280]	[-.0035, .0142]	[-.0216, .0017]	[-.0192, .0091]	[-.0884, .1349]	[-.0919, .1325]
Extraversion	.0035	**-.0122***	-.0087	.0141	.0054	**.0111***	**-.0140***	-.0028	-.0624	-.0652
	[-.0020, .0099]	[-.0211, -.0046]	[-.0191, .0013]	[-.0499, .0788]	[-.0589, .0707]	[.0021, .0259]	[-.0309, -.0033]	[-.0222, .0152]	[-.1757, .0485]	[-.1791, .0432]
Agreeableness	-.0026	**.0120***	**.0094***	**-.0823***	**-.0729***	**-.0132***	.0050	-.0082	.0814	.0733
	[-.0077, .0014]	[.0046, .0207]	[.0009, .0189]	[-.1460, -.0190]	[-.1363, -.0096]	[-.0305, -.0033]	[-.0035, .0176]	[-.0268, .0075]	[-.0260, .1896]	[-.0324, .1801]
Neuroticism	-.0072	.0073	.0001	-.0103	-.0102	**-.0224***	.0041	-.0182	-.0018	-.0201
	[-.0190, .0044]	[-.0001, .0153]	[-.0139, .0139]	[-.0739, .0521]	[-.0724, .0511]	[-.0458, -.0058]	[-.0048, .0172]	[-.0446, .0027]	[-.1073, .1089]	[-.1249, .0899]
N			6,044					1,581		
Number of considerations			1,581 (25.16%)							
Number of adoptions								224 (14.17%)		

Notes: This table presents the mediation effects through risk preference (R), environmental concern (EC), the direct and total effects (R+EC+Direct effect) for each personality trait on EE investment considerations based on Model 1, and EE adoptions for those households that have considered an investment. Bias-corrected 95% confidence intervals from 5,000 bootstrap samples are reported under each of the effects. [a]Log odds. [b]Ordered log odds. *$p < 0.05$.

some of the Big Five personality traits indirectly influence EE adoptions through both the risk preferences and environmental concern channels.

Next, EE investment in the context of income heterogeneity is discussed by estimating model M2. In the first step, it is tested whether income has a significant impact on the translation of the mediators by dividing the households into low-income (L), medium-income (M) and high-income groups (H) by using approximately the same number of households per group.[11] In the second step, in case income has a significant moderation effect, the mediation analyses for M2 is run and the differences of the effects between H and L households are tested for significance. As for M1, both the decision to consider and the decision to adopt are analysed.

Table 4.7 shows a significantly positive income moderation for risk preferences for the EE adoptions as indicated by the positive and statistically significant interaction term between risk preference and income. For illustration purposes, Figure 4.2 uses unstandardised coefficients to show how the risk preference effect on EE adoption increases with higher income levels, whereby the intercept denotes the standalone coefficient of risk preference for which the categorised income equals zero ($\frac{-.1725}{SD(\text{risk preference})} + 0 \times \frac{.4940}{SD(\text{income\_cat}\times\text{R})}$). The interaction term between risk preference and income is not significant for the decision to consider EE investments. This result can be explained by the fact that considering an EE investment is not associated with a substantial financial outlay and the translation of preferences to EE investment considerations should therefore not depend on financial capacity. There is no statistically significant income moderation for environmental concern for both EE considerations and EE adoptions.[12]

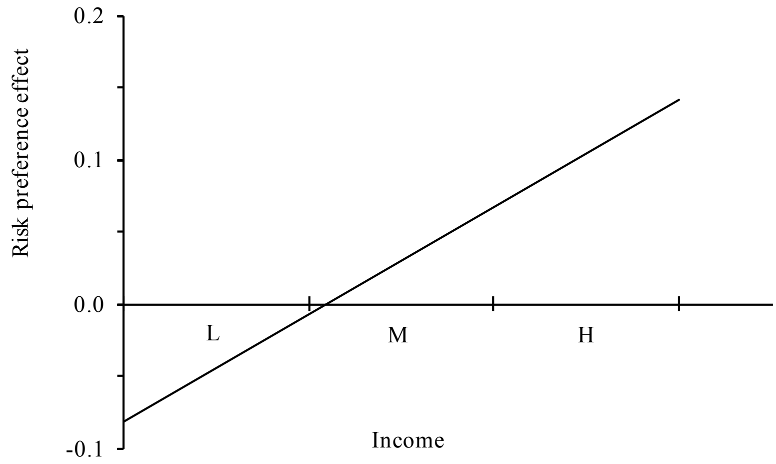
[11]To eliminate effects of scale, the variables are standardised so that categorised income is imputed as a continuous variable rather than a set of dummy variables in M2, despite being an ordinal variable.

[12]To test for robustness of the household income measure (income/household member) and dividing households equally among three income groups, the regressions in Table 4.7 are rerun by the use of an equivalised household income and alternative thresholds for the income categorisation (see Appendix A.5.1). Compared to the baseline measures, the coefficients of the moderators and income variables in the robustness checks are the same in terms of significance and direction.

Table 4.7 Moderation effects of household income on energy efficiency (EE) investments and pro-environmental behaviour (PEB) (M2)

	EE investment considerations[a]	EE adoptions[b]	PEB
Personality traits			
Openness to Experience	.0262	-.0402	.0233**
Conscientiousness	-.0286	.0232	.0228**
Extraversion	.0153	-.0647	-.0277***
Agreeableness	-.0817**	.0823	-.0106
Neuroticism	-.0108	.0006	-.0094
Mediators			
Risk preference (R)	.0852	-.1725	-.0198
Environmental concern (EC)	.1776**	.0620	.0896***
Moderators			
Income_cat[c] x R	-.0715	.4940**	.0147
Income_cat[c] x EC	.2320	.2955	.0530
Control variables			
Income_cat[c]	-.1782	-.5049	-.0912*
Children	.1225***	.0713	-.0364***
Age	.0363	-.1324**	.0890***
Gender	.1576*	.1189	-.0740***
Education	.0084	.0229	.0620***
Solar irradiance	.0900***	-.0320	
Building type	-.2519***	-.2682***	
N	6,044	1,581	3,665
Log-likelihood[d]	-19,771.86	-5,781.49	-13,082.87

Notes: [a]Log odds. [b]Ordered log odds. [c]Low-/medium-/high-income group (L/M/H) by approximately the same number of households per group. [d]Log-likelihood of the full equation model (including the regressions for risk preference and environmental concern). $*p < 0.10$, $**p < 0.05$, $***p < 0.01$.



Notes: The graph shows the unstandardised increasing coefficient of risk preference with increasing income levels from low-, medium- to high-income households (L/M/H). The income groups (L/M/H) are measured with ordinal categories 1, 2 and 3, so that the intercept at the categorised income value of zero is hypothetical. It can be approximately considered as the risk preference effect at the lowest income within the low-income group.

Figure 4.2 Moderation of risk preference effects by income for energy efficiency (EE) adoptions

M2 is therefore only tested for EE adoptions (Table 4.8). The results show that, except for Conscientiousness, the effects of the Big Five traits are mediated by risk preferences, but not by environmental concern. The differences of these risk mediation effects between H and L households are statistically significant and indicate a stronger mediation of personality traits for H households (Table 4.9).

The results in M2 indicate that higher income can ease the translation of risk preferences into EE adoptions, therefore facilitating the mediation of the personality traits through this channel. In M2, the concern about the environment, however, does not significantly affect the decision to invest in EE once a household has considered such an investment.

As a robustness check, the weighted personality traits and other individual-level characteristics for households' couples are taken instead of using the averages (according to the individuals' share on households' income) and M1 and M2 are run. Except for an additional significant effect of Neuroticism through environmental concern for EE investment considerations, the results are the same in terms of signs and significance of the results, showing only minor differences in the strength of the coefficients (see Appendix A.5.2).

Table 4.8 Mediation effects of the Big Five traits on energy efficiency adoptions, conditionally on household income (M2)

Ordered log odds	R			EC			R+EC			Direct	Total		
	L	M	H	L	M	H	L	M	H		L	M	H
Openness to Experience	**.0518***	**.1315***	**.2111***	.0675	.1233	.1792	**.1194***	**.2548***	**.3903***	-.0402	.0791	.2146	.3500
	[.0214,	[.0434,	[.0624,	[-.0135,	[-.0782,	[-.1429,	[.0359,	[.0416,	[.0428,	[-.1530,	[-.0545,	[-.0163,	[-.0012,
	.0912]	.2426]	.3964]	.1570]	.3418]	.5279]	.2102]	.4808]	.7536]	.0715]	.2206]	.4710]	.7372]
Conscientiousness	.0068	.0173	.0277	-.0141	-.0257	-.0373	-.0073	-.0084	-.0096	.0232	.0159	.0148	.0136
	[-.0099,	[-.0244,	[-.0388,	[-.0591,	[-.1304,	[-.2049,	[-.0531,	[-.1107,	[-.1703,	[-.0840,	[-.0965,	[-.1245,	[-.1697,
	.0294]	.0766]	.1268]	.0039]	.0120]	.0207]	.0210]	.0609]	.1016]	.1352]	.1322]	.1476]	.1737]
Extraversion	**.0262***	**.0665***	**.1068***	-.0282	-.0516	-.0749	-.0020	.0149	.0319	-.0647	-.0667	-.0497	-.0328
	[.0073,	[.0153,	[.0224,	[-.0839,	[-.1804,	[-.2776,	[-.0615,	[-.1231,	[-.1901,	[-.1797,	[-.1882,	[-.2172,	[-.2641,
	.0582]	.1517]	.2489]	.0022]	.0230]	.0458]	.0436]	.1331]	.2215]	.0502]	.0561]	.1197]	.1926]
Agreeableness	**-.0311***	**-.0788***	**-.1265***	.0101	.0185	.0268	-.0209	-.0603	-.0997	.0823	.0613	.0220	-.0174
	[-.0640,	[-.1694,	[-.2806,	[-.0060,	[-.0140,	[-.0227,	[-.0579,	[-.1572,	[-.2620,	[-.0268,	[-.0510,	[-.1203,	[-.2064,
	-.0109]	-.0230]	-.0344]	.0519]	.1133]	.1775]	.0221]	.0357]	.0497]	.1912]	.1748]	.1679]	.1716]
Neuroticism	**-.0527***	**-.1337***	**-.2147***	.0084	.0153	.0222	-.0443	-.1184	-.1925	.0006	-.0437	-.1178	-.1918
	[-.0959,	[-.2515,	[-.4092,	[-.0084,	[-.0177,	[-.0277,	[-.0922,	[-.2444,	[-.4008,	[-.1134,	[-.1619,	[-.2808,	[-.4242,
	-.0214]	-.0418]	-.0578]	.0498]	.1125]	.1741]	.0059]	.0054]	.0049]	.1141]	.0733]	.0449]	.0334]

Notes: This table presents the mediation effects through risk preference (R), environmental concern (EC), the direct and total effects (R+EC+Direct effect) in ordered log odds for each personality trait on energy efficiency adoptions, conditionally on income per household member (low-/medium-/high-income group (L/M/H)), based on Model 2 ($N = 1,581$). The conditional effects are calculated for three different income groups with approximately the same number of households per group. The bias-corrected 95% confidence intervals from 5,000 bootstrap samples are reported under each of the effects. $*p < 0.05$.

Table 4.9 Differences of risk preference mediation effects between high-income and low-income households for energy efficiency adoptions

	ΔR
Openness to Experience	.1593*
	[.0375, .3050]
Conscientiousness	.0209
	[-.0269, .0989]
Extraversion	.0805*
	[.0152, .1946]
Agreeableness	-.0954*
	[-.2185, -.0217]
Neuroticism	-.1620*
	[-.3219, -.0340]

Notes: This table presents the differences of the risk preference mediation effects for each personality trait on energy efficiency adoptions between high-income (H) and low-income (L) households in ordered log odds (R), based on Model 2 ($N = 1,581$). Bias-corrected 95% confidence intervals from 5,000 bootstrap samples are reported under each of the differences. $*p < 0.05$.

4.5.2 The Big Five and PEB

The estimation results of M1 with PEB as a dependent variable show that only the mediation effects through environmental concern are significant, but not the effects through risk preferences (Table 4.10).

Support is found for 5 out of 10 hypotheses (Table 4.1) regarding the mediation of the Big Five and PEB relationship. The results indicate that there is no risk preference mediation for Conscientiousness, Extraversion, and Neuroticism, but there is a positive mediation for Openness to Experience and Agreeableness by environmental concern. Also, the direct effects for Openness to Experience, Conscientiousness and Extraversion show significant influence and are considerably stronger than the mediating effects, thus indicating a straightforward impact on PEB. Openness to Experience and Extraversion show further

Table 4.10 Mediation effects of the Big Five traits on pro-environmental behaviour (M1)

	R	EC	R+EC	Direct	Total
Openness to Experience	-.0016	**.0145***	**.0129***	**.0232***	**.0362***
	[-.0050, .0017]	[.0103, .0192]	[.0076, .0186]	[.0037, .0438]	[.0162, .0565]
Conscientiousness	.0001	**-.0049***	**-.0048***	**.0227***	.0178
	[-.0002, .0010]	[-.0087, -.0011]	[-.0087, -.0010]	[.0034, .0423]	[-.0015, .0377]
Extraversion	-.0012	**-.0040***	**-.0052***	**-.0278***	**-.0330***
	[-.0037, .0013]	[-.0081, -.0001]	[-.0100, -.0006]	[-.0475, -.0080]	[-.0528, -.0130]
Agreeableness	.0007	**.0069***	**.0076***	-.0107	-.0031
	[-.0007, .0024]	[.0030, .0112]	[.0034, .0121]	[-.0302, .0094]	[-.0224, .0181]
Neuroticism	.0020	**.0040***	**.0060***	-.0097	-.0037
	[-.0022, .0061]	[.0002, .0081]	[.0003, .0117]	[-.0291, .0100]	[-.0233, .0163]

Notes: This table presents the mediation effects through risk preference (R), environmental concern (EC), the direct and total effects (R+EC+Direct effect) for each personality trait on pro-environmental behaviour, based on Model 1 ($N = 3,665$). Bias-corrected 95% confidence intervals from 5,000 bootstrap samples are reported under each of the effects. *$p < 0.05$.

significant total effects. Overall, it is concluded that: (1) depending on the trait, the Big Five have a direct and indirect influence on the PEB through the channel of environmental concern; and (2) the mediation by risk preferences does not influence the Big Five – PEB relationship.

It is also tested whether the mediated effects of the Big Five vary with financial capacity in the context of PEB (M2). The results suggest, however, that there is no significant moderation (Table 4.7), i.e. income does not significantly ease or reinforce the translation of either risk preference or environmental concern into actual PEB.[13]

4.6 Representativeness of the study sample

A caveat needs to be noted regarding the representativeness of this study. Drawing inference of the found effects to the UK population should be done with caution because the income,

[13] The same is suggested by the robustness checks with the equivalised household income and alternative thresholds for categorising the households into income groups in Appendix A.5.1.

education level, share of male respondents and age in the study sample are considerably higher than in the overall Understanding Society sample (see Section 4.4.4). As elaborated in Section 4.4.4, two main causes for the sample bias are the restriction of the analysis to owner-occupied dwellings and missing data.

Knowing that including rented dwellings in the analysis would significantly change attributes of the sample hardly allows making any implications of the results to the UK population since it is likely that not the renters but owners of those dwellings decide on major EE installations, and information on them is not provided by the survey. Nevertheless, it can be expected that the found mediation effects of personality traits are weaker if rented dwellings are accounted for: the translation of the mediators (risk preference and environmental concern) to an EE outcome (either to consider an EE investment or to undertake one) is likely to be weaker for owners of rented dwellings because some possibly lack the motivation to reduce energy costs when renters are paying for the energy bills. This view is supported by the higher number of EE measures evidenced for owner-occupied than for rented dwellings (Davis, 2011).

Considering that the sample bias is also partly due to missing data of owner-occupied households, who can decide on major EE upgrades, more detailed implications to the UK population can be deduced. The results suggest that income amplifies the translation of risk preferences to EE investments (see Figure 4.2), so that the personality trait effects through the risk preference channel are likely to be weaker if low-income households from the population are also included because it is harder to afford an EE installation with less income. For the decision to adopt an EE measure, the effect of Openness to Experience and Extraversion through risk preference is thus likely to be less positive in the UK population, while the effects of Agreeableness and Neuroticism are likely to be less negative (see Table 4.8). The lower income in the UK population is not expected to influence the mediation of the Big Five through the environmental concern channel since it does not significantly affect the translation of environmental concern (see non-significant moderator for environmental concern in Table 4.7).

Differently, the biased variables might influence the translation of both mediators (risk preference and environmental concern) to EE outcome through perceived control. Perceived control describes “the belief that one can determine one’s own internal states and behaviour, influence one’s environment, and/or bring about desired outcomes” (Wallston et al., 1987). Persons with low perceived control are thus less likely to put one’s attitudes and preferences into action. For instance, not believing at all that one can successfully organise a solar panel installation, a realisation thereof is probably not going to happen, irrespective of one’s willingness to take risks. Several studies find that perceived control is positively associated with income, education and being male, while it is negatively linked to age (see, for example, Infurna et al., 2011). Because income, education level and the share of male persons are lower in the population than in the sample, the perceived control might on average be smaller in the population, so that the translation of preferences, and, thus, personality trait effects on EE outcomes, are likely also mitigated. The lower age in the population, on the other hand, could enhance the personality effects because young people tend to perceive more control over their actions. Perceived control might also affect the translation of mediators for PEB.

Overall, except for the effect of age through perceived control, the sample bias suggests that the mediated personality trait effects are likely to be weaker in the UK population than found in this study.

4.7 Conclusions and policy implications

This paper set out to empirically investigate whether the propensity to engage in green behaviour, such as investments in domestic energy efficiency (EE), can be explained by the decision-maker’s personality traits. The analysis of the UK household panel data shows that personality traits, as measured by the Big Five, are indeed significant predictors of

EE investments and other less costly pro-environmental behaviours (PEBs). Openness to Experience, Extraversion and Agreeableness influence the probability of considering and making high-cost EE investments and engaging in PEB. Neuroticism shows associations with PEB and realisations of EE investments, whereas Conscientiousness influences PEB only.

Besides providing an insight on the impact of personality traits on PEB, this study suggests that personality traits contribute to the explanation of households' heterogeneity with respect to one-time high-cost EE investments. The importance of personality traits for environmental engagement is, therefore, not only manifested in habitual green activities but also in infrequent high-cost decisions that are driven by more deliberate thinking. Hence, personality traits should be acknowledged as one of the many possible determinants of green decisions, such as convenience, norms, ideological and socio-economic factors among others (Allcott & Rogers, 2014; Hamilton et al., 2014; Peattie, 2001).

It is found that personality traits influence decisions to consider investments in EE through environmental concern. Risk preferences, on the other hand, have a principal function for the mediation of personality traits in the case of implementation of EE measures. A personality trait constellation that results in high risk preference and high environmental concern increases the likelihood of investing in EE. If either risk preference or environmental concern are low, the likelihood of EE investment depends on the strength of the corresponding effects. If personality trait profiles are expressed in both low risk preference and low environmental concern, EE investments are unlikely. This offers a potential reason for the EE gap, in addition to the commonly observed market imperfections (e.g. lack of information).

Given the crucial role of risk attitudes in a household's decision to implement EE measures and that it is difficult to change personality traits in the short term, it is suggested that a greater emphasis should be placed on risk-sharing and risk reduction when designing government policies and private-sector investment products. Risk reduction can be achieved by increasing the range of lending products for EE measures that are currently offered by liquidity providers. Such loans can be tailored to mitigate the risk in EE projects by using floating interest rates linked to energy prices (i.e. decline/increase in energy prices leads to downward/upward adjustment of the interest rate). Furthermore, the strength of the link between energy prices and interest rate (i.e. the hedge) can be varied. Offering a variety of lending products, appealing to different risk preference profiles, would increase the uptake of EE investments.

Since personality traits also affect EE decisions through environmental concern, they can similarly guide the design of pro-environmental programmes. According to energy conservation studies, direct provision of information does not lead to significant changes in energy saving behaviour (Steg, 2016). Thus, it is proposed that, instead of simply informing people about environmental issues, policy-makers and environmental organisations customise their messages to different target audiences. For instance, since Openness to Experience influences EE considerations and investments through environmental concern, eco-labels could be designed with visual effects that engage with the typical openness facets of inner feelings and emotions. Alevizou et al. (2015) argue that consumers are not proficient in reading standard eco-labels such as Blue Angel, Nordic Swan, and EU Daisy, but “they have a right to truthful, useful and substantiated on-pack information” (p. 8743). Along these lines and based on this study it is proposed that, instead of using alphabetical letters or figures of carbon emissions, the levels of EE on eco-labels could be visualised with pictures ranging from polluted cities (low EE) to green landscapes or blue skies (high EE). Such visualisations might be more effective for openness-prone people than just highlighting the financial value of energy savings since those individuals tend to react more to aesthetics than others (Costa & MacCrae, 1992). For example, people high on openness are found to experience more awe-related feelings (e.g. wonder, being moved and touched) from images of the sky and space (Silvia et al., 2015). Such visualisations will also help communicate more saliently the environmental impact of products (in this case EE), the need for which has been identified by Alevizou et al. (2015).

The EE results further reveal that the mediation of personality traits through risk preference depends on the level of the household income. In particular, this mediation effect is stronger for wealthier households. This suggests that the individuals with certain personality profiles could be motivated to invest into EE if sufficient financial incentives (e.g. governmental subsidies, tax breaks) are made available.

With regard to the low-cost PEB, the findings broadly fall in line with those of previous studies of environmental habits. A positive relationship (indirect through environmental concern and total) is found between Openness to Experience and PEB, as observed by Markowitz et al. (2012) and Brick and Lewis (2016). It is further observed that a positive direct effect of Conscientiousness is consistent with the study of Brick and Lewis. While Milfont and Sibley's (2012) Study 2 on electricity conservation actions suggests a total positive impact for Conscientiousness, Agreeableness and Neuroticism, these findings suggest indirect effects of the latter two traits through environmental concern and a total negative impact of Extraversion instead. A possible explanation for the difference in findings is the difference in the model specification, time of data collection and geography (UK vs New Zealand). The negative impact of Extraversion on PEB further differs to the positive relationship found by Brick and Lewis. The contradictory finding might be due to differences in the PEB measures: Brick and Lewis include activities related to routine purchases (e.g. buying organic/local food), which are possibly more appealing to extraverts and their more impulsive and broader range of activities compared to other environmental habits, such as switching off lights.

For PEB, the main mediator of personality traits is environmental concern with some traits exerting a direct impact. In contrast to the effects of EE investments, the coefficients for PEB sensitivity to personality traits do not depend on income level. Thus, policy-makers should capitalise on the sensitivities of PEB to personality traits through environmental concern by making the impact of PEB more salient. This can be done, for instance, by displaying the savings from switching off the lights on the light switch or by displaying the savings from keeping the temperature down by 1 degree on the thermostat.

Overall, this study demonstrates that personality traits may pose another barrier on the way to achieve energy reduction goals in the residential sector. Differentiated and targeted products and policies informed by such behavioural insights are crucial for encouraging higher levels of residential EE investments and PEB.

4.8 Chapter summary

This chapter reveals that some personality traits affect one-time high-cost energy efficiency investments indirectly. Openness to Experience and Extraversion both increase the probability to invest in energy efficiency through risk preferences, whereas Agreeableness and Neuroticism have a decreasing effect through this channel. Additionally, Openness to Experience is found to have a positive impact on energy efficiency investment through environmental concern, while Extraversion shows a negative effect through the same channel. At the same time, low-cost pro-environmental habits such as conserving energy and buying green products are mediated only through the environmental attitude, but not through the risk preference channel. This is consistent with the fact that these everyday habits carry a much lower financial risk than a costly energy efficiency investment. The results show that besides many other determinants (e.g. socio-economic factors, convenience, norms) personality traits contribute in explaining the heterogeneity of energy efficiency investment decisions. The findings imply that for personality trait constellations that result in both low risk preferences and environmental concern, energy efficiency investments are unlikely, posing another barrier to energy efficiency goals.

This chapter does not specifically address surrounding factors in which the personality trait effects evolve. In the context of high-cost energy efficiency investments, however, external financial incentives (financial incentives not inherent in the energy efficiency investments themselves) might influence the investment decisions. The next chapter elaborates on personality traits effects on energy efficiency investments in a context of historically large financial subsidies and compares the effects to settings where the provision of subsidies has been more restrictive.

Chapter 5

Personality trait effects on pro-environmental investments in the context of financial subsidies

This chapter analyses the role of personality traits for pro-environmental investments in the context of long-standing financial subsidies. The conceptual model derived in Chapter 3 is estimated for solar PV systems in Germany, which have been subsidised through large payments for selling renewable electricity to the grid. The findings are compared to personality trait effects in the same model for pro-environmental investments for which the provision of subsidies has been more restrictive due to more stringent and complex regulations (solar thermal collectors, thermal insulation and at least double-glazed windows). The comparison suggests that personality trait effects through risk preferences are washed out for solar PV systems because the easily accessible financial incentives have likely made the risks of the investments to be virtually zero. Because risks of the less subsidised investments likely remained, several of the Big Five traits are found to influence the likelihood of investing in solar thermal collectors/energy efficiency: homeowners high on Openness to Experience and Extraversion are more likely to have invested, whereas those high on Agreeableness and Neuroticism are less likely to have done so. Apparently irrespective of the subsidy context, effects of Openness to Experience and Neuroticism are found to evolve through environmental concern on both groups of investments. All found personality trait effects are small.

5.1 Introduction

In Germany, households accounted for a quarter of all energy use in 2015, and most energy for residential use was generated from fossil fuels (UBA, 2017). Population growth, an increasing number of one-person households, and tendency towards bigger living spaces are expected to further increase household energy consumption. Investments in household energy efficiency and renewable energy (pro-environmental investments) can help mitigating energy use and fossil fuel consumption. Economists claim that these investments are also profitable in the long term, but the uptake of energy-efficient and green household installations seems to be below of what would be optimal (Allcott & Greenstone, 2012; Hirst & Brown, 1990; Jaffe & Stavins, 1994). While existing research has recognised the critical role of market barriers for the observed reluctance, such as informational and capital constraints (Gerarden et al., 2017; Jaffe & Stavins, 1994), possible behavioural explanations are still relatively unexplored (Stern et al., 2016a).

There is a growing body of literature recognising the importance of personality traits for different decision outcomes. Notably, a number of publications focus on the relationship between personality traits and low-cost pro-environmental habits (e.g. recycling) (Brick & Lewis, 2016; Markowitz et al., 2012; Milfont & Sibley, 2012). Other studies show interest in the role of personality traits in financial investment decisions unrelated to environmental aspects (Durand et al., 2008; Fenton-O'Creevy et al., 2007; Gambetti & Giusberti, 2012). Despite the importance of personality in these research fields, there is little evidence whether any personality traits are associated with investments in renewable energy systems and energy efficiency. These undertakings are pro-environmental and costly financial decisions, unlike pro-environmental habits or investments unconnected to environmental features, which refer either to the environmental or investment aspect.

To fill this knowledge gap, this study uses large-scale data to rigorously model associations between personality traits and domestic investments in renewable energy and energy efficiency in Germany. It presents the first study of how personality traits are linked to those investments in an environment that is characterised by historically long and substantial governmental policy-making to foster renewable energy and energy efficiency: Germany enacted early and large financial subsidies for generating electricity from renewable energy resources (Bundesgesetzblatt, 1990) and has been running extensive thermal retention programmes to improve energy efficiency of buildings (Gertis & Holm, 2017).

5.2 Individual differences, pro-environmental decisions and financial investments

Environmentally relevant behaviour is caused not just by price signals, but also individual differences, beliefs and experiences (Stern et al., 2016b). Frequent, low-difficulty pro-environmental behaviours are related to personality traits (Brick & Lewis, 2016), values (Stern, 2000) and political ideology in the United States (Gromet et al., 2013). Whether individuals adopt expensive, single-time installations for renewable energy or energy efficiency is linked to heterogeneity in demographics, preferences and habits (Gerarden et al., 2017). The adoption of green installations is associated with education and age (Hamilton et al., 2014; Mills & Schleich, 2012), differences in discounting behaviour (Newell & Siikamäki, 2014) and pro-environmental habits (e.g. energy and water conservation) (Ramos et al., 2015b). This study extends these findings to pro-environmental investments by focusing on personality trait differences.

Personality traits are one possibility to differentiate between individuals since they represent "consistent patterns of thoughts, feelings, or actions that distinguish people from one another" (Johnson, 1997). They can guide life outcomes in health, relationships, social status (Caspi et al., 2005) and economic outcomes including employment status, income and household allocation of wealth (Brown & Taylor, 2014; Fletcher, 2013; Gherzi et al., 2014).

A widely used taxonomy for measuring personality traits is the "Big Five", which describes five dimensions of traits: Openness to Experience, Conscientiousness, Extraversion, Agreeableness and Neuroticism (John & Srivastava, 1999). Openness to Experience is characterised by flexible, abstract thinking and an appreciation for aesthetics. Conscientiousness represents diligence, planning and a sense of duty. Extraversion is energetic engagement with a diversity of activities including social interaction. Agreeableness is valuing interpersonal harmony, and Neuroticism is the tendency to experience negative emotions such as anxiety and sadness. It shall be emphasised here that the Big Five do not exist in a factual way but are a useful tool to think of personality characteristics. The concept, therefore, should not be seen as a representational model of the actual world but as a methodological guide that allows to describe certain clusters of human behaviours (Galvin, 2011; Harré, 2009) (see also Section 3.2.2).

Openness and Conscientiousness are the Big Five personality factors that appear most associated with pro-environmental behaviour (Hirsh, 2010). However, most previous research focused on low-cost behaviours or combined low- and high-cost behaviours, and most environmental psychology research has been restricted to the United States (Gifford & Nilsson, 2014). It is unknown whether personality is associated with expensive pro-environmental installations, or whether personality effects generalise outside of the United States.

Unrelated to the literature dealing with pro-environmental decisions, studies observe associations between personality traits and financial investments. Mayfield et al. (2008) show that people scoring highly in Neuroticism and Extraversion have lower and higher intentions for short-term investing, respectively. The former effect is explained by the higher anxiety of people high on Neuroticism and the latter by the outgoing and optimistic tendency of extraverted people, who are possibly more likely to consult a financial advisor or start investing on their own. They further find that investors who are open to experience invest more long-term arguing that such people are characterised by imagination and intellectual expression. Other studies suggest that personality traits are relevant for portfolio compositions (e.g. small-cap versus large-cap stocks, share of equity) (Durand et al., 2013b, 2008; Gambetti & Giusberti, 2012).

Thus far, previous studies on personality traits and environmentally related decisions have predominantly addressed low-cost pro-environmental habits. Studies on the link between personality traits and financial investment decisions, on the other hand, have assessed outcomes that are not specifically related to environmental aspects. Literature dealing with personality traits and outcomes that involve environmental and investment aspects, and that are conducted outside the US remains narrow in focus. Cross-cultural research is necessary to build accurate models of environmental attitudes and behaviour. For example, environmental concern predicts support for pro-environmental action strongly in the United States, but weakly in most other countries (Eom et al., 2016). This type of finding shows that it is necessary to study how psychological traits lead to pro-environmental behaviours across different countries.

Therefore, the current study extends research on personality traits and pro-environmental behaviour outside the US and analyses the role of personality traits in domestic renewable energy and energy efficiency investments in Germany. Germany is special in part due to its long-standing policy programmes for fostering renewable energy and energy efficiency, particularly of historically large subsidies for green electricity. Financial subsidies can undermine intrinsic motivations in pro-environmental decisions (Bolderdijk and Steg, 2015; Griskevicius et al., 2010; Handgraaf et al., 2013; Heyman and Ariely, 2004) and identifying behavioural differences in such specific settings as in Germany could help inform interventions (e.g. public messaging) aimed at increasing pro-environmental household installations.

5.3 Germany's policy landscape for the provision of subsidies for renewable energy and energy efficiency

Many policy instruments and regulations for fostering the use of renewable energies and energy efficiency exist in Germany at the federal, federal state and local authority level. The following section aims to summarise the most important policy and regulatory developments relevant for providing subsidies for renewable energy and energy efficiency installations of residential buildings at the federal level.

5.3.1 Renewable energy regulations

In 1991, Germany was the first country where the government offered fixed-unit prices (feed-in tariff (FIT)) for selling electricity from alternative energy resources (e.g. solar or wind energy) to the grid (Bundesgesetzblatt, 1990). The programme did not show measurable effects on the uptake of electric renewable energy systems because the payments were too low to cover their installation costs (BMW, 1995).

The first noticeable increase in the deployment of electric renewable energy systems, specifically of solar photovoltaic (PV) technologies, was observed after changing the FIT legislation to the Renewable Energy Source Act in 2000 ("Erneuerbare Energien Gesetz" (EEG)) (Bundesgesetzblatt, 2000). Different to the first law, which used an average pricing schedule of the preceding two years to calculate the purchasing price, the EEG 2000 guaranteed payment of 51 EUR cents/kWh over a period of 20 years.

Adjustments of the EEG in 2003 and 2004 removed initially set ceilings of maximum plant sizes and increased the tariffs for rooftop PV to up to 57.4 EUR cents/kWh, leading to a surge into solar panel installations in Germany (Bundesgesetzblatt, 2003, 2004).

The rush in installations held on until 2013 due to decreasing prices of solar panels, although the FITs were gradually decreasing after implementing a series of changes to more restrictive EEGs (Hoppmann et al., 2014). The continuing surge of installations was likely due to the higher reductions in prices of solar PV modules than declines in FITs, which made the investments in solar panels more profitable.

From 2013 on, the number of yearly solar panel installations dropped considerably (-57% in 2013, -42% in 2014, ca. -30% in 2015) due to massive reductions in the FIT as well as increasing limitations on new installations, the feed-in into the grid and self-consumption (e.g. extra taxes and charges) (Fraunhofer ISE, 2018).

One of the most important promotion measures for heat-producing renewable energy systems is the Market Incentive Programme (MIP) ("Marktanreizprogramm"). Started in 1999 and put into law in 2009, the MIP has fostered the uptake of mainly small-scale solar thermal and biomass installations and heat pumps by providing financial subsidies through the Federal Office of Economics and Export Control (BAFA) ("Bundesamt für Wirtschaft und Ausfuhrkontrolle") (BMWi, 2016c).[1] For existing buildings, besides basis funding, additional bonuses can be applied for for particularly efficient systems or combinations of the different technologies (BMU, 2010). Since 2009, new buildings must cover the heat energy requirement partially through renewable energy and because the law does not allow subsidies for measures that are mandatory, financial incentives for heat-generating systems from renewables for new buildings are only provided if they go beyond the standards required by the Renewable Energy Heat Act ("Erneuerbare-Energien-Wärmegesetz" (EEWärmeG))

[1] The MIP also provides subsidises for large-scale heat-producing renewable energy systems (>100 kW) through the government-owned German Development Bank ("Kreditanstalt für Wiederaufbau" (KfW)) (BMWi, 2016c) but these are not of further interest because this study focuses on domestic small-scale installations.

(Bundesgesetzblatt, 2008). The Federal budget for the subsidies has increased from 100 million EUR in the year 2000 to 490 million EUR in 2009. In 2010, the government cut back the broad-scale support for heat-producing renewable energy systems after even stopping the programme for a few months due to budgetary concerns (baulinks.de, 2010; Hinrichs-Rahlwes, 2013), and the number of subsidised projects dropped from 221,071 in 2009 to only 53,283 in 2010 (BMU, 2011). From 2010 on to 2015, the number of subsidised projects slightly rebounded and showed a decreasing trend with some fluctuations (BMWi, 2016c, 2017b).

In 2016, the Federal Ministry launched the Energy Efficiency Incentive Programme (Anreizprogramm Energieeffizienz (APEE)) as an extension of the MIP to provide some extra subsidies specifically for the modernisation of heating and ventilation systems (BMWi, 2016a,b). The APEE aims to foster the replacement of old and inefficient oil and gas heating systems, whose replacement are not yet obligatory according to energy efficiency standards, with efficient biomass systems or a heating pump, and the uptake of heat-supporting solar thermal systems (BMWi, 2016b, 2018).

Compared to the FITs for solar PV systems, the provision of subsidies for heat-producing renewable energy installations throughout the last two decades can be considered to have been less expansive and secure. The total BAFA subsidies for heat-producing renewable energy installations in the MIP up to and including 2015 were about 2.5 billion EUR[2], while the cumulative remuneration of solar PV feed-in until 2015 amounted ca. 62 billion EUR (BMWi, 2017a). The remuneration for solar PV systems is financed by sales revenues received at the market for the produced renewable electricity and a surcharge imposed on consumers obtaining their electricity from the grid (EEG surcharge) (Fraunhofer ISE, 2018). Taking only the EEG surcharge of 54 billion EUR until 2015 (62 billion EUR total remuneration

[2]The number was provided by the Federal Ministry of Economic Affairs and Energy (Bundesstelle für Wirtschaft und Energie (BMWi)) upon a request on the 28.09.2018.

exclusive the revenues received at the market) (BMWi, 2017a), the cumulative financial incentives for solar PV systems are still considerably higher than those for heat-producing renewable energy installations in the MIP.

Excess heat cannot be sold to the market to generate additional revenues as it is the case for excess electricity. The subsidies for heat-producing renewable energy installations are not continuous payments as the FITs but low-interest loans or one-time payments in the form of grants. The FITs reduce risks by guaranteeing payments over a time horizon of 20 years, whereas the one-time grants might be seen as ad hoc funding that is not sustainable, especially if the subsidies are temporarily withdrawn as observed in the MIP in 2010. The uncertainty of payments arises partly due to the fact that the funding in the MIP depends on governmental budget, whereas the FITs are financed by the electricity market price plus the EEG surcharge which is paid by consumers; the difference between the market price for power on the electricity exchange and the higher fixed remuneration rate for renewable energies (Fraunhofer ISE, 2018).

5.3.2 Energy efficiency regulations

The first regulations dealing with the energy efficiency of buildings in Germany came into effect with the German Thermal Insulation Ordinance ("Wärmeschutzverordnung") in 1977 (Gertis & Holm, 2017). The main goal of the law was to limit coefficients of heat transmission for components used for new buildings and major building refurbishments (e.g. roofs, windows, walls). After several improvements of the heat transmission coefficients, the law was replaced by the Energy Saving Ordinance ("Energieeinsparverordnung" (EnEV)) in 2002. Compliance with the law was required if 20% or more of the surface of a component was refurbished (e.g. external wall, roof) (the threshold changed to 10% with the EnEV 2009) (Tuschinski, 2009). The main difference to the preceding Thermal Insulation Ordinance is that the EnEV focuses on the overall energy performance of buildings rather than solely on their components by addressing both thermal insulation coefficients and the systems for the heat supply (Weißenberger et al., 2014). The EnEV sets out requirements for the annual primary energy demand of a building. A weak insulation can thus be compensated with a better heating technology or vice versa within certain limitations. These limitations encompass maximum heat transfer coefficients for particular components and obligatory replacements of outdated boilers under certain conditions, among others (Bundesgesetzblatt, 2013). Since its first version till 2017, the EnEV was amended 7 times, including tightening of standards and refinements of the regulations (Gertis & Holm, 2017).

From 2007 on, the EnEV was of importance for the provision of subsidies for improving the energy efficiency of buildings. Launched in 2001, the CO2 Building Rehabilitation Programme (CBRP) („Gebäudesanierungsprogramm“) started to offer low-interest loans through the government-owned German Development Bank (“Kreditanstalt für Wiederaufbau” (KfW) for fostering new energy-efficient constructions and refurbishments (Rosenow & Galvin, 2013). In 2007, grants were added to the scheme and the main principle of the CBRP changed from providing low-interest loans and grants based on specific packages of measures (“Massnahmepakete”; e.g. modernisation of heating system, wall and roof insulation) to setting the required energy performance in reference to the EnEV standards. The CBRP removed the packages of measures from its programme in 2009 and at the same time started to offer financial support for single measures (“Einzelmassnahmen”; e.g. roof insulation) (Rosenow, 2013).

The general idea of the CBRP is to provide more financial support, the higher the level of energy efficiency beyond the minimum energy efficiency standards. Until 2016, the refurbishment standard for primary energy use was 40% less stringent than that of new buildings because it is more challenging to achieve a certain level of energy efficiency for refurbishments than for new builds. From 2016 on, the difference changed to 87% after the requirement for primary energy use became another time more stringent for new builds (Verbraucherzentrale, 2017).

Due to the difference in the difficulty to achieve energy efficiency standards, the trigger for financial subsidies for refurbishment projects is also set less stringent than for new builds: refurbishments are eligible for subsidies if the renovated building does not consume more than 115% of a new build in standards of the EnEV 2009, and new constructions if they meet an energy consumption of 55% or lower of the same standards (KfW, 2018a,b). The trigger levels for subsidies for both refurbishments and new builds are beyond their corresponding legal standards.[3] The reason put forward by Federal policy-makers for setting trigger levels for subsidies beyond required EnEV standards is that refurbishing to the standards does not cost anything since the standards are set such that the renovations pay for themselves, whereas energy efficiency improvements beyond the EnEV standards are expected to generate shortfalls in payback (Galvin, 2010, 2012). In the same vein, the trigger levels for new builds are set according to cost optimality calculations as stated by policy-makers.

Besides its importance for energy efficiency, the EnEV has also been indirectly relevant for subsidising renewable energy. Renewable energy systems have been considered in the KfW programmes through EnEV requirements insofar that the use of renewable energy can be deduced from the primary energy demand of a building, helping to go beyond the EnEV standards in order to get a KfW subsidy. For renewable electricity, the primary energy demand can be reduced by removing it from the final energy demand if the electricity is produced "on-site", it is predominantly used for a building's own consumption and only the remainder of electricity is sold to the grid (Tuschinski, 2015). For "on-site" produced environmental energy ("Umweltenergie"), including solar thermal and geothermal energy,

[3]For refurbishments, the mandatory legal requirement is a maximum of 140% of primary energy demand of a new build in standards of the EnEV 2009. After more stringent standards for new builds were introduced in 2016, the legal minimum requirement for new builds became 70% in EnEV 2009 standards (KfW, 2015).

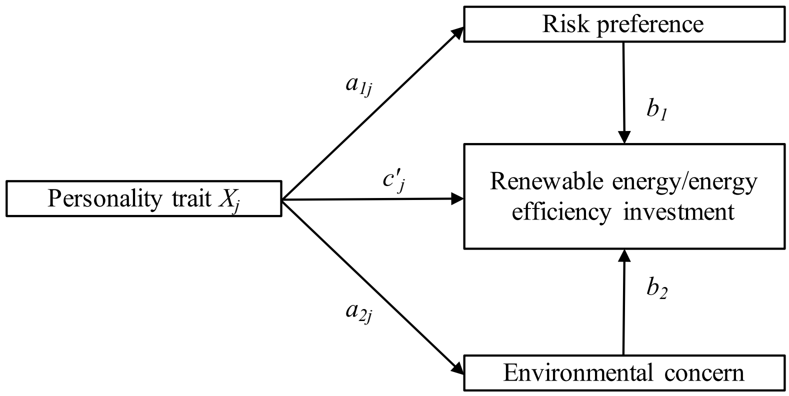
ambient heat and free cooling, a primary energy factor of zero is used to convert the final energy to primary energy demand (energie-experten.org, 2013; Wuppertal Institut, 2015).

The overview of Germany's policies for renewable energy and energy efficiency at the federal level suggests that those for renewable energy have offered substantial subsidies for generating renewable electricity through the FIT programmes. Comparable financial incentives have not been offered for heat-generating renewable energy systems or energy efficiency installations. Subsidies for the former have been offered to a lesser extent and have been less secure, and both kinds of installations depend to a great part on more restrictive energy efficiency regulations. Different to renewable electricity, the financial support for heat-generating renewables and energy efficiency has been harder to obtain mainly due to the requirement that thermal improvements of buildings go beyond the EnEV standards, and, the complexity of the policies. Investments in renewable electricity can thus be considered as highly subsidised projects but less so other renewable energy investments (solar or geothermal installations) or energy efficiency investments.

5.4 Personality traits versus financial incentives

To analyse the role of personality traits in renewable energy and energy efficiency investments in Germany, the conceptual model derived in Chapter 3 is used. The model describes energy efficiency outcomes from the individual point of view and describes whether each of the Big Five traits relates to the decision to invest in energy efficiency directly and indirectly through risk preferences and environmental concern (see Figure 5.1). As outlined in Section 1.6 of Chapter 1 (p. 10), renewable energy systems can be categorised as an active form of energy-efficient technology and thus can be assessed in the presented conceptual framework.

Investing in relatively uncommon renewable energy systems or energy efficiency systems involves uncertainty and risk. These installations cannot easily be removed, the technology can be new and unfamiliar, and the effectiveness and profitability of the installations uncertain



Note: Model of the Big Five traits (X_j) mediation through risk preference and environmental concern on renewable energy/energy efficiency investment with $j = \{$Openness to Experience, Conscientiousness, Extraversion, Agreeableness, Neuroticism$\}$.

Figure 5.1 Big Five mediation on pro-environmental investment

(Epper et al., 2011; Linares & Labandeira, 2010; Ryan et al., 2012). Higher preferences for risk should therefore generally facilitate the decision to adopt renewable energy or energy efficiency systems.

Pro-environmental attitudes and environmental concern also facilitate pro-environmental decisions (Stern et al., 1999). For example, even if a pro-environmental installation has a lower expected financial profitability compared to a stock purchase, pro-environmental attitudes may motivate pro-environmental investment.

The coefficients b_1 and b_2 in Figure 5.1 are thus expected to have a positive sign ($b_1 > 0$, $b_2 > 0$).

The supposed associations, however, might work differently in Germany due to its heavy policy measures. The change of the renewable energy legislation in Germany to the EEG introduced a phase in which the risks of solar panel installations were massively reduced. The guaranteed price for renewable electricity over a horizon of 20 years made investments in solar panels from the financial profit point of view a “no-brainer”. It might be that under such circumstances, where the objective financial profit of an investment is so evident and the financial risk of the solar panel installations minimal, less tangible factors such as personality traits might play a minor role in the decision-making process. It is possible that the mediation of the Big Five personality traits through the risk preference channel on solar panels is capped. Even an individual with a very risk-averse personality trait constellation might be willing to invest in solar panels if large financial guarantees as the FITs in Germany are provided due to the virtually non-existent investment risks. Hence, it is hypothesised that a homeowner's risk preference for the decision of investing in solar panels is not relevant ($b_1 = 0$) and the effect of the Big Five traits on solar panels through risk preference is limited. On the other hand, the effects of the Big Five through environmental concern might prevail irrespective of the financial subsidies.[4]

It is harder to determine what effect the subsidies offered by the BAFA and government-owned bank KfW had on renewable energy systems that are not subsidised by the FIT programme (e.g. solar thermal collectors) and energy efficiency investments (e.g. thermal insulation for walls, roofs), respectively. The cumulative subsidies provided through the BAFA for non-electricity renewable installations are smaller and have been less secure compared to FITs. Subsidies for both non-electricity renewable installations and energy efficiency investments are only provided for measures that go beyond the legal standards. According to Federal policy-makers, no KfW subsidies are provided for energy efficiency improvements that only go to the minimum standards since those are expected to pay for themselves (Galvin, 2013). The subsidies are intended to cover the costs of improving energy efficiency beyond the EnEV standards, so that homeowners who are already planning to renovate are possibly incentivised to do so to higher levels than required by the standards. The Federal policy-makers argue that the KfW subsidies motivate those homeowners to further

[4]For a detailed description of the expected associations between the Big Five traits and risk preferences and environmental concern (a_{1j} and a_{2j} in Figure 5.1), see Section 3.2.3 in Chapter 3 (p. 89).

improve energy efficiency since they can get something for no more costs (Galvin, 2010). But the abundant amount of laws and various changes in the minimum energy efficiency requirements became increasingly complex (Gertis & Holm, 2017). The energy efficiency regulations gradually tightened and it became more expensive and technically challenging to achieve the higher standards (Sprengard et al., 2013). Therefore, the challenges that homeowners are facing when improving energy efficiency to only legal standards are even more so at hand when going beyond these standards (e.g. technical feasibility and non-linear cost increases with increasing energy efficiency (Galvin, 2012)), calling into question the effectiveness of the subsidies.

Different possibilities exist how to achieve energy efficiency levels that qualify for a KfW subsidy. Subsidy programmes for major refurbishments and new builds refer to the overall energy performance of a building, which considers the retention of heat and technology for the heat supply. A weak insulation could be compensated with a better heating technology or vice versa (Weißenberger et al., 2014). Renewable energy produced "on-site" can be deduced from primary energy demand. Different insulation products can be used, such as rock wool, glass wool, sheep wool, polystyrene etc. with each having its own conductivity specification. The steady improvements of the products and manifold changes of the energy efficiency laws, specifically the EnEV standards, are likely to impede a straightforward appraisal of the profitability of improving energy efficiency to levels beyond which subsidies are provided. Homeowners are often unsure whether the renovations are truly profitable (Weiss et al., 2012). They face much effort to determine if and how they can trigger a financial support for their energy efficiency investments. Getting a low-interest loan or grant for an energy-efficient home is likely harder and less straightforward compared to receiving FITs for renewable electricity, which instead can be considered as "low hanging fruits". It is thus difficult to identify a product among energy-efficient technologies or energy systems not producing renewable electricity that similarly to solar panels has been offered so massive and evident financial support.

The Federal financing programmes for energy efficiency technology (e.g. wall and roof insulations) and renewable energy technology other than producing electricity can therefore not be considered as schemes of substantial subsidies and thus risk reductions comparable to the scale of the FITs for solar panels. Homeowners' risk preferences might well remain a factor in deciding whether to adopt those technologies, besides environmental concern. Thus, it is hypothesised that the effects of the Big Five on energy efficiency and renewable energy systems not generating electricity (e.g. heat-generating systems) can unfold through the channel of risk preferences and environmental concern.

Based on the elaborations above and existing evidence of associations between the Big Five traits and risk preferences and environmental concern (see details in Section 3.2.3 on p. 89), the effects of the Big Five on the pro-environmental investments through risk preferences and environmental concern are summarised in Table 5.1. The left-hand side shows the expected effects for solar PV systems, which received large subsidies through the FIT programme, and the right-hand side those for renewable energy systems not subsidised by the FIT programme and for energy efficiency investments. The hypotheses are tested in a cross-sectional empirical analysis.

5.5 Data

This section reports how the sample size is determined to test the hypotheses, all measures in the study and all data exclusions. For the analysis, the German Socio-Economic Panel study (SOEP) is used, an annual and geographically representative survey of German households that gathers socio-demographic, financial and other household information (SOEP, 2016; Wagner et al., 2007). All items are translated from German by the SOEP.

Table 5.1 Hypotheses for pro-environmental investments

	Solar PV		Non-electricity RE tech. and EE	
	R	EC	R	EC
Openness to Experience	0	+	+	+
Conscientiousness	0	0/+	-	0/+
Extraversion	0	0	+	0
Agreeableness	0	+	-	+
Neuroticism	0	0	-	0

Note: This table presents the hypotheses for the mediation of the Big Five traits through risk preferences (R) and environmental concern (EC) on (1) solar PV investment and (2) renewable energy (RE) technology investments other than for electricity production and energy efficiency (EE) investments (+/-/0: positive/negative/neutral relationship).

Pro-environmental investments. The survey contains data on households' renewable energy systems and energy efficiency measures. It is known whether households had a solar PV or thermal installation, thermal insulation or windows that are at least double-glazed in 2015. The data were assessed by the following questions:

1. "Does this owner-occupied dwelling/building have a photovoltaic system to produce solar electricity?"

2. "Does this owner-occupied dwelling/building have its own solar thermal system, that is, solar collectors for heat generation?"

3. "What amenities does your dwelling have? Does it have...

    3.1 thermal insulation (e.g. on the facade, roof, basement ceiling)?

    3.2 windows with at least double-glazing?"

Respondents could answer with a "Yes" or "No" to each question.

Answers to the first question are used to test the hypotheses in the left-hand side of Table 5.1 addressing the influence of personality traits on pro-environmental investments in the context of massive financial subsidies. As outlined in the previous section, the products in the other questions cannot be considered as significantly subsidised investments and can thus be used to test the hypothesis in the right-hand side of Table 5.1. For that, a new variable is defined that identifies households with either a solar thermal system, thermal insulation (e.g. facade, roof or basement ceiling) or windows with at least double-glazing. Only homeowners are included because renters often lack the control and incentives for major building upgrades.

Personality traits. The survey measured the Big Five personality traits for the head of household and separately for their partner in 2009 and 2013: Openness to Experience (O), Conscientiousness (C), Extraversion (E), Agreeableness (A) and Neuroticism (N). The personality traits were assessed by self-report questionnaire using a 15-item version of the Big Five Inventory (BFI-S) based on the original 44-item Big Five Inventory (Hahn et al., 2012). Participants rated the statements on a 7-point Likert-type scale ranging from 1 (does not apply to me at all) to 7 (applies to me perfectly). Three items assessed each personality trait. The internal consistency of the measures is poor (Cronbach's α = .61, .58, .66, .49, .64, for Openness to Experience, Conscientiousness, Extraversion, Agreeableness and Neuroticism, respectively), which is likely due to the use of the brief 15-item instead of a more comprehensive measure. Panel data studies as the German SOEP often face a trade-off between presenting longer and more sophisticated questionnaires and collecting lower quality information due to refusal to participate or careless responses.

The stability of the personality traits throughout time is tested to assess whether those from 2013 can be mapped with the data on pro-environmental investments from 2015. The findings suggest that the changes between 2009 and 2013, the years when the personality traits were surveyed, are relatively small: for 95% of the personality trait differences, the change is not above 2 levels in absolute terms, while 90% of the observations show a smaller difference than 1 ($N = 8,550$ for each personality trait). This result is supported by previous studies showing that personality traits tend to stay relatively stable throughout time (Brown & Taylor, 2014; Busic-Sontic et al., 2017; Cobb-Clark & Schurer, 2012). Because the tested differences refer to a time span of 4 years, the changes are likely small for even a higher proportion of individuals if putting forward the personality data by only 2 years to 2015. The 2013 personality data can, therefore, be used in 2015 without expecting big changes in personality traits for most individuals.

The survey further includes an item measuring whether the respondent or their partner has the last word in household financial decisions. The trait ratings from the person with the last word are used, and in the case of the respondent saying both people are equally involved in financial decisions, the traits of the respondent and partner are averaged (last-word model). Averaging personality traits as a method to map individual-level variables to household outcomes is similarly used in other studies (e.g. Brown & Taylor, 2014). If there is no partner or no data available on the partner, the attributes of the respondent are taken. To test the robustness of the last-word model, a second analysis is run assuming that partners in all non-individual households have equal word in the decisions by averaging the traits of the respondent and partner for all households (collective model).

Risk preferences. Individuals were asked one question about their personal willingness to take risks: "How do you see yourself: are you generally a person who is fully prepared to take risks or do you try to avoid taking risks?" Respondents rated their willingness on an 11-point Likert-type scale ranging from 0 (not at all willing to take risks) to 10 (very willing to take risks).

Environmental concern. Environmental concern was measured with one item: "What is your attitude toward environmental protection? Are you concerned about it?" Participants responded on a 3-point Likert-type scale of 1 (very concerned), 2 (somewhat concerned), or 3 (not concerned at all). The answers are reversed to create a measure with higher scores indicating greater environmental concern.

Control variables. Based on known covariates for household energy use in the green investment literature, it is controlled for age, education, gender, number of children in a household and equivalised household income[5]. Households with younger and more educated members are more likely to adopt energy-efficient technology (household appliances such as refrigerators and dishwashers) (Mills & Schleich, 2012), possibly because of the longer return period of energy savings for younger members and better ability to predict future operational costs by more educated individuals (Di Maria et al., 2010). Women report more pro-environmental behaviour than men (Zelezny et al., 2000). The number of children in a household and income are positively associated with adopting energy efficiency measures, perhaps because of the higher energy and comfort necessities of households with children and higher costs of energy-efficient technology, respectively (Ramos et al., 2015b).

It is also controlled for the type of building and different solar irradiance levels across Germany by taking the annual sunshine duration for each state averaged from 1980 to 2015, provided by the Deutscher Wetterdienst (DWD, 2016). Buildings with multiple housing units or unfavourable roof conditions (e.g. high-rise) and shorter sunshine durations might impede a solar panel installation, for example.

15,991 surveyed households in 2015 returned fully or partially filled questionnaires. Keeping only owner-occupied households reduces the number to 6,784. Matching the data with the Big Five from 2013 and missing data decreases the number of available households for the analysis to 3,974. Table 5.2 shows the number of missing observations by variable.[6] The biggest reduction in household observations is due to matching the Big Five from 2013 with the pro-environmental installations and other data from 2015 (1,509) because new

[5]The equivalised household income accounts for the fact that additional adults or children in a household have less additional living expenditure than the first adult. For instance, more income is expected to be at disposal for an adult and a child than for two adults. Therefore, guided by the modified OECD equivalence scale (Hagenaars et al., 1994), an equivalised household size is calculated that weighs the first adult in a household by the factor one, each additional adult by the factor 0.5 and each child aged at 15 or under by the factor 0.3.

[6]Note that some households are missing multiple variables so that the numbers of missing observations are not cumulative.

households entered the survey or some were no longer surveyed in 2015 (panel attrition). For 420 of the matched households, the Big Five were not part of the questionnaire and 123 observations are missing due to non-response. 465 households are missing data on the building type, 391 on income and 133 on environmental concern. The loss of observations due to other variables is in the lower range.

Table 5.2 Missing household observations by variable

	Unmatched households	Not part of questionnaire	Non-response	Total missing
Big Five	1,509	420	123	2,052
Building type	-	465	-	465
Income	-	-	391	391
Environmental concern (EC)	-	81	52	133
Education	-	-	85	85
Last word in fin. decisions	-	-	51	51
Pro-environmental investment	-	-	25	25
Risk preference (R)	-	-	24	24
Gender	-	-	12	12

Table 5.3 presents the summary statistics for the last-word model, which uses the indicator on who in the household has the last word in financial decisions. There are no meaningful differences between the last-word and collective model (assuming partners in all non-individual household have equal say), mainly because 85% of partner households responded that both partners have equal say in financial decisions (see Table B.1 in Appendix B.1).

Since the final sample for the analysis excludes rented dwellings and is missing data on several variables, the sample possibly has different characteristics than the overall German population represented by all participants in the SOEP data (total sample). To address a possible sample bias, the participants of the final sample are compared with the total sample of the SOEP survey before excluding renters and data cleansing. The attributes are weighted using sampling weights provided by the SOEP survey to account for different selection probabilities of the different samples that are used in the survey, selective non-responses

Table 5.3 Summary statistics for pro-environmental investments

	N	M[a] / %	SD[b]	Min	Max
Solar PV system	3,974				
Yes	258	6.49%			
No	3,716	93.51%			
EE[c]/solar thermal collectors	3,974				
Yes	3,794	95.47%			
No	180	4.53%			
Personality traits					
Openness to Experience	3,974	4.61	1.04	1	7
Conscientiousness	3,974	5.91	0.78	1.33	7
Extraversion	3,974	4.85	0.93	1	7
Agreeableness	3,974	5.38	0.84	2	7
Neuroticism	3,974	3.64	1.03	1	7
Mediators	3,974				
Risk preference	3,974	4.76	2.02	0	10
Environmental concern	3,974	2.12	0.55	1	3
Control variables	3,974				
Income[d]	3,974	2.19	1.22	0.18	16.67
Children	3,974	0.36	0.77	0	6
Age	3,974	58.92	13.79	25	101
Gender	3,974	0.48	0.34	0	1
Education[e]	3,974	4.09	1.33	2	6
Solar irradiance[f]	3,974	104.98	4.21	100	112
Building type[g]	3,974	2.77	1.23	1	7

Note: [a]Mean. [b]Standard deviation. [c]Energy efficiency: thermal insulation or windows that are at least double-glazed. [d]1,000 EUR/month/equivalised household size. [e]Highest education according to the ISCED-1997-classification (general elementary to higher education). [f]Annual sunshine duration averaged from 1980 to 2015 relative to the state with the lowest sunshine duration (= 100). [g]1 (*farm house*), 2 (*1-2 family house*), 3 (*1-2 family rowhouse*), 4 (*apartment in 3-4 unit building*), 5 (*apartment in 5-8 unit building*), 6 (*apartment in 9+ unit building*), 7 (*high-rise*).

(response probabilities) and panel attrition (Kroh et al., 2016). For instance, the weights compensate for unequal selection probabilities due to oversampling certain groups (e.g. migration and refugee sample).

Table 5.4 compares the total sample (representing the population) and final sample mean by individual's attributes. The absolute value of the relative sample bias[7] suggests significant

[7]Sample bias $= 100 \times \left|\frac{\bar{x}_{\text{Final sample}} - \bar{x}_{\text{Total sample}}}{\bar{x}_{\text{Total sample}}}\right|$, where $\bar{x}_{\text{Final sample}}$ denotes the final sample and $\bar{x}_{\text{Total sample}}$ the total sample mean (Groves & Peytcheva, 2008; Olson, 2006).

Table 5.4 Comparison of total and final sample mean by individual variables in Germany

	Total sample mean	Final sample mean	N_{Total}	N_{Final}	p-value[a]	Sample bias[b]
Openness to Experience	4.55	4.55	15,626	6,445	1.000	0.0%
	(1.20)	(1.02)				
Conscientiousness	5.82	5.91	15,626	6,445	0.000	1.5%
	(0.92)	(0.74)				
Extraversion	4.80	4.80	15,629	6,445	1.000	0.0%
	(1.13)	(0.92)				
Agreeableness	5.39	5.36	15,631	6,445	0.019	0.6%
	(0.97)	(0.82)				
Neuroticism	3.77	3.69	15,631	6,445	0.000	2.1%
	(1.23)	(1.04)				
Risk preference (R)	4.79	4.67	27,114	6,445	0.000	2.5%
	(2.38)	(1.98)				
Environmental concern (EC)	2.11	2.12	25,221	6,445	0.188	0.5%
	(0.63)	(0.52)				
Education	3.74	3.94	25,846	6,445	0.000	5.3%
	(1.42)	(1.21)				
Income	1.57	1.92	21,006	6,445	0.000	22.3%
	(1.30)	(1.31)				
Age	52.01	59.14	27,181	6,445	0.000	13.7%
	(18.36)	(12.12)				
Gender	0.48	0.50	27,181	6,445	0.001	4.2%
	(0.50)	(0.43)				
Mean sample bias						**4.8%**

Notes: Standard deviations are provided in brackets. Note that the lower N_{Total} for the Big Five compared to the other attributes is mainly due to non-matched 2015-households with the 2013-data on the Big Five (see Table 5.2). The unmatched data and non-responses, among others, are accounted for by using weights provided by the SOEP survey.

[a] t-test on the equality of means. The t-test assumes independent samples and thus does not account for the covariance between individuals that are in both samples. Considering that the covariance is positive (same values for matched individuals), a test statistic accounting for the non-independence would generate a lower p-value due to a higher test statistic score (see, for example, Looney and Jones (2003)). This implies a higher likelihood of rejecting the hypothesis that the means are equivalent compared to assuming independent samples in the t-test, which already suggests significant differences for all variables at the 0.05 and lower significance level except for Openness to Experience, Extraversion and environmental concern. These three variables, however, are of minor concern since they do not belong to those with the biggest sample biases.

[b] Sample bias $= 100 \times \left| \frac{\bar{x}_{\text{Final sample}} - \bar{x}_{\text{Total sample}}}{\bar{x}_{\text{Total sample}}} \right|$.

differences ($p < 0.05$) between the means for all variables except for Openness to Experience, Extraversion and environmental concern.

The biggest sample bias is observed for income with an overestimation of the population mean by 22.3%, followed by age, education and gender with a 13.7%, 5.3% and 4.2% overestimate. These differences are likely due to restricting the analysis to owner-occupied dwellings because homeownership is positively associated with income, age, education attainment and being male (Bramley & Karley, 2007; MHCLG, 2018; Vignoli et al., 2016). The other significant differences ($p < 0.05$) of means range from 0.6% to 2.5%. Implications of the sample bias for the findings are discussed after the presenting the results.

5.6 Estimation

I run a multiple mediator bootstrapping model according to Preacher and Hayes (2008) using Structural Equation Modelling (SEM) (see Figure 5.1). For each household, the total effect of personality trait X_j on either solar PV system or the group of other investments (solar thermal collectors, thermal insulation or at least double-glazed windows) is decomposed into the direct effect c'_j and the indirect effects of X_j on the two kinds of investments via the mediators of risk preference and environmental concern, with j representing Openness to Experience, Conscientiousness, Extraversion, Agreeableness and Neuroticism. The coefficients a_{1j} and a_{2j} describe the effects of personality trait X_j on the mediators, whereas paths b_1 and b_2 represent the effects of the mediators on the two kinds of investments, respectively. The five personality traits are entered jointly into the equation system together with the control variables.

Because the pro-environmental investments are binary outcomes ("Yes" or "No"), the standard assumption in SEM of joint normality of the observed variables does not apply. By using maximum likelihood, the coefficients are therefore estimated conditional on the explanatory variables as given, without assuming normally distributed variables.

Similarly, not assuming any specific distributions of the estimated coefficients the significance of the coefficients is tested by applying bootstrapped confidence intervals with 5,000 replications (Preacher & Hayes, 2008). Standardised values are used for the personality traits, risk preferences, environmental concern and the control variables to allow easier comparison of the path coefficients since the observations have different scales.

5.7 Results

The mediation effects of the Big Five personality traits on solar PV systems in Germany are presented in Table 5.5. In this setting, there is no evidence that Big Five traits are linked to solar panel installation behaviour mediated by risk preferences. As seen in column two of Table 5.6, this lack of effects is likely due to the absence of a significant association between risk preferences and solar PV investments, even though the Big Five have significant associations with risk preferences (see column four). However, environmental concern is positively associated with solar panel investments. In the environmental concern channel, high Openness and high Neuroticism households are more likely to have invested in solar panels (see Table 5.5). The mediation effects are small.

Regarding control variables, the most significant effect is found for dwelling type (see Table 5.6). Buildings with more dwelling units (e.g. high-rise) are less likely to have solar panel installations, possibly because more parties are involved in the decision. The number of children in a household, being male, higher education and a region with higher solar irradiance levels are positively linked to the probability of solar panel investments.

The mediation effects for solar thermal collectors, thermal insulation installations and at least double-glazed windows can be found in Table 5.7. Different to solar panels, several of the Big Five show significant effects on the decision to invest in those measures through risk preferences: homeowners high on Openness and Extraversion are more likely to have invested, whereas those high on Agreeableness and Neuroticism are less likely to have done

Table 5.5 Mediation of the Big Five personality traits on solar PV systems

Log-odds	R	EC	R+EC	Direct	Total
Openness to Experience	-.01 [-.04, .02]	**.04*** [.02, .07]	.03 [-.01, .07]	.00 [-.15, .14]	.03 [-.11, .17]
Conscientiousness	.00 [-.01, .00]	.00 [-.01, .01]	.00 [-.01, .01]	-.03 [-.15, .11]	-.03 [-.15, .11]
Extraversion	-.01 [-.02, .01]	.00 [-.02, .00]	-.01 [-.03, .01]	-.08 [-.22, .07]	-.09 [-.23, .06]
Agreeableness	.01 [-.01, .02]	.01 [.00, .02]	.01 [-.01, .03]	-.04 [-.18, .09]	-.03 [-.16, .10]
Neuroticism	.01 [-.01, .02]	**.03*** [.01, .05]	**.04*** [.01, .06]	.01 [-.14, .14]	.04 [-.10, .17]

Notes: This table presents the mediation effects through risk preference (R), environmental concern (EC) and the direct and total effects in log-odds for each personality trait on solar PV systems ($N = 3,974$). Bias-corrected 95% confidence intervals from 5,000 bootstrap samples are reported under each of the effects. *$p < 0.05$.

Table 5.6 Regressions of the mediation models for solar PV and energy efficiency (EE)/solar thermal collector installations

	Solar PV system[a]	EE[b]/solar therm. collector[a]	Risk preference	Environmental concern
Openness to Experience	.00	.26**	.21***	.16***
Conscientiousness	-.03	-.17*	.00	.00
Extraversion	-.07	.04	.08***	-.02
Agreeableness	-.04	.07	-.10***	.02
Neuroticism	.01	-.02	-.11***	.12***
Income	.02	-.05	.03	-.01
Children	.17*	.04	.00	.02
Age	-.06	-.19*	-.11***	.02
Gender	.67**	.35	.34***	-.17***
Education	.21**	.13	.05**	.03
Solar irradiance	.15*	-.14	-.04**	-.03
Building type	-.73***	.02	-.01	.04**
Risk preference	-.06	.47***		
Environmental concern	.26***	-.18*		
N	3,974	3,974	3,974	3,974

Notes: [a]Log-odds. [b]Thermal insulation or windows that are at least double-glazed. *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

Table 5.7 Mediation of the Big Five personality traits on energy efficiency and solar thermal collector installations

Log-odds	R	EC	R+EC	Direct	Total
Openness to	**.10***	**-.03***	**.07***	**.26***	**.33***
Experience	[.06, .14]	[-.06, .00]	[.02, .11]	[.09, .43]	[.16, .49]
Conscientiousness	.00	.00	.00	-.17	-.17
	[-.01, .02]	[-.01, .01]	[-.02, .02]	[-.38, .01]	[-.38, .01]
Extraversion	**.04***	.00	**.04***	.04	.08
	[.02, .07]	[.00, .02]	[.02, .07]	[-.13, .21]	[-.09, .26]
Agreeableness	**-.05***	.00	**-.05***	.07	.01
	[-.08, -.03]	[-.02, .00]	[-.08, -.03]	[-.11, .23]	[-.16, .18]
Neuroticism	**-.05***	**-.02***	**-.07***	-.02	-.09
	[-.08, -.03]	[-.04, .00]	[-.11, -.04]	[-.19, .16]	[-.26, .09]

Notes: This table presents the mediation effects through risk preference (R), environmental concern (EC) and the direct and total effects in log-odds for each personality trait on energy efficiency (thermal insulation or windows that are at least double-glazed) and solar thermal collector installations ($N = 3{,}974$). Bias-corrected 95% confidence intervals from 5,000 bootstrap samples are reported under each of the effects. $^{*}p < 0.05$.

so. The personality trait effects in the risk preference channel are enabled by the significant link between risk preference and solar thermal collectors/energy efficiency installations (see column three in Table 5.6), suggesting that risk preferences do matter in decisions of undertaking those kinds of pro-environmental investments in Germany.

Counter-intuitively, environmental concern shows a negative association with the likelihood of investing in energy efficiency or solar thermal collectors (not highly significant with $p < 0.10$). This results in a negative link between the outcome variable and Openness to Experience and Neuroticism in the environmental concern channel (see Table 5.7). As for solar panels, the found mediation effects of the personality traits are small. However, a notable difference is that Openness to Experience shows a significant and relatively large direct effect on solar thermal collectors/energy efficiency installations compared to the mediated effects. Except for age, the socio-demographic attributes are not significant for solar thermal collectors/energy efficiency installations.

The robustness checks of the collective model show a comparable pattern of effects for both solar PV systems and solar thermal collectors/energy efficiency installations (see Tables B.2 to B.4 in Appendix B.1).

5.8 Discussion

The goal of this study was to investigate the relationships between personality traits and costly renewable energy and energy efficiency investments in Germany, which has been running significant policy measures to promote energy efficiency and the use of renewable energies. Overall, the analyses reveal no associations between the Big Five personality traits and solar PV systems through risk preferences, whereas weak links through the risk channel are found between some of the Big Five and investments in solar thermal collectors for heat generation and energy efficiency (thermal insulation, at least double-glazed windows). Some of the Big Five also show weak associations with the pro-environmental investments through environmental concern.

Besides the indirect effects through risk preferences and environmental concern, which is elaborated on more thoroughly in the next two sections, Openness to Experience shows a direct and relatively large positive effect on the likelihood to have invested in solar thermal collectors/energy efficiency. Separate regressions for solar thermal collectors and energy efficiency suggest that the effect stems from the energy-efficient technology (thermal insulation and at least double-glazed windows) and not solar thermal collectors (see Table B.5 in Appendix B.2). The curiosity of high-Openness homeowners might make it more likely to consider energy-efficient technology, which is a first step towards initiating a thermal insulation or window modernisation.[8] A limitation of this explanations is that no effect of

[8]Considering an energy efficiency upgrade is not inevitably associated with an investment, but as a condition it increases the likelihood to do so (without first considering energy efficiency measures, an investment is likely not going to happen).

Openness to Experience is observed for solar PV systems and thermal collectors, for which curiosity could in the same way increase likelihood to consider these kinds of investments. Therefore, other, unknown mechanisms might be at work for this personality trait effect.

5.8.1 Big Five mediation through risk preferences

No mediations of the Big Five on solar panels are observed through risk preferences. It is likely that the massive financial subsidies for solar panels after the launch of the Renewable Energy Source Act in 2000 (Bundesgesetzblatt, 2000) have swamped the personality trait effects through the risk preference channel. Guaranteeing fixed FITs for 20 years, the programmes reduced the risks of solar panel investments to households. The significant risk reduction may have caused individual differences in risk preferences not to be significantly associated with solar panel investment decisions.

In contrast, the significant link between risk preferences and solar thermal collectors/energy efficiency installations suggests that risk considerations are of importance when investing in these kinds of projects, implying that risks have likely remained in solar thermal and energy efficiency investments, possibly because they have not been flooded by subsidies comparable to the FIT scope. Subsidies for solar thermal collectors offered through BAFA have been less extensive and those for both solar thermal collectors and energy efficiency installations offered through the KfW bank have been harder to obtain because the requirements for receiving the subsidies for major refurbishments and new builds go beyond legal standards and due to the complexity of the energy efficiency regulations (see Section 5.3). The KfW subsidies thus likely incentivise homeowners who have already decided to improve energy efficiency to go beyond the required standards (Galvin, 2012; Rosenow & Galvin, 2013). It is questionable whether the subsidies induce new energy efficiency upgrades. Indeed, a survey conducted on a sample of German households for the KfW bank shows that the subsidies have a positive effect on the extent and/or depth of refurbishments once they become necessary, but they are not found among the reasons quoted by homeowners to induce retrofits (IWU, 2016). The receivers of the KfW subsidies criticised explicitly the complex and burdensome application procedure but also the fact that small-scale loans for smaller refurbishment projects are not offered ("all-or-none" principle).

Due to the more restrictive subsidy provision and complex policy landscape, investment risks have likely not been cut back to the extent comparable to solar PV systems, so that personality effects can unfold through the risk preference channel. In line with previous studies, individuals high on Openness to Experience and Extraversion are found to show higher willingness for taking risks (Brown & Taylor, 2014; Lee et al., 2008; Nicholson et al., 2005), translating into a higher likelihood of having invested in solar thermal collectors or energy efficiency. Lower risk preferences of agreeable and neurotic individuals (Borghans et al., 2009; Lee et al., 2008; Nicholson et al., 2005), on the other hand, decrease the likelihood of investment.

Although the subsidies for solar thermal collectors/energy efficiency installations might have been smaller and more restrictive than the FITs, they nevertheless might have mitigated investment risks to a certain degree, possibly explaining the only small effects of the personality traits. Despite the rather restrictive provision of the KfW subsidies, for example, monitoring studies of the KfW programmes and some researchers present the programmes as a big success in terms of energy savings and CO_2 emission reductions (Boonekamp & Eichhammer, 2007; Schröder et al., 2011), arguing that they do motivate homeowners to induce new energy efficiency improvements. Among other reasons, they attribute the success to consultations with energy advisers recommended or mandatory in some KfW programmes, transparency increase of costs and benefits by exposing homeowners to the terms and conditions of the loans and subsidies, cost reductions of energy-efficient technology because of financial support, uncertainty decrease by providing the funding through the government-owned bank KfW and the possibility to easily get an energy performance certificate after the refurbishments which are legally required in Germany (Schröder et al., 2011). Such effects linked to the KfW programmes possibly do reduce risks to some degree, so that the mediation of personality traits through the risk preference channel is small. The small effects are also likely due to cyclical maintenance and mandatory standards when refurbishing. Homeowners have to undertake more comprehensive maintenance from time to time resulting from ageing (e.g. roof or facade renovation) (IWU, 2016) and they have to adhere to the legal standards prescribing certain energy efficiency measures irrespective of their risk preferences.

5.8.2 Big Five mediation through environmental concern

Effects of Openness to Experience and Neuroticism through environmental concern are translated by a positive link between the concern and solar panels, and an unexpected negative relationship between the concern and solar thermal collectors/energy efficiency installations. The direction of a personality trait effect in the environmental concern channel for solar panels thus equals the sign of the association between that trait and environmental concern, whereas it shows the opposite sign of the trait-concern link for solar thermal collectors/energy efficiency installations. For example, the positive link between Openness to Experience and environmental concern translates to a positive effect on solar panels. For solar thermal collectors/energy efficiency, the positive effect of the same trait is translated to a negative effect on the likelihood of investment instead. Therefore, the difference between the two kinds of investments is in the translation of environmental concern. The Big Five-environmental concern links are the same.

The positive link between Openness and environmental concern is supported by previous findings (Hilbig et al., 2013; Hirsh, 2010; Markowitz et al., 2012). Individuals high on Openness to Experience tend to be open-minded and curious. This includes a readiness to question one's values and this requires an ability to oppose the status quo. High-Openness individuals may thus be more likely to recognise and be concerned about adverse climate change. Neuroticism is positively associated with environmental concern, possibly because individuals high on Neuroticism perceive more threat from climate change (Milfont et al., 2015).

Generally, one would expect a higher concern for the environment to facilitate pro-environmental decisions. This view is supported by the solar panel findings in this study but not for solar thermal collectors/energy efficiency, which show even a negative association between environmental concern and behaviour, albeit at the 0.10 significance level only. This might be attributed to several reasons.

First, adopting energy-efficient technology might be not perceived as pro-environmental behaviour. Some of the most used materials for thermal insulation – glass and stone wool, expanded and extruded polystyrene, polyurethane – show also some of the biggest environmental impacts in life cycle analyses (Papadopoulos, 2005). For instance, expanded polystyrene (EPS) and polyurethane is produced of finite resources and emits on average 50 times more emissions than natural materials, such as sheep wool (Zabalza Bribián et al., 2011). Some homeowners refrain from thermal insulation adoptions because the conventional materials, such as the EPS, and the required ancillary materials (e.g. glue) have to be disposed of eventually as hazard waste (IWU, 2016). Achtnicht (2011) finds that CO_2 emission reductions do not matter for German homeowners when deciding whether to adopt thermal insulation. Similarly, for a German household sample, Galassi and Madlener (2017) show that the environmental concern is not relevant for energy efficiency upgrade decisions but rather aspects related to the inner comfort (e.g. air quality, noise), aesthetics and financial considerations.

It is conceivable that German homeowners with a concern for the environment, therefore, do not associate energy efficiency upgrades with pro-environmental measures as they do for other investments (e.g. renewable energy). Since financial resources of households are likely limited, they might even avoid energy efficiency investments in favour of projects that they perceive as more pro-environmental actions. I test this presumption with separate regressions for energy-efficient technology (thermal insulations/windows that are at least double-glazed) and solar thermal collectors (see Table B.5 in Appendix B.2). The findings indicate that environmental concern is negatively associated with the likelihood of having invested in thermal insulation/at least double-glazed windows, whereas it is positively related to having invested in solar thermal collectors, lending support to the idea that energy-efficient technology is less likely to be perceived as a pro-environmental act in Germany.

Second, previous research suggests that a general definition of attitudes likely weakens the associations to specific pro-environmental behaviour (see, for example, Oskamp et al., 1991). The environmental concern measure in this study (see Section 5.5) might be associated by respondents with different environmental issues, such as scarcity of energy resources or air pollution. If most respondents consider energy efficiency primarily contributing to energy conservation and at the same time associate environmental concern with other worries than the scarcity of energy resources (e.g. air pollution), investing in thermal insulation installations, for example, might not be considered appropriate to relieve their concern and might thus be avoided.

Third, the investments are a function of motivational factors and external conditions, and the conditions, such as regulation and norms, can be of greater importance than motivational factors in pro-environmental decisions (Guagnano et al., 1995). Specifically for buildings, homeowners have to undertake cyclical maintenance regardless of whether they are concerned about the environment or not. The owners can decide at their own discretion when a building is due for major renovations (Galvin, 2012) but if they decide to undertake them, they are required to comply with the EnEV standards, leaving them no choice than to adopt energy-efficient technology irrespective of their intrinsic motivations. If more than 10% of the surface of a building element (e.g. roof) is refurbished, the EnEV standards apply and thermal upgrades are mandatory.

Related to social norms, homeowners might prefer adopting pro-environmental products that are visible (e.g. solar panels), so they can communicate their pro-environmental attitude to peers (social status) (Noppers et al., 2015, 2016) and indicate that they fulfil the social norms. Due to capital budgeting considerations, a non-visible project (e.g. thermal insulation) might be given up in favour of visible ones, resulting in a negative association between environmental concern and products that are less visible. This hypothesis is supported by the separate regressions for solar thermal collectors and the energy efficiency products (see Table B.5 in Appendix B.2): a significantly positive link between environmental concern and solar thermal collectors is observed, which are mostly placed on the roof of a building, and a negative and no association between environmental concern and at least double-glazed windows and thermal insulations, which are visually less evident or not noticeable.

Such external conditions might also help explain the small sizes of personality trait effects through environmental concern. In a survey of German households, cyclical maintenance is found to be the most often quoted reason to induce refurbishments, whereas economic and ecological aspects rather influence the decisions process after having decided to refurbish (IWU, 2016). This implies that intrinsic attitudes as environmental concern are not prime decision factors to undertake refurbishments, likely weakening the mediation of the personality traits through the environmental concern channel for solar thermal collectors/energy efficiency.

5.8.3 Regulatory and institutional barriers

As already touched on in the discussion of cyclical maintenance, regulatory and institutional frameworks might impede intrinsic attitudes to come into effect. The mandated standards for energy efficiency have been moved to levels that are becoming infeasible for homeowners, not allowing to do lower-level energy efficiency improvements (Galvin, 2012). The high standards might not be applicable for specific building fabrics (e.g. the roof overhang can be too small to accommodate thicker wall insulations). Homeowners with certain personality profiles as mediated through environmental concern might be motivated to upgrade energy efficiency to lower than mandatory levels and that are technically feasible but these effects are likely lost because of the very demanding regulations for energy efficiency. Personality trait effects mediated through risk preferences could be lost in the same vein because some homeowners would have a sufficiently high risk preference for smaller but not bigger refurbishments, possibly contributing to explain the small effects through the risk channel for solar thermal collectors/energy efficiency.

Similarly, though intended to foster the uptake of new renewable energy technology, regulatory and institutional mechanisms can undermine intrinsic motivation. Renewable energy systems are regulated by multiple laws at the federal level (e.g. EEG, EEWärmeG and indirectly EnEV) and keeping track of them without support from experts is tedious apart from the requirement to comply with regulations at the state and local level. Homeowners may refrain from the uptake of renewable energy technology due to complicated and bureaucratic procedures for getting permissions and realising financial incentives (Klessmann et al., 2011). Lack of regulatory consistency, such as the temporary withdrawal of the BAFA funding for heat-generating renewable energy systems in 2010, can fuel mistrust and pose another institutional barrier for adopting renewable energy systems (Painuly, 2001). Involving stakeholders in the policy-making process is important for effective policies too (Yaqoot et al., 2016). By focusing on big scale carbon emission reductions, policy-making accounting for the heterogeneity of homeowners may come short, resulting in misplaced priorities in the policies. In an assessment of non-cost barriers for renewable energy growth in the EU, Germany is mentioned as one of the countries with lengthy procedures for obtaining necessary permits for renewable energy technology, lack of experience of civil servants for biogas installations in some regions and heterogeneous applications of the same law across regions (ECORYS, 2010). Although such regulatory and institutional barriers are evaluated to be smaller in Germany compared to other EU countries, they exist and might undermine personality effects on uptakes of new renewable energy technology by hampering the translation of intrinsic risk and environmental attitudes. Including solar thermal collectors in the group of investments that have been not massively subsidised might contribute to the weak mediation effects of personality traits. For solar panels, such barriers possibly explain the weak mediation effects of the personality traits through environmental concern.

Institutional interventions might further disincentivise renewable energy investments that are specifically used for reputation purposes, i.e. products used to signal to peers that one chooses and can afford "green" goods. The sales of the "green" car Toyota Prius, for instance, started to increase only after its tax benefits were removed (Griskevicius et al., 2010). Supporting schemes of governmental institutions might similarly withhold investments in new renewable energy technology in the building sector by disincentivising personalities that would go "green" because of reputational reasons.

5.8.4 Data representativeness

Testing the studied sample for representativeness of the German population revealed that the studied sample is biased in terms of several attributes (see Section 5.5). This is due to restricting the analyses to owner-occupied households and missing data. The found effects are therefore likely to differ in the German population.

It is likely that the mediation effects of personality traits are weaker if rented dwellings are considered because the owners (for which the personality characteristics are not known in this study) often lack the motivation to upgrade the building since they may not pay for the energy bills (split incentives) (Bird & Hernández, 2012; IWU, 2016). A study finds that compared to rental properties, owner-occupied dwellings are 20% more likely to have a ceiling insulation (Gillingham et al., 2012). The motivation to put one's risk or environmental attitudes into action is therefore likely lower, implying a weaker translation of personality traits in the German population than in the sample.

Translating attitudes into behaviour also depends on a person's perceived control, the perception to which extent one can influence one's environment and actions (Wallston et al., 1987). Studies find that perceived control differs across socio-demographic groups. Specifically, income, younger age, high educational attainment and being male is positively associated with perceived control (Infurna et al., 2011). Because the German population shows a particularly lower income, educational attainment and share of male individuals compared to the studied sample (see Table 5.4), the translation of attitudes, and thus also of the significant personality effects, are likely weaker in the population. Only the younger age level suggests a stronger translation.

Overall, a weaker translation of the personality effects in the German population is expected than in the studied sample. This means that for solar panels, the effects of Openness to Experience and Neuroticism through environmental concern (see Table 5.5) are likely to be less positive in the population, and those for the same traits for solar thermal collectors/energy efficiency installations less negative (see Table 5.7). Openness to Experience and Extraversion are further likely to show weaker positive effects and Agreeableness and Neuroticism less negative impacts on solar thermal collectors/energy efficiency installations through the risk preference channel.

5.9 Limitations

There are several design aspects that may have contributed to the small effect sizes for personality. First, the survey in this study used brief measures of personality traits and mediators. When time and resources are limited, personality researchers are often confronted with the choice between a brief or no measure of personality at all (Gosling et al., 2003).

For example, the longest instrument of the Big Five with 240 items (Costa & MacCrae, 1992) takes approximately 45 minutes to complete and is likely impractical for surveys with multiple focuses, such as panel studies.

The brief 15-item version of the Big Five Inventory in this study revealed a low reliability of the personality trait dimensions as assessed by Cronbach's alphas. Because low score reliabilities may obscure true relationships (Credé et al., 2012), the short personality inventory might be a reason for the weak link found between personality traits and pro-environmental investments. Futures studies could use more items per trait to assess whether the weak associations are truly related to reliability and validity issues of the personality measures.

Similarly, the validity of the single-item measures of risk preference and environmental concern could be improved by the use of multiple items, which could reduce measurement error and therefore increase the validity of the variables (Credé et al., 2012). This would also allow testing for internal consistency of reliability of these measures which cannot be computed with single-item scales.

Second, inferring longitudinal processes from this cross-sectional survey data should be done with caution. The cross-sectional design of the mediation analysis fails to account for causation that may occur throughout time and prior measures of time-varying variables may well have an impact in later periods (Maxwell et al., 2011). The effects of mediators such as risk preference and environmental concern may not unfold immediately on renewable energy or energy efficiency investments. Because the cross-sectional mediation estimates do not account for time-dependent impacts, they may be biased estimates of longitudinal parameters and should not be taken as indicators for longitudinal mediation (Maxwell & Cole, 2007; Maxwell et al., 2011). Future work might assess whether a longitudinal mediation model is feasible with a binary outcome that is generally not reversed, such as solar panel or thermal insulation installations.

Finally, personality traits are only one way to test for individual differences. Other factors excluded from this report, such as personal values and norms (Jansson et al., 2010; Mirosa et al., 2013), may also be linked to renewable and energy efficiency investments.

5.10 Conclusion and policy implications

This study furthers the understanding of how personality traits relate to uncommon pro-environmental household investments that have been heavily subsidised (solar PV systems) compared to those for which the provision of large-scale subsidies is not evident (solar thermal collectors and energy efficiency investments). The results suggest weak mediations for some of the Big Five personality traits through environmental concern for both kinds of investments. Personality trait effects mediated through risk preferences, however, are not observed for the historically heavily subsidised investments but only for those with more restrictive financial incentives. It is likely that the risks of the former have been almost completely wiped out by the significant financial incentives, whereas risks in the latter have not.

A few ideas can be deduced from this study for how policy programmes could take into consideration personality traits. In countries with historically large subsidies for renewable energy systems such as for solar panels in Germany, the findings suggest that policy programmes might engage with individuals through the environmental concern rather than risk preference channel since the risks of solar panel investments are likely already close to zero. For individuals high on Neuroticism, for example, stressing the adverse impacts of climate change through environmental concern could show more effect for motivating investments in already subsidised renewable energy systems than reducing investment risks.

The findings for solar thermal collectors and energy efficiency imply that messages targeting risk preferences might be only effective for products that have not been massively subsidised and thus still involve risks. One cost-saving possibility is to offer alternative risk reduction schemes to large financial subsidies, such as risk-sharing contracts between government and households. The idea is comparable to Energy Performance Contracting (EPC) that is used in the German public sector to some extent already (Boza-Kiss et al., 2017), where a capital investment is recovered from future energy cost savings guaranteed by the EPC provider. For example, opportunity costs arising after installing an energy-efficient technology due to decreasing energy prices of conventional energy resources (e.g. fossil fuels) could be shared through payments by governments to households depending on the energy price reductions. The extensive portfolio of a government allows diversification and hedging of the energy price risk so that such subsidies could cost national budgets less than predetermined fixed payments as the FITs for solar panels.

The results further suggest that energy efficiency measures (thermal insulation, at least double-glazed windows) are not necessarily perceived as a pro-environmental act. Policy-making might want to consider this when drafting pro-environmental interventions since engaging with homeowners through the environmental concern channel might be ineffective for measures that might look "green" at the first glance but are not perceived by homeowners as such.

The small personality effects found in this study might be due to the large financial subsidies, regulatory requirements and other external circumstances (e.g. cyclical maintenance), which possibly undermine more intrinsic factors in the decision process such as personality trait effects. Personality-related interventions as outlined above are therefore likely less effective in such settings.

Nevertheless, existing policies, which predominantly use financial interventions or mandatory standards to motivate pro-environmental investments in residential buildings, could increase their potential by taking more into consideration the heterogeneity of homeowners. This does not require engaging with each separate personality, which would be way to burdensome, but could include more diverse options and motivators for homeowners to invest in pro-environmental measures, so they can respond to those that they find most appealing.

5.11 Chapter summary

In sum, this chapter gives evidence that apart from socio-economic factors and building type, personality traits can be associated with the likelihood of investing in pro-environmental measures, albeit their effects are small. It is shown that the significance of the personality trait effects depends on whether pro-environmental investments have been massively subsidised or not. Homeowners scoring highly in Openness to Experience and Extraversion, and low in Agreeableness and Neuroticism (traits associated with a high willingness to take risks) show a higher likelihood to have invested in projects with more restrictive provisions of subsidies (thermal insulation, at least double-glazed windows or solar thermal collectors), but not so for the historically heavily subsidised solar PV systems because their risks are practically non-existent and, thus, risk preferences likely do not matter in this setting. Differently, Openness to Experience and Neuroticism show indirect effects on both investment groups through their correlations with environmental concern.

While Chapter 5 revolves around the decision of investing in pro-environmental technologies in different settings of external financial incentives, the next chapter focuses on social context. It presents and evaluates a model that elaborates on the relationship between personality traits and social norms.

Chapter 6

Does your personality shape your reaction to your neighbours' behaviour? A spatial study of the diffusion of solar panels

The literature review in Chapter 2 identifies norms as an important factor for explaining individuals' pro-environmental behaviour (see Section 2.4.2). Knowing the energy use of neighbours, for example, can significantly reduce households' own energy consumption (Allcott, 2011). The previous chapters tend to overlook such social context. Hence, the purpose of this chapter is to complement the analyses of individuals' decision-making process by addressing the relationship between personality traits and the way in which norms are perceived in the context of energy efficiency investments. Another main difference to the previous chapters is that personality is not measured at the individual but aggregated regional level to account for different natures of social systems. By running a first-difference model, it explores how geographical concentrations of personality traits in the UK affect peer pressure to invest in solar photovoltaic (PV) installations. The results suggest that postcode districts with spatial concentrations of Conscientiousness exhibit stronger peer effects.

6.1 Introduction

Personality traits are crucial for understanding the variations in human behaviour and their interactions with the environment. One of the core differences between people, the willingness to adhere to norms (Cialdini & Trost, 1998; Rogers, 2003), can be ascribed to personality characteristics. Differences in personality determine how effectively values of peers can be transmitted (Di Palma & McClosky, 1970). For example, talkative people are exposed to communication more frequently and intensely, therefore increasing the probability to encounter and acquire the values held by the majority of their neighbours.

Against the backdrop of mitigating climate change, many governments have put renewable energy targets on their policy agendas. In view of meeting its binding EU target of 15% of energy consumption coming from renewable sources by 2020 (EU, 2009), the UK has implemented various legislation to increase the uptake of renewable energy systems. One prominent programme covers the feed-in tariffs (FITs) which guarantee a predetermined price for selling electricity from renewable energy systems to the grid (DECC, 2015).

Besides such governmental incentives, the uptake of renewables can be fostered by observing and emulating peer behaviour. Studies show that previously installed solar photovoltaic (PV) systems in a neighbourhood increase the probability of further system adoptions (Bollinger & Gillingham, 2012; Fornara et al., 2016; Graziano & Gillingham, 2015). Several reasons are suggested for this relationship out of which two stand out. The first is interpersonal communication such as word of mouth. Talking to neighbours can provide useful information concerning the adoption process which can help in reducing uncertainties in the decision process. The second reason is people's tendency to conform to norms. Seeing an increasing number of solar PV panels on neighbours' roofs can make people more aware of their existence and activate desires to follow the behaviour of the majority. It can be helpful to understand how these two effects can be leveraged for fostering adoptions of green technology instead of using traditional subsidies, such as financial incentives, since it has been shown that social incentives can generate greater changes in behaviour (Nolan et al., 2008). An important step to make effective use of the peer effects is to first understand which people may be influenced by them the most.

This study elaborates on the effects of personality traits in domestic decisions to mimic the behaviour of neighbours of investing in solar PV systems in the UK. The contributions are threefold. First, a theoretical framework is suggested for why personality traits are expected to influence social spillovers from peers. Second, by using data on postcode districts in the UK, this is the first study that measures the impact of personality traits on peer effects for a high-cost renewable energy system empirically. Third, it is one of the first studies that uses rigorous econometric modelling to analyse the impact of spatially aggregated personality traits on an economic outcome. The results suggest that for every 100 solar PV installations, postcode districts with above average levels of Conscientiousness show on average 3 additional adoptions compared to all postcode districts in the studied sample.

The remainder of the article is organised as follows. The next section discusses previous literature on peer effects in the green decision-making realm, followed by the theoretical investigation of the relationship between personality traits and peer effects. Next, the data and methods used for the empirical analysis are described before presenting and discussing the results. The article closes with concluding remarks and policy implications.

6.2 Literature review

Several studies suggest that energy-saving and pro-environmental behaviour can be motivated by social norms (Allcott & Mullainathan, 2010; Ferraro et al., 2011; Goldstein et al., 2008). People aim to comply with commonly accepted standards because not engaging in such behaviour is considered inappropriate and can result in feelings of guilt (Bolderdijk & Steg, 2015). A notable example of the impact of social norms is the field experiment on electricity bills by Allcott (2011). Households received a series of reports which compared their use of electricity to that of their neighbours by indicating whether their consumption was below or above the average consumption. The provision of the reports resulted in an average decrease in energy usage by 2%. Fischer (2008) reviews more than twenty studies on different feedback reports about home energy consumption and finds typical energy savings between 5% and 12% (e.g. feedback on energy costs, meter reading, personalised energy audit, normative comparison). In contrast to the study of Allcott (2011), no significant change in energy usage is found if the feedback reports include normative comparison (e.g. with neighbours, national or regional average). It is argued that while high-energy consumers may be incentivised to conserve energy, low-energy users may rather increase their consumption since they are doing relatively well compared to others.

Results are more consistent in studies of peer effects in energy-efficient and renewable technology installations. Fornara et al. (2016) find that decisions and attitudes of homeowners' relatives and neighbours regarding green energy devices have significant impact on their willingness to adopt energy efficiency measures, such as solar thermal and PV systems and thermal insulation installations. Bollinger and Gillingham (2012) compare uptakes of solar panels across different regions in California and conclude that a higher number of existing installations increases the probability of additional adoptions. They argue that the visibility of the solar panels increases people's awareness and fosters information exchange about the technology which reduces uncertainties associated with the installation process and therefore increases the likelihood of further investments. Similarly, Graziano and Gillingham (2015) show in a study in Connecticut, US, that a high installed base of solar PV systems in an area significantly increases succeeding adoption rates, and the effect diminishes with distance and time. They also find an impact of the built environment (e.g. housing density) and political affiliation on the adoption rates.

A search of the literature reveals only a few studies that systematically question different reactions to social norms as a consequence of consumer heterogeneity. One study illustrates that individuals respond differently to feedback reports on neighbours' energy consumption depending on their personality profiles (Shen et al., 2015). It is shown that customising the reports to different personality profiles reduces energy consumption in domestic buildings more compared to standardised reports (i.e. 15.5–20.0% vs 1.2–11.5%). Khashe et al. (2016) examine the effectiveness of different social messages such as direct and foot-in-the door requests and compare them with reciprocity requests which obliges people to follow certain norms.[1] The results show that neurotic people have a lower compliance in direct requests, while people who score highly in Openness to Experience comply more in reciprocity requests.

Taken together, these studies support the notion that peers can influence people's green decisions. While some research has been carried out on the relationship between personality traits and peer effects in the energy conservation realm, there remains a paucity on this link in the context of high-cost installations of energy efficiency and renewable energy systems. The aim of this study is to narrow this gap by proposing a theoretical framework for the role of personality traits on peer effects and to test the suggested framework for solar PV systems empirically.

[1] Different to the direct request, the foot-in-the-door request asks individuals to comply with a very small task that nearly anyone would comply with, before requesting the desired larger outcome (e.g. request to turn off lights in one room before requesting the same for additional rooms). In the reciprocity approach, a small favour or gift is provided before requesting the desired outcome.

6.3 Personality traits and peer effects: a theoretical framework

The Diffusion of Innovation (DoI) model by Rogers (2003) is used to analyse the theoretical link between personality traits and peer effects. The model describes how an innovation is disseminated among members of a social system through certain channels of communication over time. According to the model, the relative speed of the adoption process is influenced mainly by five different categories of attributes: the perceived attributes of the innovation (e.g. complexity, trialability), type of innovation-decision (e.g. collective vs individual), the extent of change agents' promotion efforts,[2] communication channels and the nature of the social system.

The focus of the present study (as opposed to Rogers') is on the communication channels and the nature of the social system. The communication channels can be broadly categorised into means from outside the social system (e.g. mass media communication) and mechanisms within the social system like interpersonal communications (Bass, 1969; Rogers, 2003). This study targets the latter communication channel since it focuses on effects from peers. Both channels can provide basic information about the technology, therefore increasing people's awareness of its existence. Interpersonal communication can additionally transfer experience effects (Xiong et al., 2016). In contrast to general information, receiving detailed know-how through the experience of previous adopters can reduce uncertainties. For instance, it may clarify if and how much energy is saved by a green energy system.

The nature of the social system determines the degree to which people are linked by interpersonal networks within which norms are transmitted by interpersonal communication. Two key elements of the nature of the social system are its degree of interconnectedness and

[2] According to Rogers (2003), a change agent is a person "who influences clients' innovation decisions in a direction deemed desirable by a change agency".

the diffusion effect. The transmission mechanism of information is stronger in social systems where members are more interconnected. The diffusion effect captures the individuals' possible self-generated pressure to adopt or reject an innovation according to the social system norms as the number of adoptions among peers and corresponding feedback about an innovation increase over time.

Interpersonal communication and a higher degree of interconnectedness through social networks, therefore, facilitate the transmission of information within a social system. It follows that differences in interpersonal communication and social ties affect how well information about a technology is transferred from previous to potential adopters and, thus, can have an impact on the adoption speed (Rogers, 2003, p. 258). Individuals with more social participations, for example, are expected to adopt new technology earlier than others.

Unlike other diffusion models, such as the widely cited Bass model and most of its extensions (Bass, 1969; Mahajan et al., 1990), the DoI model does not assume a homogeneous and fully connected social system, in which potential adopters are equally influenced by their peers and the technology. The advantage of the model is that it allows for heterogeneity at the individual and the aggregate social system level. At the individual level, it assumes heterogeneous responses of potential adopters to influences through communication channels (e.g. advertising, interpersonal communication) (Peres et al., 2010). At the aggregate level, the model allows for heterogeneity of the nature of a social system by assuming differences in the importance of social norms and the degree of interconnectedness among its members (Peres et al., 2010; Rogers, 2003). As such, the model considers heterogeneity across individuals and the interaction networks between them, so that it is well placed to address the impact of personality traits at different levels of a social system. In addition, by modelling communication channels and the nature of a social system as separate factors, it is possible to distinguish between the underlying mechanisms of the social effects. For example, social learning is attributed to the communication channels, whereas social pressure is captured in the nature of the social system. In aggregate fit models assuming homogeneous populations, however, the social effects are often indistinguishable (Van den Bulte & Stremersch, 2004).

The DoI model considers personality as a source for heterogeneous responsiveness to peer influence. However, it is expressed by means of vague terms, such as rationality, intelligence and attitudes towards education, whereby a sophisticated framework for capturing personality is missing. Moreover, the heterogeneity of communication behaviour is assessed in the DoI theory independently from personality variables. Meanwhile, the widely accepted framework of the Big Five, which conceptualises the structure of personality with five dimensions (Openness to Experience, Extraversion, Conscientiousness, Agreeableness and Neuroticism), suggests, however, that communication skills can differ across personalities (Goldberg, 1992). I argue, therefore, that personalities with pro-communicational traits, firstly, exchange opinions with others more frequently, and, secondly, are more connected through social networks, possibly being more influenced by peer effects than others. Hence, the model by Rogers (2003) is extended by assuming the communication channels and the nature of the social system to be an implicit function of the Big Five personality traits which in turn influence the adoption rate of technology:

$$AR = f(A, TY, CC(\mathbf{Big5}), NoSS(\mathbf{Big5}), CA) \tag{6.1}$$

AR = Adoption rate (relative speed with which a technology is adopted by members of a social system).

$f(.)$ = Function f.

A = Attractiveness of a technology, depending on its compatibility, complexity, trialability, observability and relative advantage to conventional technology.

TY = Type of decision: optional, collective or authority.

CC = Communication channels, depending on the Big Five personality traits.

$NoSS$ = Nature of social system, depending on the Big Five personality traits.

$CA =$ Extent of change agents' promotion efforts.

Typically, conversational people with preferences for the company of others are individuals who score highly in Extraversion (Goldberg, 1992; McCrae & Costa, 2003). Entering conversations concerning novel technologies requires also curiosity and willingness to learn, which is a trait frequently observed with individuals who score highly in Openness to Experience. Neurotic people, on the other hand, can show tendencies of social anxiety and are therefore likely to show less interpersonal communication, while agreeable and conscientious people are generally not associated with either distinctly low or high communication skills (Costa & MacCrae, 1992; McCrae & Costa Jr, 1999). Extraversion, Openness to Experience and Neuroticism are therefore expected to influence (1) the communication channels (*CC*) through interpersonal communication and (2) the nature of the social system (*NoSS*) through the degree of interconnectedness.

Frequent communication and strong interpersonal networks may facilitate the transmission of peer effects. Whether the peers' views will be considered in the adoption decisions depends additionally on people's readiness to follow norms, which is captured by the diffusion effect of the nature of the social system (*NoSS*) (Rogers, 2003). Individuals who score highly in Agreeableness tend to agree with the views of others in order to avoid interpersonal conflicts, therefore being more inclined to comply with norms than others (Costa & MacCrae, 1992). Conscientious individuals tend to show goal-directed behaviour which besides planning and organising includes following rules and norms (John & Srivastava, 1999). Hence, Agreeableness and Conscientiousness are expected to further influence the nature of the social system *NoSS* through the diffusion effect (i.e. people's readiness to follow norms).

Formally, Equation (6.1) can be therefore specified as follows:

$$AR = f(CC(\gamma(\underset{+}{E},\underset{+}{O},\underset{-}{N})),NoSS(\delta(\underset{+}{E},\underset{+}{O},\underset{-}{N}),\varepsilon(\underset{+}{A},\underset{+}{C})),.) \tag{6.2}$$

γ = Interpersonal communication as part of the communication channels (*CC*).

δ = Degree of interconnectedness as part of the nature of the social system (*NoSS*).

ε = Diffusion effect as part of the nature of the social system (*NoSS*). A high value indicates a higher readiness to follow norms.

E, O, N, A, C = Extraversion, Openness to Experience, Neuroticism, Agreeableness, Conscientiousness with +/– indicating a positive/negative impact on the corresponding variables ($\gamma, \delta, \varepsilon$).

In sum, it is argued that personality trait concentrations in a social system are manifested in peer effects through interpersonal communication (γ), social networks (δ) and readiness to follow norms (ε), which in turn affect the technology adoption rate (*AR*) (Figure 6.1). It is hypothesised that peer effects are stronger in social systems with personality trait concentrations that are expected to have stronger γ, δ and ε, and vice versa:

H1. Peer effects are stronger in social systems with high concentrations of **Extraversion**, assuming stronger interpersonal communication and degree of interconnectedness in such systems.

H2. Peer effects are stronger in social systems with high concentrations of **Openness to Experience**, assuming stronger interpersonal communication and degree of interconnectedness in such systems.

H3. Peer effects are less pronounced in social systems with high concentrations of **Neuroticism**, assuming weaker interpersonal communication and degree of interconnectedness in such systems.

H4. Peer effects are stronger in social systems with high concentrations of **Agreeableness**, assuming stronger readiness to follow norms in such systems.

H5. Peer effects are stronger in social systems with high concentrations of **Conscientiousness**, assuming stronger readiness to follow norms in such systems.

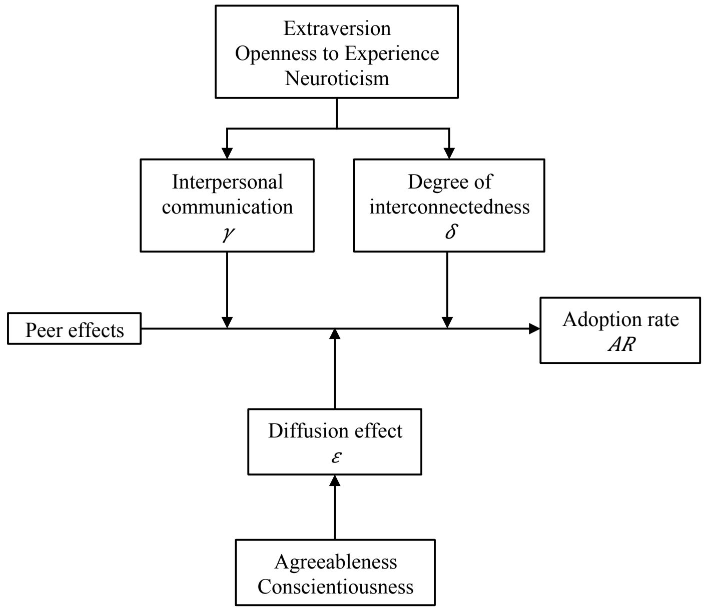


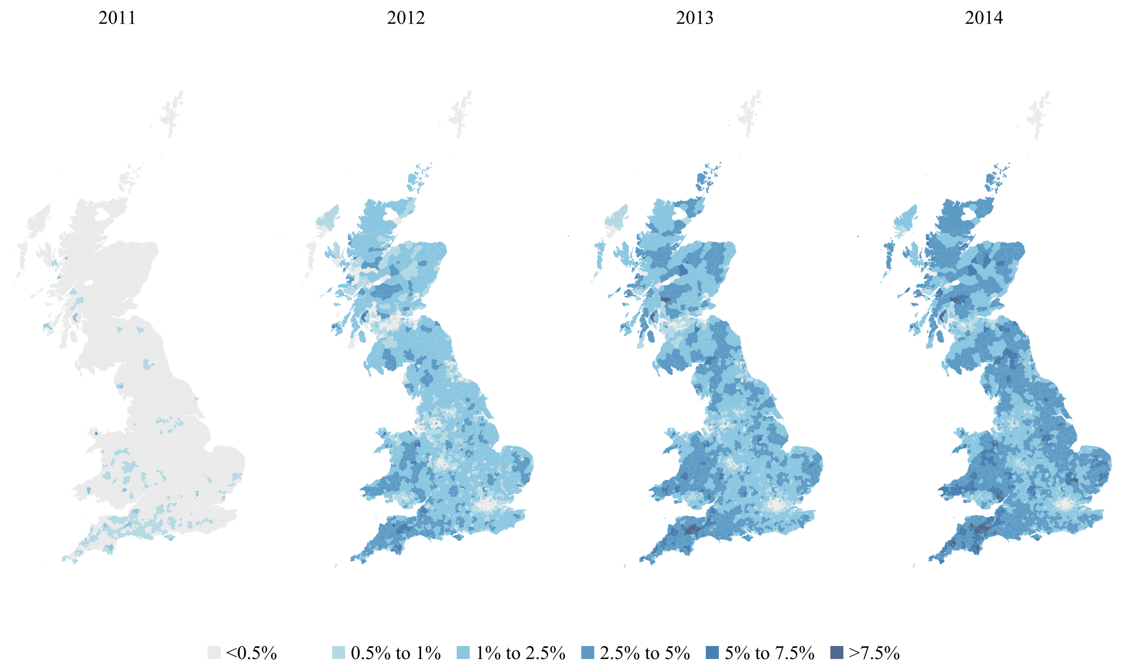
Figure 6.1 Impact of personality traits on peer effects

6.4 Data

In April 2010, the UK government introduced a feed-in tariff (FIT) scheme with the intention to foster the deployment of small-scale renewable electricity generation technologies (less than 5 MW), including solar PV, wind and hydro systems (DECC, 2015). The state guarantees the payments of the FITs for a period of 20–25 years with a predetermined price scheme for both electricity that is used for own consumption or sold to the grid. The programme introduced an increase particularly in solar panel deployments in the following years. The adoption patterns of these installations are analysed to elaborate on the impact of the Big Five traits on peer effects.

Three data sources are used for the investigations. The first is provided by the Office of Gas and Electricity Markets (OFGEM) which publishes quarterly data on the renewable electricity generation installations that have been registered under the FIT scheme since its launch in April 2010 (OFGEM, 2016). The data contain individual level information on all installations in the UK (except for Northern Ireland), including details on technology type (solar PV, wind, hydro etc.), installed capacity (kW), installation type (i.e. domestic, community, non-domestic), the day of registration and a geographical identification at the postcode district level.

Figure 6.2 shows the deployment of the domestic solar PV installations under the FIT scheme across the UK from April 2011 to April 2014. It is apparent from these maps that the diffusion speed differs across the postcode districts. After four years of the inception of the FIT scheme, some districts in the north of the UK, for example, show higher installation rates (number of installations per number of dwellings) than districts in the south. It is further evident that solar PV installations tend to cluster spatially. Postcode districts with high



Source: OFGEM (2016).

Figure 6.2 Installation rates of domestic solar PV systems across the UK installation rates, for example, are concentrated in the South West, Wales and eastern coastal area of England, whereas postcode districts in the South East, North West and specifically in the London area show comparatively lower rates. To test the visual impressions of spatial clustering for the solar PV systems, Moran's I measure for spatial autocorrelation is assessed (Moran, 1950). The Moran' I statistics for the installation rate of solar PV systems are 0.14, 0.38, 0.44 and 0.48 for the year 2011, 2012, 2013 and 2014, respectively (statistically significant at $p < 0.01$), indicating that the installations are spatially not randomly distributed but that postcode districts with high and/or low installation rates tend to cluster. The increasing value throughout the years suggests that the clustering effect becomes stronger as the number of installations increases.

The second data set is a large internet-based survey designed and administered by the Department of Psychology, University of Cambridge, in collaboration with the British Broadcasting Corporation (BBC) (University of Cambridge (Department of Psychology) & British Broadcasting Corporation, 2015). Using a 5-item Likert scale, the survey measured the Big Five personality traits of nearly 600,000 individuals across the UK between 2009 and 2011. The total sample after the data cleansing consists of 374,743 individuals (e.g. excluding non-UK residents and uncompleted questionnaires). Geographical indicators allow to match aggregated personality traits with the solar PV installations from the OFGEM data source at the postcode district level, giving 2,590 postcode district observations.

Since the personality traits were surveyed independently from the solar PV installations, the observation periods of the two data sources are not the same. However, based on findings that personality traits are relatively stable throughout time (Brown & Taylor, 2014; Busic-Sontic et al., 2017; Cobb-Clark & Schurer, 2012; Matthews et al., 2009), no significant differences are expected in the personality trait patterns for the observation period of the OFGEM data set between 2011 and 2014. This view is also supported by studies that show links between personality traits and genetic factors (Lo et al., 2017; Riccelli et al., 2017).

Although attitudes and actions can be influenced by social dynamics (Bond et al., 2012), such impacts are not expected to evolve within a few years, but rather in the long term. Thus, the Big Five data can be used to assess the longitudinal adoption patterns of the solar PV installations from the OFGEM data.

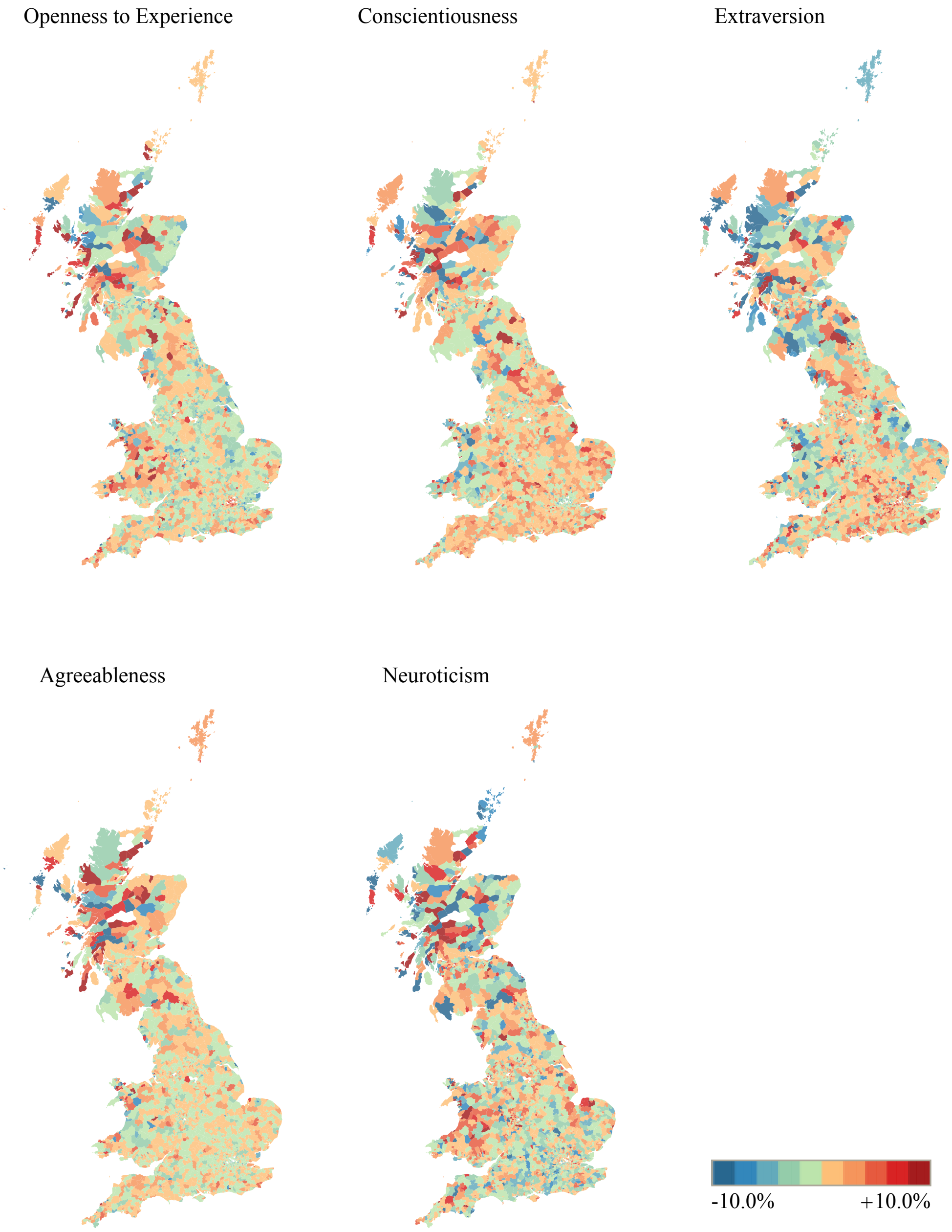
The maps displayed in Figure 6.3 show the spatial concentrations of each of the Big Five personality traits compared to their UK averages. It can be seen that there is a spatial clustering of personality traits across postcode districts. For example, high levels of Openness to Experience are rather present in the regions of Wales, while districts with low levels of Extraversion are relatively more prevalent in the north western parts of Scotland.

The sample size of individuals per district in the internet-based personality survey ranges from 1 to 1,138 observations with a mean of 145 (see Table C.1 in Appendix C), meaning that some of the districts exhibit very few observations and thus should be tested whether they can represent their district populations accurately. To test the representativeness of the Big Five for each postcode district sample, a lower bound for the number of observations per postcode district is first derived by defining the amount of sampling error that is tolerable in the sampling estimates (Cochran, 1977; Lohr, 2010), and socio-demographic variables in a district in the internet-based personality survey are compared with the population characteristics in that district in the UK 2011 Census data (NRS, 2017; ONS, 2017).

Considering that the Big Five are measured on a 5-item Likert scale, the frequency of each outcome (1, 2, 3, 4 or 5) can be expressed as a proportion relative to the overall frequency. The desired precision of the estimated proportions can be defined by setting the risk (α) of underestimating or overestimating the true proportion by a specified amount (margin of error e) (Cochran, 1977):

$$\Pr(|p-P| \geq e) = \alpha \tag{6.3}$$

where Pr denotes the probability, p is the estimated proportion in the sample and P the unknown proportion in the population. For instance, for a risk level of $\alpha = 5\%$ and margin



Note: The maps show the deviations of each of the Big Five personality traits to their mean values by postcode districts, measured between 2009 and 2011.

Source: University of Cambridge (Department of Psychology) & British Broadcasting Corporation (2015).

Figure 6.3 Spatial concentrations of the Big Five personality traits across the UK of error of $e = 3\%$, it can be expected that a sample proportion will equal or deviate more than 3 percentage points in either direction in only 5 of 100 sampling cases from what would have been obtained if the whole population of a postcode district was surveyed. The lower bound of observations for each postcode district can be calculated as

$$n_{min} = \frac{z^2_{\alpha/2} p(1-p)}{e^2 + \frac{z^2_{\alpha/2} p(1-p)}{N}}, \tag{6.4}$$

where z is the z-score and N the population per postcode district taken from the UK 2011 Census data (Lohr, 2010).

Usually, the choice of the desired risk level α ($1-\alpha$ level of confidence) and acceptable range of margin of error e is evaluated against cost, time and difficulty of achieving the required sample sizes (Cochran, 1977; Rea & Parker, 2014). Since the Big Five data were already collected by the Department of Psychology, University of Cambridge, and the BBC, such ex ante sampling considerations are not applicable and instead, the specification of precision is based on widely accepted standards in the research community.

Based on the guidelines by Rea and Parker (2014), a 5% and 1% risk of under or overestimation (95% and 99% level of confidence) are mostly used in determining the minimum sample size, while 5% is well accepted among researchers because it represents a reasonable balance between the risks associated with Type I and Type II errors. A margin of error of 3% to 5% is generally accepted for proportional data (Rea & Parker, 2014).

Even though p could be calculated for each Likert outcome and personality trait separately, it is recommended to take one value of p that gives a conservative lower bound of required observations, i.e. for any other value of p, n would be smaller (Lohr, 2010). This is the case with a proportion of 0.5 since then $p(1-p)$ attains its maximal value, so that $p = 0.5$ is used in determining the minimum sample size for the postcode districts.

Table 6.1 presents the average lower bound of observations per postcode district $\overline{n}_{min}$ and the number of districts that meet their required minimum number of observations ($n \geq n_{min}$)

for $p = 0.5$ and the described risk levels and margins of error. It can be seen that only a small number of the total 2,590 postcode districts exceed their minimum sample sizes required to achieve the stated precisions.

Table 6.1 Minimum sample sizes for postcode districts

	5% risk (α)		1% risk (α)	
Margin of error (e)	$\overline{n}_{min}$	$n \geq n_{min}$	$\overline{n}_{min}$	$n \geq n_{min}$
±3%	956	1	1,571	0
±4%	558	23	933	2
±5%	365	112	616	13

Note: This table presents the average lower bound of observations per postcode district $\overline{n}_{min}$ and the number of districts that meet their required minimum number of observations ($n \geq n_{min}$) for the proportion $p = 0.5$ and different risk levels and margins of error.

With $\alpha = 5\%$, $e = 3\%$ and $p = 0.5$, Equation (6.4) gives an average lower bound of 956 observations per postcode district but only one district has observations equal or above its required minimum number of observations with these values. A margin of error of $e = 4\%$ gives only a slightly higher number of districts that meet their minimum sample size (23), whereas with $e = 5\%$, the number increases to 112 districts with an average lower bound of 365 observations per postcode district. In terms of trade-off considerations between the degree of accuracy and number of available districts that can be used in the analysis, a margin of error of 5% is preferred at the 5% risk level: a one percentage point increase of the margin of error from 3% to 4% gives 12 additional districts, whereas a further increase to 5% yields 89 additional districts. Since the numbers of districts meeting the minimum sample sizes at the 5% risk level are already small, setting a risk level of 1% may be too restrictive for sample selection in this study.

The following analyses will, therefore, be restricted to the 112 postcode districts ($\alpha = 5\%$, $e = 5\%$) in the first stance. In the second stance, the postcode district means of the Big Five traits are exchanged with the higher level local authority district (LAD) means for those districts that do not meet the required number of observations at the postcode district but at the LAD level in order to keep a preferably high number of postcode districts (2,561 of total 2,590 postcode districts).

Testing the spatial clustering of the Big Five with the restricted data set of 112 postcode districts suggests a weak but significant positive autocorrelation for Conscientiousness and Neuroticism with a Moran's I statistic of 0.05 ($p < 0.01$) and 0.02 ($p < 0.05$), respectively. The spatial autocorrelations for the other personality traits are not significant, suggesting a random distribution of the postcode districts. This might be attributed to the statistic assuming neighbouring postcode districts to have a larger impact on each other than districts that are farther away and the restricted sample contains few neighbouring districts. The majority of districts is distributed across the UK with spatial gaps, disabling a comparison of many nearby districts.[3]

Table 6.2 compares the socio-demographic characteristics between the internet-based personality survey and the UK 2011 Census data for the 112 postcode districts that meet the required number of observations. The numbers suggest that the distribution of the socio-demographic variables in the survey does not resemble the Census distribution: testing the difference of means of the variables with the two-sided Wilcoxon matched-pairs signed-ranks test[4] suggests that for the postcode districts in the internet-based survey, participants are younger, attained a higher education level and the income and share of male respondents are lower. The districts in the survey further show significant differences in the share of Black, Asian, White and Mixed ethnicities between the survey and Census data (the differences are all statistically significant at $p < 0.01$).[5] The same pattern of differences applies when

[3]Note that in the case of using LAD means as proxies for postcode districts, districts in the same LAD would have the same Big Five mean, so that an artificial clustering of postcode districts with a positive autocorrelation would be produced and an assessment of Moran's I would not be meaningful.

[4]The paired t-test, which differently to the Wilcoxon signed-ranks test requires that the differences of means are normally distributed, leads to the same conclusions.

[5]Similar results are found if all 2,590 postcode districts are compared with the exception that there is no significant difference observed for the proportion of the Mixed ethnicity (see Table C.1 in Appendix C).

Table 6.2 Comparison between the internet-based personality survey and UK Census 2011 by socio-demographic variables for the restricted sample of 112 postcode districts

	Internet-based personality survey *n*=59,965					UK Census 2011 *N*=6,154,316					Difference of means	*p*-value[d]
	Mean	Median	SD	Min	Max	Mean	Median	SD	Min	Max		
n or N per postcode district	508.62	462	134.12	381	1,138	54,949.25	51,970	20,551.04	23,115	154,233		
Median age	30.96	31	4.20	21	39	34.60	34	5.25	22	49	-3.64	0.000
Education[a]	4.52	4.58	0.35	3.68	5.08	4.08	4.04	0.43	3.27	5.11	0.44	0.000
Median income[b]	443.32	424.25	74.40	335.18	810.62	538.17	525.40	73.24	427.70	699.90	-94.85	0.000
Gender (prop.[c] male)	0.37	0.37	0.03	0.32	0.46	0.49	0.49	0.01	0.47	0.54	-0.13	0.000
Prop. Black	0.02	0.01	0.03	0.00	0.16	0.05	0.02	0.07	0.00	0.43	-0.03	0.000
Prop. Asian	0.04	0.03	0.03	0.00	0.19	0.08	0.06	0.07	0.00	0.42	-0.04	0.000
Prop. White	0.91	0.93	0.07	0.62	0.98	0.83	0.88	0.13	0.42	0.98	0.08	0.000
Prop. Mixed	0.03	0.02	0.02	0.00	0.09	0.04	0.03	0.02	0.01	0.09	-0.01	0.000

Notes: This table compares the postcode district means between the internet-based personality survey and UK Census 2011 by socio-demographic variables for 112 postcode districts. [a]1 (No qualification), 2 (Level 1 qualification), 3 (Level 2 qualification), 4 (Apprenticeship), 5 (Level 3 qualification), 6 (Level 4 qualification and above). [b]GBP per week measured at the higher local authority district (LAD) level since income data are not available for postcode districts in the Census 2011 data. [c]Proportion. [d]*p*-value of the two-sided Wilcoxon matched-pairs signed-ranks test.

comparing the means of socio-demographic variables in the sample of restricted postcode districts (112 districts) with those of all districts (2,590) except that the shares of Black, Asian and White ethnicities are not significantly different (Table 6.3). The sampling bias implies that the findings of this study cannot be generalised to the population of the 112 districts or the UK population. This issue is taken into consideration in the discussion of the results (Section 6.7).

The third data source used in the analysis is the 2011 Census data from the Office for National Statistics and National Records of Scotland to control for dwelling type, age, gender education and commuting behaviour at the postcode district level (NRS, 2017; ONS, 2017). It is controlled for income at the higher LAD level since income data are not available for postcode districts. It is also controlled for the average FIT rate for domestic solar PV installations, which decreased from an average rate of 42 pence per kilowatt-hour (p/kWh) in 2010 to slightly above 10p/kWh in 2014. Table 6.4 summarises the longitudinal descriptive statistics of the variables for the restricted sample with 112 postcode districts.[6]

The heat map in Figure 6.2 reveals postcode district differences in the installation rates of solar panels and Moran's I statistics suggest that they are not spatially randomly distributed. For a sample of 112 postcode districts, a sufficient number of district observations is available from an internet-based personality survey on the Big Five – out of which two traits exhibit weak spatial clustering – to test whether personality traits aggregated at the postcode district level are associated with the spatial adoption rate patterns of solar panels. The next section presents the method to, firstly, test whether the spatial clustering in the installation rates of

However, this comparison is less meaningful because most postcode districts (except the 112 districts) have fewer observations than required to make reliable statements on the socio-demographic estimates from the internet-based personality survey.

[6]The longitudinal descriptive statistics for the large sample with 2,561 postcode districts where the Big Five means are exchanged with the LAD means for those districts that do not meet the required number of observations at the postcode district level can be found in Table C.2, Appendix C.

Table 6.3 Comparison of the restricted sample of 112 postcode districts and all 2,590 districts by socio-demographic variables

	Internet-based personality survey *n*=59,965					UK Census 2011 *N*=59,302,390					Difference of means	*p*-value[d]
	Mean	Median	SD	Min	Max	Mean	Median	SD	Min	Max		
n or N per postcode district	508.62	462	134.12	381	1,138	22,896.68	20,946	16,328.56	52	154,233		
Median age	30.96	31	4.20	21	39	41.70	42	5.93	22	64	-10.74	0.000
Education[a]	4.52	4.58	0.35	3.68	5.08	3.52	3.50	0.47	2.07	5.56	1.00	0.000
Median income[b]	443.32	424.25	74.40	335.18	810.62	499.82	479.29	72.64	365.30	1,006.90	-56.51	0.000
Gender (prop.[c] male)	0.37	0.37	0.03	0.32	0.46	0.49	0.49	0.01	0.42	0.64	-0.12	0.000
Prop. Black	0.02	0.01	0.03	0.00	0.16	0.02	0.00	0.05	0.00	0.43	0.00	0.382
Prop. Asian	0.04	0.03	0.03	0.00	0.19	0.05	0.01	0.09	0.00	0.74	0.00	0.131
Prop. White	0.91	0.93	0.07	0.62	0.98	0.92	0.97	0.13	0.11	1	-0.01	0.156
Prop. Mixed	0.03	0.02	0.02	0.00	0.09	0.02	0.01	0.02	0.00	0.26	0.01	0.000

Notes: This table compares the restricted sample of 112 postcode districts (internet-based personality survey) and all 2,590 districts (UK Census 2011) by socio-demographic variables. [a]1 (No qualification), 2 (Level 1 qualification), 3 (Level 2 qualification), 4 (Apprenticeship), 5 (Level 3 qualification), 6 (Level 4 qualification and above). [b]GBP per week measured at the higher local authority district (LAD) level since income data are not available for postcode districts in the Census 2011 data. [c]Proportion. [d]*p*-value of the corrected *z*-test by Looney and Jones (2003) for partially matched (non-independent) data, which accounts for the covariance between the two samples (note that the two sample t-test assuming indpendent samples leads to the same conclusions).

Table 6.4 Summary statistics solar PV installations, Big Five personality traits and control variables for the restricted postcode district sample

Variables	Mean	SD	Min	Max	Source
Number of domestic solar PV installations per number of dwellings by postcode district	0.01	0.01	0	0.07	OFGEM[d]
Big Five personality traits (5-item Likert scale)					
Openness to Experience	3.72	0.10	3.53	3.99	UoC/BBC[e]
Conscientiousness	3.60	0.08	3.38	3.76	UoC/BBC
Extraversion	3.27	0.07	3.11	3.48	UoC/BBC
Agreeableness	3.72	0.04	3.63	3.84	UoC/BBC
Neuroticism	2.97	0.05	2.77	3.12	UoC/BBC
Dwelling type[a]	2.85	0.56	1.73	3.88	UoC/BBC
Median income (GBP per week measured at the local authority district)	538.17	74.32	402.50	775.30	ONS/NRS[f]
Median age	34.60	5.22	22	49	ONS/NRS
Gender (prop.[b] of male population)	0.49	0.01	0.47	0.54	ONS/NRS
Education[c]	4.08	0.43	3.27	5.11	ONS/NRS
Commuting population (prop.)	0.93	0.02	0.87	0.97	ONS/NRS
Feed-in tariff (p/kWh)	24.15	13.66	10.35	41.58	OFGEM

Notes: Each variable has 5,376 observations, where an observation is a postcode district month.

[a] 1 (Detached house/bungalow), 2 (semi-detached house/bungalow), 3 (terraced and end terraced house/bungalow), 4 (purpose-built block of flats/maisonettes or equivalent), 5 (caravan or other mobile or temporary structure).

[b] Proportion.

[c] 1 (No qualification), 2 (Level 1 qualification), 3 (Level 2 qualification), 4 (Apprenticeship), 5 (Level 3 qualification), 6 (Level 4 qualification and above).

[d] Office of Gas and Electricity Markets. [e] University of Cambridge/British Broadcasting Corporation. [f] Office for National Statistics/National Records of Scotland.

solar panels is linked to the adoption behaviour of peers and, secondly, to investigate whether the Big Five personality traits are associated with these peer effects.

6.5 Methodological design

To estimate a causal influence of peer effects on people's adoption behaviour, the literature on the diffusion of technologies traditionally bases their studies on the "installed base", which is the number of agents in a social system that have already adopted a product or service (Bass, 1969; Graziano & Gillingham, 2015; Mahajan et al., 1990; Richter, 2014). The identification of peer effects by using the installed base as a predictor for current adoption behaviour requires attention regarding three main potential issues: simultaneity, homophily and correlated unobservables (Bollinger & Gillingham, 2012; Narayanan & Nair, 2013).

Simultaneity can bias the estimates of peer effects if a household is influenced by adoptions of its peers, and at the same time the peers' adoption behaviour is influenced by the household. In line with previous studies, this issue is addressed with the fact that a decision to invest in a solar PV system does not lead to an immediate installation (Bollinger & Gillingham, 2012; Graziano & Gillingham, 2015). In the UK, the average temporal lag from the decision to adopt solar panels to completion of an installation is estimated to be three months (Richter, 2014). It can be therefore assumed that a household's decision to adopt a solar PV system three months prior to its completion was only influenced by the installed base of its peers but not vice versa since the household did not have any experience about the installation that could be shared with others. The adoption decision is reflected three months later in the adoption rate $AR_{d,t}$, which is defined as the ratio of number of solar PV installations in postcode district d in month t to the number of dwellings without an installation. By estimating the peer effects with the impact of the installed base from $t-3$ on the adoption rate AR in t, the issue of simultaneity can be mitigated.

Another bias in the peer effect estimates could be caused by the self-selection of peers (homophily), whereby people with similar attitudes and interests tend to cluster in the same spatial regions. The observed differences in the adoption rates across postcode districts may therefore reflect rather different preferences than peer effects. The bias could be further pronounced by any other correlated unobservables in a district such as local availability of solar panel contractors. The possibility of homophily and correlated unobservables is accounted for by (1) including control variables in the analysis (see Table 6.4), (2) using district fixed effects (FEs) at the postcode district level and by (3) considering time specific FEs to control for time unobservables, which can have an impact across all postcodes districts at a specific time (e.g. changes in policy programmes).

Taking the outlined model assumptions together (excluding the control variables), the adoption rate $AR_{d,t}$ can be expressed as follows:

$$AR_{d,t} = \alpha + \beta IB_{d,t-3} + \lambda_d + \sum_{i=1}^{I-1} \eta_i D_{i,t} + \sum_{l=1}^{3} \nu_l S_{l,t} + \varepsilon_{d,t}, \tag{6.5}$$

where α is the constant, $IB_{d,t-3}$ denotes the peer effects by the cumulative number of adoptions relative to the number of dwellings in $t-3$ for postcode district d and β is the coefficient of the peer effects. λ_d stands for the district specific FEs and $\sum_{i=1}^{I-1} \eta_i D_{i,t}$ for the time specific year FEs with D_{1t} being a dummy variable taking the value of 1 for all first year observations and zero otherwise; D_{2t} taking the value of 1 for all second year observations and zero otherwise etc. $\sum_{l=1}^{3} \nu_l S_{l,t}$ is a set of dummy variables indicating the season of the year (i.e. spring, summer, autumn and winter) with S_{1t} being a dummy variable taking the value 1 for observations in the first season of the year and zero otherwise etc. and $\varepsilon_{d,t}$ is the error term.[7]

[7]Note that for all except for one year and one season of the year a dummy variable is introduced in order to avoid the dummy variable trap (Gujarati & Porter, 2010).

In order to identify impacts of the Big Five traits on the peer effects, interaction terms are used between the aggregated postcode district means of the Big Five traits, x_{dj}, and the installed base $IB_{d,t-3}$, where $j=${Openness to Experience, Extraversion, Conscientiousness, Agreeableness and Neuroticism}. The main reasons to use interaction terms are that (1) they accurately translate the theoretical to a statistical model because the personality traits are hypothesised to amplify or mitigate the peer effects (see Figure 6.1) and (2) the Big Five traits are time invariant, so that they are interacted with the time-varying installed base to make them suitable for first-difference estimation in a later step, which requires variation of the explanatory variables throughout time (Wooldridge, 2012). Together with the control variables, Equation (6.5) can be extended to

$$\begin{aligned} AR_{d,t} = \alpha + \beta IB_{d,t-3} + \sum_{j=1}^{5} \gamma_j x_{d,j} IB_{d,t-3} + \sum_{k=1}^{K} \delta_k z_{d,k} IB_{t-3} \\ + \lambda_d + \sum_{i=1}^{I-1} \eta_i D_{i,t} + \sum_{l=1}^{3} \nu_l S_{l,t} + \varepsilon_{d,t}, \end{aligned} \tag{6.6}$$

where γ_j denotes the coefficient for the interaction term between the peer effects and personality trait j and δ_k is the coefficient for the interaction term between the peer effects and the k^{th} control variable z_k.

The coefficients in Equations (6.5) and (6.6) are only consistently estimated under the assumption of strict exogeneity, i.e. the variance of the error term is independent of the variances of the explanatory variables. The installed base, however, is a function of past unobservables by construction whose effects are included in the error terms and therefore violate the condition of strict exogeneity. It has been shown that first-differencing accounts for this issue (Bollinger & Gillingham, 2012; Graziano & Gillingham, 2015; Narayanan & Nair, 2013), so that Equation (6.5) can be adjusted to specify the base model as follows

(Model 1):

$$
\begin{aligned}
AR_{d,t} - AR_{d,t-1} = \beta(IB_{d,t-3} - IB_{d,t-4}) + \sum_{i=1}^{I-1} \eta_i (D_{i,t} - D_{i,t-1}) + \sum_{l=1}^{3} \nu_l (S_{l,t} - S_{l,t-1}) \\
+ (\varepsilon_{d,t} - \varepsilon_{d,t-1}),
\end{aligned} \tag{6.7}
$$

where the district specific FEs (λ_d) are cancelled out in the first-differencing process. In the same vein, taking the first difference of Equation (6.6) gives Model 2:

$$
\begin{aligned}
AR_{d,t} - AR_{d,t-1} = \beta(IB_{d,t-3} - IB_{d,t-4}) &+ \sum_{j=1}^{5} \gamma_j (IB_{d,t-3} - IB_{d,t-4}) x_{dj} \\
&+ \sum_{k=1}^{K} \delta_k (IB_{d,t-3} - IB_{d,t-4}) z_{dk} + \sum_{i=1}^{I-1} \eta_i (D_{i,t} - D_{i,t-1}) \\
&+ \sum_{l=1}^{3} \nu_l (S_{l,t} - S_{l,t-1}) + (\varepsilon_{d,t} - \varepsilon_{d,t-1}).
\end{aligned} \tag{6.8}
$$

6.6 Results

The results of the outlined first-difference regressions are presented in Table 6.5. The left-hand side shows the findings when restricting the analysis to 112 postcode districts, which meet the required minimum number of observations, while the two middle rows show the results when the Big Five means are exchanged with the higher-level LAD means for the postcode districts with a lower number of observations than required (for details, see Section 6.4).

When restricting the data to 112 postcode districts and excluding the Big Five traits and the control variables (Model 1), a statistically significant impact is found of the installed base (peer effects) on the adoption rate of solar PV systems. The coefficient suggests that a one percentage point increase in the installed base increases the probability of household

Table 6.5 First-difference model estimation of adoption rates of solar PV systems

	Restricted sample with 112 postcode districts		Large sample with 2,561 postcode districts		High-C sample
	Model 1	Model 2	Model 1	Model 2	Model 1
Installed base (IB)	**0.0857*****	-2.2412	**0.0645*****	-1.3227	**0.1203*****
	(0.0148)	(2.5779)	(0.0116)	(0.9440)	(0.0130)
Openness to Experience (O) × IB		-0.1326		0.0516	
		(0.2172)		(0.0392)	
Conscientiousness (C) × IB		**0.5223****		**0.0899***	
		(0.2501)		(0.0530)	
Extraversion (E) × IB		-0.0063		-0.0707	
		(0.1639)		(0.0626)	
Agreeableness (A) × IB		-0.0016		-0.0004	
		(0.2952)		(0.0888)	
Neuroticism (N) × IB		0.2346		**0.1260***	
		(0.2827)		(0.0736)	
Dwelling type × IB		0.0072		**-0.1301*****	
		(0.0386)		(0.0266)	
Median income (log) × IB		-0.0001		0.0069	
		(0.0211)		(0.0112)	
Median age × IB		0.0014		0.0005	
		(0.0055)		(0.0030)	
Gender × IB		-0.1497		0.5408	
		(1.3977)		(1.0497)	
Education × IB		**0.1002****		-0.0102	
		(0.0504)		(0.0262)	
Commuting population × IB		-0.3647		**0.5595*****	
		(0.9373)		(0.1481)	
Feed in Tariff (FIT) × IB		**0.0162*****		**0.0147*****	
		(0.0008)		(0.0006)	
Year indicators	yes	yes	yes	yes	yes
Season of year indicators	yes	yes	yes	yes	yes
N	4,928	4,928	112,684	112,684	2,640
R^2	0.09***	0.24***	0.04***	0.13***	0.09***

Notes: The dependent variable is the number of solar PV system adoptions per dwellings without a solar PV installation in a postcode district-month. The installed base is the number of installations per dwellings in a postcode district three months prior adoption. Robust standard errors clustered in postcode district are in parentheses. $*p < 0.10$, $**p < 0.05$, $***p < 0.01$.

adoption in the same postcode district three months later by 0.000857. At the average number of 23,479 dwellings in a postcode district of the restricted data, 100 additional solar PV installations increase the number of adoptions three months later by 9.[8] A lower effect of the installed base is found in Model 1 for the more comprehensive data set with 2,561 districts, suggesting that at the average number of 10,083 dwellings in a postcode district in the larger sample, 100 additional solar PV installations result in 6 new adoptions three months later.[9]

Model 2 shows the results of the regression including the interaction terms between the installed base and the Big Five traits and control variables, respectively. In the restricted data set, it is found that postcode districts with higher levels of Conscientiousness are associated with significantly larger peer effects at the 0.05 significance level. In the larger data set, postcode districts with high concentrations of Conscientiousness and Neuroticism show significantly stronger peer effects at the 0.10 significance level.

Regarding the control variables, it is evident that in both data sets the spillovers from peers are significantly positively associated with the feed-in tariff (FIT) for solar electricity, suggesting that financial incentives facilitate behaviour to mimic the adoption decisions of neighbours. Additionally, in the restricted sample, postcode districts with people having a higher educational attainment exhibit significantly larger peer effects. A straightforward explanation for this association is difficult to deduce from existing education literature and peer behaviour since the majority of the studies elaborate on the impact that peers can have on educational attainment (Yeung & Nguyen-Hoang, 2016). An idea of the causal mechanism might provide the findings showing that people scoring highly on Conscientiousness show

[8] At the average number of 23,479 dwellings in the 112 postcode districts, a one percentage point increase in the installed base equals about 235 new installations (0.01×23,479). This increase translates into a 0.000857 higher adoption rate, which at the average number of households without an installation of 23,337 is equivalent to 20 new adoptions (0.000857×23,337), giving 9 additional adoptions three months later per 100 new installations (100/235×20).

[9] At the average number of 10,083 dwellings in the 2,561 postcode districts, a one percentage point increase in the installed base equals about 100 new installations (0.01×10,083). This increase translates into a 0.000645 higher adoption rate, which at the average number of households without an installation of 9,994 is equivalent to 6 new adoptions (0.000645×9,994).

higher academic performance (Hakimi et al., 2011) and at the same time a tendency to conform to norms and rules (Roberts et al., 2014), which might explain the stronger peer effects in districts with higher educational attainment.

In the large data set, dwelling type and the proportion of commuting people both show significant effects. The negative effect of dwelling type suggests that postcode districts with more combined building units or blocks of flats exhibit weaker peer effects. The causes of this effect are likely due to the housing tenure and building structure. Terraced building units, for example, have multiple owners which can complicate an agreement on a solar panel installation. High buildings, such as blocks of flats, can make the installations more costly (e.g. scaffold costs). The positive effect of the proportion of commuters in a postcode district suggests that a higher percentage of commuting individuals exhibit significantly larger peer effects. A possible explanation for this effect is that travelling to work increases the chances of spotting solar panel installations which may increase the likelihood to consider such an investment for one's own home.

To illustrate the effect of Conscientiousness, which is found in the restricted and large sample, only postcode districts with Conscientiousness levels above the restricted sample mean are taken and Model 1 is re-estimated (see last column in Table 6.5). The finding is compared to the initial result including all districts that meet the minimum number of observations (see 2nd column in Table 6.5). As expected, the peer effects are stronger in postcode districts with above average levels of Conscientiousness compared to those of all postcode districts in the restricted sample. At the average installed base, the peer effects are translated to 3 more adoptions for every 100 installations in the high-Conscientiousness sample.[10]

[10]The additional adoptions for the high-Conscientiousness (C) sample are derived as follows:
$\beta_{\text{High C}} - \beta = \Delta = 0.1203 - 0.0857 = 0.035$
$\frac{\text{Adoptions}}{\text{1 installation}} = \frac{0.01 \times \Delta \times \text{Average \# of dwellings in postcode district without solar panel adoption}}{\text{1pp increase in average installed base}} = \frac{0.01 \times 0.035 \times 23{,}337}{234.79} = 0.03.$

6.7 Discussion

Prior studies have noted the importance of personality traits driving energy saving behaviour under peer pressure (Khashe et al., 2016; Shen et al., 2015). To the best of my knowledge, this is the first study that elaborates on the link between personality and peer effects for high-cost renewable energy systems.

In a sample of 112 postcode districts in the UK, this study finds significant spatial clustering of the Big Five personality traits Conscientiousness and Neuroticism (Section 6.4), supporting previous studies observing spatial clusters of the same two and other personality traits at different geographical scales (Jokela et al., 2015; Rentfrow et al., 2013, 2015). This study does not find significant geographical concentrations of Openness to Experience, Extraversion or Agreeableness, possibly due to restricting the analysis to a fraction of UK postcode districts with sufficient numbers of observations. Fewer adjacent districts are therefore available, impeding a detection of personality concentrations because spatial autocorrelations are likely to weaken for more distant districts (Jokela et al., 2015).[11]

Literature on geographical psychology suggests several mechanisms for the spatial distribution of personality traits. Research on *selective migration* indicates that people tend to move to places that satisfy and reinforce their psychological needs. High-Openness, high-Conscientiousness and extraverted individuals are found to move from their home states to a different state, whereas agreeable individuals rather stay in their hometowns (Jokela, 2009, 2014; Rentfrow & Jokela, 2016). It is thus conceivable that due to the higher mobility of individuals high on Conscientiousness, people comparatively low in Conscientiousness have become more prevalent in some regions throughout time. *Social influence* proposes that the behaviour of people within the local environment may shape one own's attitudes

[11] If the autocorrelation of all postcode districts is assessed, all Big Five traits show weak significant clustering (Moran's I measure of 0.08, 0.03, 0.07, 0.05 and 0.02 for Openness to Experience, Conscientiousness, Extraversion, Agreeableness and Neuroticism, respectively ($p < 0.01$)).

and actions (Bond et al., 2012; Hofstede & McCrae, 2004). For example, places with a high proportion of anxious people/Neuroticism may increase the level of negative affect of other people (Rentfrow et al., 2015). Geographical concentrations of personality traits may be also explained by *ecological influence*. Several studies show that the natural and built environment, such as climate, ethnic diversity and green spaces, can affect an individual's psychological processes. Living close to green spaces in an urban environment, for instance, is found to reduce mental distress and increase well-being (White et al., 2013). Another example is the observation that regions with high levels of infectious diseases in the past report lower levels of Openness and Extraversion—traits that possibly reduce the risk of disease transmission through cautious behaviour (e.g. fewer social interactions) (Schaller & Murray, 2008).

It was hypothesised that spatial concentrations of the Big Five personality traits influence households' adoption of solar panels under peer pressure. The results for the restricted sample of 112 postcode districts suggest that peer effects are stronger in districts with higher concentrations of Conscientiousness. Stronger peer effects in high-Conscientiousness districts may be explained by conscientious individuals' strive for responsibility to carry out their duties and follow norms that are considered right (Costa & MacCrae, 1992; McCrae & Costa, 2003). If the behaviour of the majority of neighbours is considered as a social rule, conscientious individuals might be more likely to emulate peer behaviour because of their willingness to understand rules and conventions of their social surrounding and tendency to comply with them (conventionality) (Roberts et al., 2014). Also, such individuals might be more aware of their surrounding due to their focus on conventionality, meaning that they might rather recognise new solar panel installations in their neighbourhood.

In the approach where the means of the Big Five at the postcode district level are replaced with higher-level LAD means for those districts that do not meet the required minimum number of observations for reliable estimates, the effect of Conscientiousness is also significant but weaker than in the restricted sample, and postcode districts with high concentrations of Neuroticism exhibit stronger peer effects. Both effects are observed only at the 0.10 significance level.

The effect of Neuroticism was not expected because a weaker interpersonal communication and degree of interconnectedness was hypothesised for districts with high concentrations of Neuroticism, which would likely mitigate peer effects (see Section 6.3). The effect might be explained by the fact that individuals who feel inadequate and depressed – both tendencies of people high on Neuroticism – are observed to strive for social comparison and thus can be more susceptible to social influence (Hovland et al., 1953). This could counteract the weakening influence of low communication and interconnectedness on considering peer behaviour. The found impact of Neuroticism, however, must be treated with caution because it is not observed in the restricted data and at the 0.10 significance level only.

It is important to note that the effect of Conscientiousness found in the restricted data cannot be considered representative of the population in the analysed 112 postcode districts or the UK population. The reason for the effect not being representative of the population in the analysed postcode districts is that the sampled individuals per districts are biased in terms of several socio-demographic attributes, possibly because the personality sample is self-selected. The reason that the result is not representative of the UK population is that the analysis is restricted to a sample of postcode districts and does not cover all districts in the UK.

Compared to the Census data representing the population in the analysed postcode districts, respondents in the personality survey are younger and obtained more years of education, their income level is lower and more individuals are female. Regarding ethnicity, the proportion of the White ethnicity is higher for the sampled individuals than for the population, whereas the proportion of Black, Asian and Mixed ethnicities is lower (see Table 6.2 in Section 6.4). These differences suggest that the amplifying effect of Conscientiousness on the peer effects could be either stronger or weaker for the population in the analysed districts compared to the study. Older and wealthier individuals tend to score higher in Conscientiousness (Judge et al., 2006; Roberts et al., 2006), implying a higher level of Conscientiousness for the population and thus possibly a stronger link between Conscientiousness and the peer effects than in the study. On the other hand, less educated and male persons are found to score lower in Conscientiousness (O'Connor & Paunonen, 2007; Schmitt et al., 2008), possibly implying a weaker link in the population. Some studies find significant links between the Big Five and ethnicity, suggesting a higher level of Conscientiousness for the White ethnicity compared to other ethnicities, though the found differences are minimal in some cases (Goldberg et al., 1998; Hough et al., 2008). The significantly lower proportion of the White ethnicity in the population of the analysed postcode districts would thus imply a lower level of Conscientiousness and therefore also a weaker effect of the trait in the population than in the studied sample.

Compared to the UK population, the sampled individuals show significant deviations for the same socio-demographic variables as if compared to the population solely of the assessed districts, with the exception that the differences for three of the four ethnicities are not significant (see Table 6.3 in Section 6.4). A difference in the effect of Conscientiousness on peer effects between the analysed districts and the UK population due to biases in the proportions of ethnicities is thus less likely. For the other variables, the same implications can be made as outlined above. The smaller effect of Conscientiousness in the large data set compared to the restricted sample might imply that the effect is weaker in the UK population, but this might be also attributed to diluting the postcode district means of the Big Five with the higher-level LAD means.

Overall, the question of whether the effect of Conscientiousness in the population of the analysed postcode districts or UK population would be weaker or stronger than in the sample depends on the sensitivity of Conscientiousness to the differences in the socio-demographic variables, so that it makes it difficult to come to a conclusive answer to that question without further details on the sensitivity of Conscientiousness to each socio-demographic factor.[12]

6.8 Limitations

This study finds supporting evidence for spatial concentrations of personality traits being related to peer effects of adopting solar panels for Conscientiousness, but not for the other Big Five. Besides restricting the analysis to a sample of UK postcode districts, the reason for not finding evidence of an impact of the other personality traits might be due to several other limitations of this study, which need to be acknowledged.

The first limitation is related to defining social systems by postcode districts within which the peer effects are assumed to spread. A change in the geographic unit of measurement would change the size and the boundaries of the area and thus the individuals compromising the spatial units, so that the results of the analysis are likely to be different with different geographical units (modifiable areal unit problem) (Fotheringham & Wong, 1991; Openshaw, 1984).

The postcode districts describe administrative boundaries which may not necessarily conform to the "natural" spread of neighbourhood effects: spillovers from peers may emerge across the postcode districts because social systems might cross their boundaries, or they may encompass more than one social system (Openshaw, 1996). The districts thus serve as a proxy for the "true" social systems which may introduce measurement error if these are not represented adequately (Coulton et al., 2001; Sampson et al., 2002).

Individuals who live in the same postcode district are assumed to have the same habitat for visual exposure to solar panels and same environment to exchange knowledge about the

[12]Note that a similar representativeness analysis of the large data set and the UK population would not be meaningful because most postcode districts (except the 112 districts) have fewer observations than required to make reliable statements on the socio-demographic means from the internet-based personality survey.

solar panels, irrespective of where people actually undertake their daily activities and how much time they spend within the postcode district (Kwan & Weber, 2008; Matthews, 2008). Because space and time behaviour differ across individuals, the "true" social systems might be more adequately reflected by describing their boundaries at the individual level (Miller Harvey, 2007).

It is further likely that for peer effects of solar panels, defining social systems at lower spatial scales better captures the peer effect mechanisms at work because it can be assumed that generally, people's habitat is centred around their home so that they are more likely to be visually influenced by solar panels in the nearby neighbourhood area. The likelihood that they share the habitat of neighbours who live close to them is also higher and thus possibly makes information transmission through social interaction in the closer area more likely too. This view is supported by the study on peer effects of solar panels by Graziano and Gillingham (2015) who use different radii around the geographic centre of a block group to define a social unit and found weaker peer effects with increasing distance.

Individual data on how long people operate in which area and a preferably low scale for the geographical units are therefore likely to more accurately represent the social systems relevant for the transmission of solar panel peer effects. If the geographical units of postcode districts deviate too much from the "true" social systems, the Big Five concentrations of the "true" units might be captured only partially in postcode districts, disallowing extracting all effects that personality traits might have on peer effects. If LAD level means are applied for those districts that do not meet the minimum number of observations as done in the second approach, the dilution of the "true" concentrations of the Big Five might be even more pronounced due to the higher geographical scale, possibly explaining the weaker effect of Conscientiousness and its higher significance level than if measured at the district level. Since individual-level information on social systems is not available in the data, and geographical units at the higher spatial scale possibly deviate more from the systems in which peer effect mechanisms are at work, the lower-level postcode districts can be considered as the closest available proxy for the "true" social systems.

A caveat should be further noted regarding hypothesising the causal links between personality traits and adoption behaviour of solar panels at the individual level and measuring them at the regional level because relationships at the individual level do not need to generalise at the aggregated level (reverse ecological fallacy) (Hofstede, 2001). This might be another reason why this study does not find more of the Big Five showing significant effects on peer effects at the aggregated spatial level.

Finally, the causal processes for the impact of personality on the peer effects are not explicitly measured (e.g. communication behaviour, awareness). The observed personality effects, therefore, cannot be assigned to a specific causal mechanism. The effect of Conscientiousness can be attributed to the tendency of conscientious individuals to take responsibility to carry out duties and follow norms, or higher awareness of their surroundings. By measuring the Big Five personality traits instead of their underlying detailed facets in this study, some of the Big Five effects in spillovers from peers may remain undetected. Future studies might consider measuring the causal mechanisms (e.g. communication) explicitly at the individual and aggregated level to further disentangle the mechanisms behind the personality trait effects.

6.9 Conclusions

This study set out to examine the influence of personality traits on peer effects for domestic solar PV systems. Spatial clustering of Conscientiousness is found to have a significant impact on how strongly additional solar PV installations in a postcode district affect subsequent adoption rates. Evidence is found that for one additional solar PV installation, the probability of an adoption in postcode districts with above-average levels of Conscientiousness increases on average by 3 additional percentage points compared to the sample of districts including all levels of Conscientiousness.

The results of this study can provide guidance for policy-makers and vendors promoting solar PV systems and other green technologies. Advertisements of green technology products directly at the site of installation might be more effective in combination with peer effects. Advertisements for solar panels, for example, could yield more attraction if placed directly at their installation sites. The findings indicate that such measures should be concentrated in areas with high aggregate-levels of Conscientiousness, where households might feel more obligated to follow norms and are possibly more aware of the installations and advertisements in their neighbourhood.

This study contributes to the scientific knowledge on peer effects by providing first empirical evidence that social spillovers in the context of green technology investments depend on geographical concentrations of personality traits. A limitation of the study is that it could be carried out only on a fraction of postcode districts in the UK due to insufficient observations of the Big Five for making reliable statements on the sampling estimates in the other districts. Future studies might try to collect a higher number of observations per district on the Big Five that would allow making more comprehensive and representative analyses on the personality-peer effect link. Future research might also try to define social systems by people-based measures instead of administrative boundaries that track down individuals' habitat by their daily activities and time they spend at specific places (Kwan, 2009). Such an approach might provide more accurate proxies of people's "true" social systems. Finally, experimental individual-level data could be used to disentangle the causal mechanisms for the personality impacts on the peer effects (e.g. explicitly measure the readiness to follow norms of conscientious individuals).

6.10 Chapter summary

This chapter finds that peer effects for energy efficiency investments can be related to spatial concentrations of personality traits. Households' decisions to invest in solar panels are affected more by neighbours' solar panel adoption in districts with high concentrations of Conscientiousness. It seems possible that this result is due to the tendency of conscientious individuals to follow norms that are considered right.

Chapter 7

Conclusions

Energy efficiency investments in residential buildings are considered pivotal in achieving energy security, environmental sustainability and energy equity (accessibility and affordability) goals. The expected large-scale surge of investments, however, is not observed despite diverse economic, environmental and social benefits of energy efficiency. A large body of literature attributes this commonly called energy efficiency gap between the expected and realised investments to various market failures, and behaviour that is not anticipated under the neoclassical economic assumption of rationality (see Chapter 2).

Independent of the research on the energy efficiency gap, more recent attention is devoted to the role of personality traits in economic decision-making. A number of studies demonstrate relationships between personality traits and economic outcomes, including employment status and wages, households' financial asset allocation, financial market investments and regional entrepreneurship rates (Brown & Taylor, 2014; Durand et al., 2013b; Fletcher, 2013; Gherzi et al., 2014; Obschonka et al., 2015; von Weissenberg, 2017). The role of personality traits in domestic energy efficiency investments, however, remains unclear. In this thesis, it is proposed that disentangling this role contributes to a better understanding of domestic energy efficiency decisions and the energy efficiency gap. Chapter 3 develops a new micro-economic model that integrates personality traits in the decisions of energy efficiency investments, which is tested empirically in two cross-sectional analyses in Chapters 4 and 5. Chapter 6 suggests an alternative impact of personality traits by elaborating on the influence of personality traits on energy efficiency investments through peer effects. As such, this thesis contributes to the literature by, firstly, providing a novel theoretical model for energy efficiency in a synthesis of economic and personality theory, and, secondly, assessing for the first time the relationship between personality traits and energy efficiency investments empirically.

The first section of the Conclusion ties together the key findings of the analyses while referring to the first two research questions:

- What are the mechanisms through which personality traits affect decisions of investing in residential energy efficiency?
- Which personality traits catalyse and which curb residential energy efficiency investments?

The second section addresses the implications of the findings for policy-making by considering the third research question:

- How can financial and informational incentives (e.g. "green" loans, energy certificates) be adjusted to engage with personality traits and to help overcome obstacles and foster investments in residential energy efficiency?

The final two sections elaborate on the contributions and limitations of the thesis and recommendations for future work.

7.1 Key findings

Based on a synthesis of existing literature on economic theory, personality traits and environmental behaviour, Chapter 3 derives a new conceptual framework for the causal effect of personalty traits in domestic energy efficiency investment decisions. Previous studies found strong relationships between personality traits as measured by the Big Five framework and risk preferences and environmental attitudes, respectively (Becker et al., 2012; Brick & Lewis, 2016; Hilbig et al., 2013; Milfont & Sibley, 2012; Passafaro et al., 2015). Due to the risk inherent in energy efficiency investments and their environmental characteristics, I argue that the personality traits influence energy efficiency investments indirectly through risk preferences and environmental attitudes.

Related to the conceptual framework in Chapter 3, Chapter 4 investigates the hypothesised mediation channels through risk preferences and environmental attitudes empirically. Based on a sample of homeowners in the UK, the results suggest that personality traits as measured by the Big Five traits influence decisions to consider investments in energy efficiency indirectly through environmental concern, whereas risk preferences have additional mediation effects in the case of adoption of energy efficiency measures. Openness to Experience and Agreeableness increase the likelihood to consider an investment in solar and wind turbine installations for electricity generation and solar water heating through environmental concern, whereas Extraversion has a decreasing effect. In regard to adopting any of these measures, Openness to Experience and Extraversion show similar effects through environmental concern. Additionally, the likelihood of adoption increases through the mediation channel of risk preferences with higher Openness to Experience and Extraversion, and lower Agreeableness and Neuroticism. This chapter concludes that risk preferences and environmental attitudes do mediate personality trait effects as suggested by the newly derived theoretical model, also when controlling for socio-economic factors.

Chapter 5 estimates the impacts of personality traits on pro-environmental investments by applying the conceptual model from Chapter 3 for a historically heavily subsidised energy system (i.e. solar PV system) and compares the impacts to personality effects found in the same model for products for which the provision of subsidies has been more restrictive (solar thermal collectors, thermal insulation or at least double-glazed windows). For solar PV systems, no mediation of the Big Five is found through risk preferences. However, Openness and Extraversion are positively associated with the likelihood to have invested in solar thermal collectors, thermal insulation or at least double-glazed windows through the risk preference channel, while Agreeableness and Neuroticism show a negative link. It is likely that the financial subsidies for solar PV systems have significantly reduced the investment risks of solar panels, decoupling personality effects through the risk channel. Regarding the mediation of the Big Five through environmental concern, Openness to Experience and Neuroticism show effects for both solar PV systems and the other group of investments. Interestingly, the likelihood of households having adopted a thermal insulation or at least double-glazed windows is negatively related to environmental concern (albeit significant at the 0.10 significance level only), implying that households do not perceive some energy efficiency investments as pro-environmental undertakings. Overall, the found personality effects are small, possibly because imposed conditions, such as unavoidable cyclical maintenance of buildings and the consequential mandatory regulatory standards for energy efficiency, mitigate intrinsic motivators to evolve.

The analyses in Chapters 3 to 5 examine the decision process primarily from a decision-maker's perspective and in different settings of financial subsidies, but they do not focus on social context. There is a growing body of literature, however, that emphasises the influence of social norms on energy related decisions. A number of studies suggest that energy-saving and pro-environmental behaviour can be motivated by social norms (Allcott & Mullainathan, 2010; Ferraro et al., 2011; Goldstein et al., 2008). Chapter 6 centres on this contextual factor by elaborating on the interplay between social norms and personality traits for domestic solar panel installations. A second main difference to the previous chapters is that the analysis is run on aggregate spatial but not on individual household level. As such, to the best of my knowledge, this is the first study that (1) investigates peer pressure against the backdrop of personality trait effects for high-cost energy efficiency investments and (2) uses econometric modelling to explain the impact of spatial concentrations of personality traits on an economic outcome. The results confirm evidence of previous studies that neighbours' installations of solar panels influence the adoption behaviour of other households. They reveal that such peer pressure is stronger in districts with spatial concentrations of Conscientiousness.

Taken together, this thesis shows that personality traits can influence energy efficiency decisions through three different mechanisms. The first is an indirect impact on energy efficiency investments through risk preferences and the second through environmental concern. The third mechanism describes an effect of personality traits through peer effects.

The first mechanism supports the idea of the available personality-investment literature that the importance of personality traits for investments mainly revolves around their relationships with risk-taking behaviour. The positive effect of Openness to Experience and Extraversion on energy efficiency investments through risk preferences (Chapters 4 and 5) is consistent with findings that open individuals have less diversified financial portfolios and extraverts higher exposure to equity (Durand et al., 2013b, 2008). The negative risk preference mediation of Agreeableness and Neuroticism (Chapters 4 and 5) support previous studies showing that agreeable people tend to have lower equity exposure and anxious people prefer saving to investing (Brown & Taylor, 2014; Durand et al., 2008; Gambetti & Giusberti, 2012).

The additional manifestations of personality traits in energy efficiency investments through environmental concern (Chapters 4 and 5) and in the social context (i.e. peer effects) (Chapter 6) suggest that the discussion of personality traits in the context of pro-environmental investments should go beyond the risk matter, which the personality-investment literature commonly centres on, and consider the role of personality traits for other key components of these investments, such as environmental, altruistic or social factors.

7.2 Implications for policy-making

Financing programmes are a popular policy tool to increase the uptake of high-cost energy efficiency measures in the built environment. These one-size-fits-all approaches assume that agents maximise their utilities primarily on financial cost-benefit analysis. By lowering the financial burden for investment and making energy efficiency financially more rewarding, the programmes are expected to direct households towards energy efficiency. It is shown, however, that emphasising financial benefits can even backfire against the intention to foster pro-environmental behaviour (Schwartz et al., 2015). Individuals not only consider financial aspects but embrace risk, environmental and social factors in their energy efficiency decisions (e.g. social norms) (see Chapters 4 to 6). The findings in this thesis show that the way these factors are considered in energy efficiency investments depends on decision-makers' personality traits. An implication of this is that personality profiles with defensive attitudes towards energy efficiency may pose a barrier for the deployment of energy-efficient technology. Based on its findings, this thesis proposes four directions for how energy efficiency policy-making and marketing can tackle personality-related barriers and consider personality to foster energy efficiency:

1. Character education and training.
2. Engagement with personality traits by indirect deliberation through preferences.
3. Customising risk–return levels of energy efficiency investment products to different types of personality profiles.
4. Leveraging marketing strategies by targeting personality traits.

Despite the common idea that personality traits are fixed (Brown & Taylor, 2014; Cobb-Clark & Schurer, 2012; Matthews et al., 2009; McCrae et al., 2000), there is evidence suggesting that they can change in certain periods of life (Hill et al., 2012; Mõttus et al., 2012; Roberts et al., 2006). The first direction draws on the observations that personality exhibits continuity especially during young adulthood (Robins et al., 2001) and that character training can bring about changes in personality traits (Roberts et al., 2017).

Researchers are rediscovering that besides providing cognitive skills, education should also focus on developing character skills such as emotional and moral strengths – character education – an idea that can be traced back to the ancient Greeks (Dweck, 2007; Matthews, 2016; Sanderse, 2016). It is posited that supporting the development of character skills in early years of education helps to improve later life outcomes (e.g. longevity), promote social and economic mobility and therefore increase economic productivity (Heckman & Kautz, 2014). Consistent with this literature, this thesis finds evidence that personality traits predict energy efficiency investments. Hence, it is argued that efforts for promoting energy efficiency against the backdrop of personality effects should revolve around character building in early years and young adulthood. Two of the three empirical analyses suggest that Openness to Experience significantly predicts energy efficiency investments (Chapters 4 and 5). I, therefore, suggest to foster specifically attributes related to openness (e.g. curiosity, willingness to learn). A prominent and classic example for character building in early years is the film "The Wizard of Oz", telling the story of a young girl Dorothy and her magical journey to Oz. During the journey, Dorothy makes friends with different characters each looking for a specific trait (e.g. a lion who is in search of courage). Through the challenges they face and master on their journey, the film teaches character skills such as openness, bravery and determination (Russell III & Waters, 2010).

Individuals might also be directed towards energy efficiency by interventions to change personality in adulthood. Roberts et al. (2017) observe in a meta-analysis of clinical and nonclinical interventions that social skills training and cognitive–behavioural therapy, among other interventions, can cause lasting changes in some personality traits. Such findings could suggest a route to change people's behaviour towards energy efficiency outcomes by targeting the development of personality traits. To illustrate, programmes to improve cognitive functions (e.g. inductive reasoning) are found to increase Openness to Experience for older populations (Jackson et al., 2012). Since Openness to Experience tends to decrease in old age (Roberts et al., 2006), such interventions could potentially increase the motivation for energy efficiency behaviour in the elderly.

The second direction refers to the findings in Chapters 4 and 5 which show that effects of personality traits on energy efficiency investments are mediated through risk preferences and environmental concern. In the first instance, it is proposed to attract attention to energy efficiency by engaging with personality traits through the environmental concern channel. For example, since Openness to Experience increases the likelihood to consider energy efficiency investments (Chapter 4), policy-makers should present energy efficiency measures as new and cutting-edge (Markowitz et al., 2012) or use stronger visualisations in energy efficiency rating figures, since these are attributes that high-Openness people typically react to. Care should be exercised, however, in choosing products to be promoted through the environmental concern channel since not all energy efficiency measures that might be seen as "green" at the first glance might be perceived by homeowners as such (Chapter 5).

In the second instance, it is suggested to centre on risk reduction measures rather than on pure financial incentives to foster energy efficiency. This might unburden additional investments as implied by the positive link between risk preferences and energy efficiency investments in Chapter 4, and in Chapter 5 if the investments have not yet been vastly subsidised. Although financial subsidies contribute to reduce risks in energy efficiency investments (e.g. reduction of financial debt), there exist more cost-effective ways to do so. Apart from reducing risks by informational measures (e.g. energy savings, profitability), it is proposed to foster state-wide controls or guarantees of energy efficiency equipment or services (e.g. certification of installers and auditors) (WEC, 2013), and cost-free installations of energy efficiency systems with future paybacks and performance guarantees, whereby the investment costs are paid back by future energy cost savings (Bollinger & Gillingham, 2012).

The third direction suggests expanding the range of risk–return levels for energy efficiency investments, targeting a preferably wide range of risk preference profiles. A major risk factor in energy efficiency investments is the volatility of energy prices (Alberini et al., 2013). Residential investors usually take the full exposure of an energy price drop which can significantly reduce the return of an energy efficiency installation. Different to capital market investors, therefore, residential energy efficiency adopters cannot choose a specific risk level that would allow a risk allocation according to their personality profiles. A larger variety of risk levels could be introduced by increasing the range of mortgage or loan products offered for energy efficiency measures by some liquidity providers. Such products could be tailored specifically to mitigate the energy price risk in energy efficiency investments, for example by the use of floating rate loans that link interest rate payments to energy prices. In such a scenario, the costs of energy price reductions are compensated with lower interest rate payments, while the products could be offered with various levels of hedging. As such, individuals could choose the product that fits best to their personality profiles.

Another solution may be risk-sharing energy policies. For example, future losses or gains in energy efficiency investments could be shared between government and households. The amount of risk and give-up of return to be transferred to the government could be offered at different levels, so that individuals can again choose the level in accordance with their personality profiles. The advantage in such a setup is that governments' portfolios allow a better allocation and diversification of risk than an average household's portfolio does.

The fourth direction addresses practical implications for marketing strategies of energy-efficient products. By knowing the personality profiles of energy-efficiency-prone investors, marketers can define their customer profiles more accurately and fine tune their strategies towards the customers' psychological profiles. For example, they could engage with Openness to Experience by visualisations of biospheric and altruistic contributions of their green products since individuals with a high Openness score tend to be more affected by feelings than hard facts. By considering spatial clusterings of personality traits (see Chapter 6), markets with the most promising customers can be targeted, i.e. areas with low psychological barriers to adopt novel energy-efficient technology.

Chapter 6 finds that the number of installations of solar panels in a neighbourhood influences the adoption behaviour of households, whereby the strength of the impact depends on spatial concentrations of Conscientiousness. This implicates that marketing strategies aiming to leverage neighbourhood effects, such as campaigns fostering the exchange of information of novel green technologies or marketing programmes advertising installations directly at the site, may be more effective in areas with personality traits concentrations where peer effects are strong. The results in Chapter 6 suggest that districts with high concentrations of Conscientiousness should be favoured in this regard because peer effects are more distinct in these areas.

The findings in this thesis further suggest that personality trait effects are likely mitigated in settings of large financial subsidies and mandatory standards for pro-environmental measures (Chapter 5). The Big Five do not unfold through risk preferences for solar PV systems in Germany, which have been incentivised by the provision of large FITs, but they do unfold through the risk channel for products that have been subsidised more restrictively (solar thermal collectors and energy efficiency investments). The personality trait effects, however, are small, including those found to be mediated through environmental concern. It is likely that unavoidable cyclical maintenance and mandatory standards may undermine intrinsic motivators such as personality traits. Irrespective of risk and environmental preferences, homeowners have to undertake more comprehensive building repairs from time to time and then it is likely that they are imposed to adopt pro-environmental measures by law. This implies that engaging with personality traits through preferences, risk-return level customisations and marketing strategies as outlined above are likely more effective in settings with no or historically less extensive financial subsidies and circumstances where pro-environmental investing is not primarily determined by mandatory standards or other external conditions.

7.3 Limitations and future research directions

The studies in this research demonstrate that personality traits are relevant for residential energy efficiency investments. However, their effects are sensitive to model specification and less distinct or unobservable under certain circumstances (e.g. large-scale financial subsidies). Against this background, several limitations of this thesis need to be acknowledged.

A major limitation depicts the difficulty of quantifying not directly observable psychological factors – personality traits – in energy efficiency investment decisions because such constructs do not exist in a factual way like physical items. The Big Five framework proved to be a useful way to think of and quantify personality traits (Schmitt et al., 2007), but the possibility of measurement errors may remain. The investigations are based on self-rated personality measures, which can deviate from real characteristics because respondents may answer questions in a way that is perceived as socially desirable (Edwards, 1957), or the answers may be influenced by respondents' mood (Heide & Grønhaug, 1996).

Another limitation is sample bias. Although data from nationally representative or large-scale surveys are used in Chapters 4 to 6, the analyses are conducted on biased samples due to non-response and other missing data. Comparing the characteristics between the samples and populations in Chapters 4 and 5 implies that the found personality traits are likely to be weaker in the populations (see Sections 4.6 and 5.8). But overall, conclusive statements in this regard are difficult to make without having access to fully representative data.

A caveat needs to be noted for the mapping of variables. In Chapters 4 and 5, individual-level personality traits are mapped to household-level outcomes (e.g. solar panels, wall insulations). Great effort was put to make sure that the personality traits of the effective decision-maker are mapped to the outcomes and robustness checks were run, but the complexity of household decision-making process leaves a possibility of mismapping. Future research could design experiments in laboratory settings, in which the impact of other household members on the individuals' decisions can be excluded. The suggested novel framework for residential buildings in Chapter 3 might serve as a basis for the experimental research. The framework could be also applied to other energy efficiency domains, such as the vehicle sector.

The thesis further assesses only a fraction of possibilities of how personality may influence energy efficiency decisions. Previous studies suggest that personality matters for a variety of outcomes. It is found, for example, that Conscientiousness is positively associated with employment status and earnings (Fletcher, 2013). A possible area of future research is to investigate to what extent personality affects energy efficiency investments through such productivity-related channels.

More broadly, future work could set out to increase the understanding of personality in the context of utilitarianism. Neoclassical economics describes people as selfish and rational utility maximisers who should invest in energy efficiency if it increases their utilities. Traditionally, the expression of utilities has been restricted to monetary values and the heterogeneity of people has not been explicitly modelled, expecting homogeneous behaviour according to objective cost-benefit considerations. However, the inclusion of psychic values and heterogeneous personality profiles into the utility functions leads to subjective valuations of energy efficiency measures, resulting in different adoption decisions (see also Section 2.1). An energy efficiency investment with a positive valuation under the traditional utility maximisation model might nevertheless be rejected in the extended valuation model including personality traits (see Chapter 3). A defensive personality profile towards energy efficiency, for instance, may reduce the value of a monetary profitable investment to a negative subjective value. On the other hand, an investment with a monetary loss might still be accepted by an individual with an energy efficiency-prone personality profile that values biospheric and altruistic “income”. Analysing the difference between this objective and subjective utility could quantify the extent to which personality traits matter in the utilitarian context. Future research could try to specify this difference in laboratory experiments of hypothetical energy efficiency investments by calculating and comparing their values in the objective monetary-based and extended subjective utility model including personality traits.

Against the evidence in Chapter 5 of personality traits showing no effects for vastly subsidised energy efficiency investments, further investigations could evaluate to which extent an individual’s utility depends on personality traits subject to different levels of monetary incentives. In terms of deviations from rational behaviour as defined in the neoclassical model of economics, future studies could explore the relationship between personality traits and commonly observed behavioural failures, such as loss aversion, anchoring and time inconsistencies.

7.4 Closing remarks

The difficulties inherent in capturing factually non-existent or less tangible assets such as personality traits in energy efficiency decisions, or the complexity of the mechanisms by which these might be mediated, are real but not reasons for avoiding the challenge. It is true that personality cannot be observed in a straightforward way, such as economic factors (e.g. price, income). Nonetheless, sound frameworks exist in the field of personality psychology nowadays that allow to think of and measure personality in a reliable way. Their potential for describing energy efficiency decisions should be recognised in the fields of energy efficiency as other research disciplines have done already. They could significantly enrich the understanding of people’s complex decision-making processes in the energy efficiency realm.

Finally, the author wishes to express his personal view on utilitarianism that economic models are founded on. Although a utilitarian model is used in the thesis to put it into the wider context and describe decisions (see Section 2.1), the author distances himself from propagating it as a normative model. Despite the inclusion of biospheric and altruistic factors, the premise of the extended utility model in Chapter 3 still lies in the maximisation of one's own utility. The assumption is, therefore, that if behaviour for the good of others and the environment does not increase one's own utility, such behaviour should be abandoned, leading to a disposal of increasing utilities of others under the principle of utilitarianism. The good for others is still reflected through one's own subjective judgements of others' utilities and one's own utility maximisation. This poses a weak construct if sustainable, ethical and environmental-friendly decision-making is of interest, since the focus on self-interest, and therefore possible orientation towards egoism, stays in utilitarianism. A stronger solution for abandoning selfish behaviour and enabling sustainable living conditions for current and future generations is to acknowledge – besides one's purely subjective own utility (i.e. one's own utility including benefits from altruistic and biospheric actions) – the objective utility or good, which different to the principle of utilitarianism, allows decision-making for the good of others and the environment even if it decreases one's own utility (based on elaborations in Wojtyła, 1960, 1969).

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Appendix A

A.1 Energy conservation and EE

Energy conservation and EE might seem to be closely related at first sight. Both can save energy. However, one important difference is that energy conservation is inevitably associated with a reduction in service demand, whereas EE can save energy while holding service demand constant (Pérez-Lombard et al., 2013). Typical energy conservation measures include reducing indoor temperature, turning off lights or cycling instead of using a car.

It is less clear what can be considered energy-efficient. The lack of clarity arises because the term “EE” is used by different research disciplines and it involves two components – it is defined as the ratio of output (performance, service, goods, energy) to energy input (De T’Serclaes, 2010; EU, 2012).

From an engineering point of view, higher EE means higher energy conversion, i.e. the same energy input (e.g. solar, geothermal) can be converted to more final energy (e.g. electricity), or less energy input is required for the same amount of final energy (Goswami & Kreith, 2007). For example, HVAC (heating, ventilating, air-conditioning) systems with better conversation rates are considered more energy-efficient.

In the context of renewable sources, a system is considered more energy-efficient if energy input from exhaustible resources (e.g. fossil fuels) is reduced and service is held constant. Examples include “on-site” renewables, such as solar panels for electricity generation installed at building sites, which source energy directly from the environment and reduce energy dependence from the supply side (Pérez-Lombard et al., 2013).

EU legislation considers improved passive energy systems (e.g. thermal insulation, window glazing) and active forms – technology that transforms energy (e.g. refrigerators, lighting) – as eligible EE measures, including renewable systems that reduce energy input from the supply side: "(g) domestic generation of renewable energy sources, whereby the amount of purchased energy is reduced (e.g. solar thermal applications, domestic hot water, solar-assisted space heating and cooling)" (Energy Service Directive (ESD), Annex III, EU, 2006).

Since there is no unique definition of EE, the different explanations are integrated as done by Pérez-Lombard et al. (2013) and passive energy technology (e.g. wall insulation), and energy from renewable resources that is generated "on-site" (i.e. does not have to be delivered to the consumer) and that simultaneously reduces purchased energy, are considered to be energy-efficient (e.g. solar electricity, geothermal heating).

A.2 Stability of personality traits

The stability of personality traits is checked following Cobb-Clark and Schurer (2012) and Brown and Taylor (2014). While there are other, more sophisticated approaches using structural equation models (e.g. the analysis of the developmental patterns in the stability of personality traits by Milojev and Sibley (2014)), the mean-level method is opted for as it allows to efficiently assess the stability of personality traits across time rather than looking into developmental patterns across age. The data set contains 7,554 participants for whom it is possible to match the Big Five responses in BHPS-2005 and in Wave 3 (2011–2012) of Understanding Society (University of Essex, 2010, 2014). The average responses for each trait are presented in the third and fourth column in Table A.1. For each individual, the measure of the change in a personality trait is constructed as $\Delta Trait^i_j = Trait^i_{j2011} - Trait^i_{j2005}$, where

i-individual, $j =$ Openness to Experience, Conscientiousness, Extraversion, Agreeableness, and Neuroticism. Each of the Big Five traits is measured on the 7-point scale, which implies that the difference can range from -6 to 6. The mean change ranges from -0.149 to 0.198 with a standard deviation of about 1. The mean proportional change is very low: between 1.59% and 6.64%. The median of the change (50th percentile) is zero. This suggests that the personality traits measured by the Big Five remain stable for a period of at least 6 years. This result is consistent with the conclusions of the Cobb-Clark and Schurer (2012) study using the Australian Household, Income and Labour Dynamics survey and of the Brown and Taylor (2014) study using the British Household Panel Survey and the Understanding Society data sets. The coefficients of longitudinal correlation reported in the second column of Table A.1 and the respective t-statistics provide an additional confirmation of stability of traits: all correlation coefficients are significant at 0.001%.

Table A.1 Stability of personality traits

	Coefficient of correlation (t-stat)	Level Mean		Changes between 2005 and 2011							
							Percentile of distribution				
		2005	2011	Mean	St. dev.	% change	1st	25th	50th	75th	99th
Openness to Experience	0.549 (57.2)	4.490	4.464	-0.028	1.151	4.57	-3.000	-0.667	0.000	0.667	3.000
Conscientiousness	0.463 (45.4)	5.291	5.495	0.198	1.079	6.64	-2.667	-0.333	0.000	0.667	3.000
Extraversion	0.590 (63.5)	4.477	4.603	0.123	1.079	6.37	-2.667	-0.667	0.000	0.667	3.000
Agreeableness	0.475 (47.0)	5.450	5.624	0.175	0.982	5.41	-2.333	-0.333	0.000	0.667	2.667
Neuroticism	0.604 (65.9)	3.683	3.538	-0.149	1.182	1.59	-3.000	-1.000	0.000	0.667	3.000

A.3 Stability of risk preferences

Unfortunately, there is no British longitudinal data on risk preference that would allow to perform stability analysis of risk preference over 3–4 years similar to personality traits (Brown & Taylor, 2014; Cobb-Clark & Schurer, 2012). Instead, the differences in risk preferences between different ages have to be explored and it is tried to make inferences of what will happen as people get 3–4 years older. Risk data are available for BHPS-2008 (Wave 18) and Understanding Society-2009 (US-2009) (University of Essex, 2010, 2014). It is of interest whether/how their risk preference changed by 2012. In both data sets negative and statistically significant at 1% correlation is found between age and risk, meaning that as people age, they become more risk averse.

In the 2008 data set, the ages of the respondents vary from 15–99 years and in the 2009 data set, the ages vary from 16–98. The ages which have less than 10 observations are cut, which leaves the range of 15–91 in 2008 and 16–94 in 2009. For each age, the mean risk preference is calculated. After that the difference between the mean scores of people 4 and 3 years apart in the 2008 and 2009 data sets is calculated, respectively, to bring them to 2012: $\Delta\overline{Risk}_g^{2008} = \overline{Risk}_g^{2008} - \overline{Risk}_{g-4}^{2008}$ and $\Delta\overline{Risk}_g^{2009} = \overline{Risk}_g^{2009} - \overline{Risk}_{g-3}^{2009}$, where g is the age of the participant. This is done under the assumption that risk preferences will change by the average difference in risk preferences between the age groups 3 years and 4 years apart in 2008 and 2009, respectively.

As evident from the second and third rows in Table A.2, the mean differences in risk attitudes are quite small in absolute and relative value (% change). In over 75% of the age groups, the risk preference is lower for older people. A similar analysis is performed on the subset of US-2009 that is used in the model. After removing the age groups with less than 10 observations, the range of 26–87 years old is left. In this subset, the difference in the risk preference is even smaller than in the full sample (see fourth row in Table A.2). It is concluded that the risk preferences are likely to be stable across the period of 3–4 years with some tendency to go down as people age.

Table A.2 Stability of risk preferences

	Difference in years	# of observations	Mean difference	Standard deviation	% change	Percentiles				
						1st	25th	50th	75th	99th
BHPS-2008	4	12,714	-0.145	0.297	-2.441	-0.836	-0.331	-0.160	-0.008	0.632
US-2009	3	39,419	-0.124	0.243	-2.368	-0.680	-0.244	-0.098	-0.010	0.616
Subset of US-2009	3	6,044	-0.081	0.470	-1.095	-1.187	-0.387	-0.108	0.121	1.051

A.4 Alternative breakdown of missing household observations

Table A.3 Alternative breakdown of missing household observations

	Unmatched households	Non-response	Missing by error or implausible	Proxy respondent	Other	Total missing	Households available for analysis
							17,010
EE outcome		-8	-4		-157	-169	16,841
Big Five	-1,032	-1,581	-21	-769		-3,403	13,438
Risk preference (R)	-3,691	-11	-1,078	-178		-4,958	8,480
Environmental concern (EC)		-503	-6	-91		-600	7,880
Education			-255		-1,541	-1,796	6,084
Solar Irradiance					-1	-1	6,083
Building type			-26		-13	-39	**6,044**

Note: This table shows a breakdown of missing household observations by variables for owner-occupied households, where the missing observations are excluded in the order of variables that corresponds to the order used in the data preparation. Because multiple variables can be missing for one household, the number of missing observations per variable depends on which variable is taken first, second, third etc. to exclude missing household observations from the data set: by excluding missing household data for one variable, missing data of other variables might be excluded as well, so that these might not be seen in the further breakdown.

A.5 Robustness checks

A.5.1 Equivalised income and alternative thresholds for income categories

The equivalised household income considers that additional adults or children in a household have less additional living expenditure than the first adult. For instance, more income is expected to be at disposal for an adult and a child than for two adults. Therefore, guided by the modified OECD equivalence scale (Hagenaars et al., 1994), an equivalised household size is calculated that weighs the first adult in a household by the factor one, each additional adult by the factor 0.5 and each child aged at 15 or under by the factor 0.3. The household income is then divided by this weighted household size to derive the equivalised household income. Instead of using the same number of households per group, the thresholds for the alternative income categorisation are set at the first and third quartile. The results of the regressions using the equivalised household income and alternative thresholds are presented in Table A.4.

Table A.4 Moderation effects of equivalised household income on energy efficiency (EE) investments and pro-environmental behaviour (PEB) (M2)

	EE investment considerations[a]	EE adoptions[b]	PEB
Personality traits			
Openness to Experience	.0278	-.0347	.0227**
Conscientiousness	-.0291	.0220	.0238**
Extraversion	.0119	-.0718	-.0264***
Agreeableness	-.0811**	.0864	-.0111
Neuroticism	-.0106	.0032	-.0088
Mediators			
Risk preference (R)	.0051	-.1926	-.0180
Environmental concern (EC)	.1432	.0729	.0754***
Moderators			
Income_cat[c] x R	.0449	.4951**	.0123
Income_cat[c] x EC	.2844	.2336	.0791
Control variables			
Income_cat[c]	-.2416	-.3888	-.1176**
Children	.1365***	.0504	-.0297***
Age	.0415	-.1241*	.0858***
Gender	.1435*	.1166	-.0688***
Education	-.0027	.0136	.0649***
Solar irradiance	.0883***	-.0321	
Building type	-.2472***	-.2554***	
N	6,044	1,581	3,665
Log-likelihood[d]	-19,768.38	-5,774.02	-13,077.98

Notes: [a]Log odds. [b]Ordered log odds. [c]Low-/medium-/high-income group (L/M/H) by using the first and third quartile of the equivalised income as thresholds. [d]Log-likelihood of the full equation model (including the regressions for risk preference and environmental concern). *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

A.5.2 Weighted personality traits

Table A.5 M1 mediation effects with weighted personality traits

	EE investment considerations[a]					EE adoptions[b]				
	R	EC	R+EC	Direct	Total	R	EC	R+EC	Direct	Total
Openness to Experience	.0085	**.0375***	**.0461***	.0329	**.0790***	**.0195***	**.0332***	**.0527***	-.0490	.0037
	[-.0026, .0205]	[.0265, .0506]	[.0308, .0636]	[-.0299, .0979]	[.0158, .1429]	[.0038, .0398]	[.0143, .0593]	[.0280, .0843]	[-.1601, .0649]	[-.1014, .1135]
Conscientiousness	.0013	-.0070	-.0057	-.0256	-.0313	.0037	-.0067	-.0031	.0244	.0214
	[-.0002, .0049]	[-.0149, .0003]	[-.0140, .0020]	[-.0863, .0369]	[-.0941, .0317]	[-.0019, .0152]	[-.0208, .0018]	[-.0177, .0100]	[-.0831, .1315]	[-.0880, .1287]
Extraversion	.0050	**-.0095***	-.0045	.0181	.0136	**0.0115***	**-.0109***	.0006	-.0548	-.0543
	[-.0014, .0122]	[-.0179, -.0023]	[-.0149, .0055]	[-.0451, .0818]	[-.0492, .0774]	[.0020, .0274]	[-.0278, -.0017]	[-.0186, .0175]	[-.1646, .0583]	[-.1645, .0584]
Agreeableness	-.0034	**.0127***	**.0094***	**-.0779***	**-.0685***	**-.0125***	.0068	-.0057	.0655	.0598
	[-.0088, .0009]	[.0058, .0216]	[.0008, .0193]	[-.1383, -.0132]	[-.1290, -.0036]	[-.0294, -.0022]	[-.0016, .0202]	[-.0247, .0109]	[-.0429, .1705]	[-.0475, .1635]
Neuroticism	-.0085	**.0086***	.0001	-.0090	-.0089	**-.0180***	.0057	-.0124	-.0005	-.0129
	[-.0201, .0027]	[.0014, .0167]	[-.0135, .0135]	[-.0699, .0538]	[-.0696, .0534]	[-.0391, -.0034]	[-.0032, .0204]	[-.0359, .0071]	[-.1139, .1087]	[-.1269, .0937]
N			6,044					1,581		
Number of considerations			1,581 (25.16%)							
Number of adoptions								224 (14.17%)		

Notes: This table presents the mediation effects through risk preference (R), environmental concern (EC), the direct and total effects (R+EC+Direct effect) for each personality trait on EE investment considerations based on Model 1, and EE adoptions for those households that have considered an investment. Bias-corrected 95% confidence intervals from 5,000 bootstrap samples are reported under each of the effects. For couple households, weighted personality traits and other individual-level characteristics are taken according to the individuals' share on household income. [a]Log odds. [b]Ordered log odds. $*p < 0.05$.

Table A.6 M2 mediation effects with weighted personality traits

Ordered log odds	R			EC			R+EC			Direct	Total		
	L	M	H	L	M	H	L	M	H		L	M	H
Openness to Experience	**.0492***	**.1282***	**.2073***	.0593	.1025	.1458	**.1084***	**.2308***	**.3531***	-.0472	.0613	.1836	.3059
	[.0202,	[.0453,	[.0672,	[-.0196,	[-.0997,	[-.1835,	[.0265,	[.0234,	[.0143,	[-.1583,	[-.0696,	[-.0511,	[-.0536,
	.0867]	.2379]	.3927]	.1408]	.3028]	.4614]	.1901]	.4454]	.6960]	.0645]	.1958]	.4237]	.6686]
Conscientiousness	.0092	.0240	.0388	-.0120	-.0208	-.0296	-.0028	.0032	.0092	.0230	.0202	.0262	.0322
	[-.0060,	[-.0146,	[-.0235,	[-.0526,	[-.1145,	[-.1754,	[-.0412,	[-.0822,	[-.1247,	[-.0880,	[-.0925,	[-.1083,	[-.1344,
	.0318]	.0870]	.1427]	.0039]	.0137]	.0251]	.0240]	.0725]	.1229]	.1352]	.1382]	.1608]	.1942]
Extraversion	**.0289***	**.0754***	**.1219***	-.0195	-.0337	-.0480	.0094	.0417	.0739	-.0579	-.0485	-.0162	.0160
	[.0095,	[.0220,	[.0332,	[-.0647,	[-.1385,	[-.2107,	[-.0408,	[-.0726,	[-.1068,	[-.1661,	[-.1661,	[-.1702,	[-.1926,
	.0613]	.1673]	.2722]	.0030]	.0218]	.0423]	.0476]	.1501]	.2552]	.0535]	.0681]	.1365]	.2263]
Agreeableness	**-.0315***	**-.0821***	**-.1327***	.0121	.0209	.0298	-.0194	-.0611	-.1029	.0675	.0481	.0064	-.0354
	[-.0642,	[-.1752,	[-.2885,	[-.0035,	[-.0123,	[-.0223,	[-.0569,	[-.1625,	[-.2734,	[-.0453,	[-.0687,	[-.1455,	[-.2394,
	-.0114]	-.0260]	-.0400]	.0545]	.1194]	.1839]	.0224]	.0384]	.0525]	.1673]	.1548]	.1458]	.1476]
Neuroticism	**-.0454***	**-.1185***	**-.1916***	.0101	.0175	.0249	-.0353	-.1010	-.1667	.0010	-.0344	-.1001	-.1657
	[-.0868,	[-.2302,	[-.3763,	[-.0051,	[-.0145,	[-.0243,	[-.0817,	[-.2254,	[-.3708,	[-.1102,	[-.1496,	[-.2595,	[-.3883,
	-.0178]	-.0387]	-.0576]	.0511]	.1094]	.1690]	.0101]	.0083]	.0089]	.1121]	.0819]	.0546]	.0484]

Notes: This table presents the mediation effects through risk preference (R), environmental concern (EC), the direct and total effects (R+EC+Direct effect) in ordered log odds for each personality trait on energy efficiency adoptions, conditionally on income per household member (low-/medium-/high-income group (L/M/H)), based on Model 2 ($N = 1,581$). The conditional effects are calculated for three different income groups with approximately the same number of households per group. The bias-corrected 95% confidence intervals from 5,000 bootstrap samples are reported under each of the effects. For couple households, weighted personality traits and other individual-level characteristics are taken according to the individuals' share on household income. $*p < 0.05$.

Appendix B

B.1 Collective model

Table B.1 Summary statistics for pro-environmental investments in the collective model

	N	*M*[a] / %	*SD*[b]	Min	Max
Solar PV system	3,974				
Yes	258	6.49%			
No	3,716	93.51%			
EE[c]/solar thermal collectors	3,974				
Yes	3,794	95.47%			
No	180	4.53%			
Personality traits					
Openness to Experience	3,974	4.60	1.02	1	7
Conscientiousness	3,974	5.90	0.76	1.33	7
Extraversion	3,974	4.85	0.90	1	7
Agreeableness	3,974	5.39	0.81	2	7
Neuroticism	3,974	3.65	1.00	1	7
Mediators					
Risk preference	3,974	4.73	1.97	0	10
Environmental concern	3,974	2.12	0.54	1	3
Control variables					
Income[d]	3,974	2.19	1.22	0.18	16.67
Children	3,974	0.36	0.77	0	6
Age	3,974	58.90	13.78	25	101
Gender	3,974	0.48	0.31	0	1
Education[e]	3,974	4.08	1.30	2	6
Solar irradiance[f]	3,974	104.98	4.21	100	112
Building type[g]	3,974	2.77	1.23	1	7

Note: [a]Mean. [b]Standard deviation. [c]Energy efficiency. [d]1,000 EUR/month/equivalised household size. [e]Highest education according to the ISCED-1997-classification (general elementary to higher education). [f]Annual sunshine duration averaged from 1980 to 2015 relative to the state with the lowest sunshine duration (= 100). [g]1 (*farm house*), 2 (*1-2 family house*), 3 (*1-2 family rowhouse*), 4 (*apartment in 3-4 unit building*), 5 (*apartment in 5-8 unit building*), 6 (*apartment in 9+ unit building*), 7 (*high-rise*).

Table B.2 Mediation of the Big Five personality traits on solar PV systems in the collective model

Log-odds	R	EC	R+EC	Direct	Total
Openness to Experience	-.02 [-.05, .01]	**.04*** [.02, .07]	.02 [-.02, .06]	.02 [-.12, .15]	.04 [-.09, .17]
Conscientiousness	.00 [.00, .01]	.00 [-.01, .01]	.00 [-.01, .01]	-.03 [-.16, .10]	-.03 [-.16, .11]
Extraversion	-.01 [-.02, .00]	-.01 [-.02, .00]	-.01 [-.03, .00]	-.07 [-.21, .07]	-.09 [-.23, .06]
Agreeableness	.01 [.00, .03]	.01 [.00, .02]	.01 [.00, .03]	-.03 [-.16, .11]	-.02 [-.14, .12]
Neuroticism	.01 [.00, .03]	**.03*** [.01, .05]	**.04*** [.02, .07]	.00 [-.13, .14]	.04 [-.08, .18]

Notes: This table presents the mediation effects through risk preference (R), environmental concern (EC) and the direct and total effects in log-odds for each personality trait on solar PV systems ($N = 3,974$). Bias-corrected 95% confidence intervals from 5,000 bootstrap samples are reported under each of the effects. $*p < 0.05$.

Table B.3 Mediation of the Big Five personality traits on energy efficiency and solar thermal collector installations in the collective model

Log-odds	R	EC	R+EC	Direct	Total
Openness to Experience	**.09*** [.06, .14]	**-.03*** [-.06, .00]	**.07*** [.02, .11]	**.25*** [.07, .43]	**.32*** [.14, .48]
Conscientiousness	.00 [-.02, .01]	.00 [-.01, .01]	.00 [-.02, .01]	-.15 [-.35, .04]	-.16 [-.35, .04]
Extraversion	**.04*** [.02, .07]	.00 [.00, .02]	**.04*** [.02, .07]	.08 [-.10, .24]	.12 [-.06, .28]
Agreeableness	**-.04*** [-.07, -.02]	.00 [-.02, .00]	**-.05*** [-.08, -.03]	.04 [-.14, .21]	.00 [-.18, .16]
Neuroticism	**-.05*** [-.08, -.03]	**-.02*** [-.04, .00]	**-.07*** [-.11, -.04]	.00 [-.18, .18]	-.07 [-.25, .10]

Notes: This table presents the mediation effects through risk preference (R), environmental concern (EC) and the direct and total effects in log-odds for each personality trait on energy efficiency (thermal insulation or windows that are at least double-glazed) and solar thermal collector installations ($N = 3,974$). Bias-corrected 95% confidence intervals from 5,000 bootstrap samples are reported under each of the effects. $*p < 0.05$.

Table B.4 Regressions of the mediation models for solar PV and energy efficiency (EE)/solar thermal collector installations in the collective model

	Solar PV system[a]	EE[b]/solar therm. collector[a]	Risk preference	Environmental concern
Openness to Experience	.02	.25**	.20***	.16***
Conscientiousness	-.03	-.15	-.01	.00
Extraversion	-.07	.08	.08***	-.02
Agreeableness	-.03	.04	-.09***	.02
Neuroticism	.00	.00	-.11***	.12***
Income	.03	-.06	.02	-.02
Children	.17*	.04	-.01	.01
Age	-.09	-.18	-.12***	.01
Gender	.53*	.22	.32***	-.17**
Education	.20**	.16	.05**	.03
Solar irradiance	.14*	-.14	-.05**	-.03*
Building type	-.73***	.02	-.01	.04*
Risk preference	-.10	.46***		
Environmental concern	.26***	-.18*		
N	3,974	3,974	3,974	3,974

Notes: [a]Log-odds. [b]Thermal insulation or windows that are at least double-glazed. *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

B.2 Supplementary regressions

Table B.5 Separate regressions for solar thermal collectors and energy efficiency investments

	Solar thermal collectors[a]	EE investment[ab]
Openness to Experience	-.11	.26**
Conscientiousness	.06	-.20*
Extraversion	-.03	.04
Agreeableness	-.03	.05
Neuroticism	.04	-.02
Income	.11*	-.04
Children	.19***	.05
Age	-.11	-.19*
Gender	.13	.38
Education	.28***	.13
Solar irradiance	.22***	-.14
Building type	-.58***	.03
Risk preference	.14*	.45***
Environmental concern	.17**	-.18*
N	3,945	3,947

Notes: [a]Log-odds. [b]Thermal insulation or at least double-glazed windows. *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

Appendix C

Table C.1 Comparison between the internet-based personality survey and UK Census 2011 by socio-demographic variables for all postcode districts

	Internet-based personality survey n=374,743					UK Census 2011 N=59,302,390					Difference of means	p-value[d]
	Mean	Median	SD	Min	Max	Mean	Median	SD	Min	Max		
n or N per postcode district	144.69	120	120.19	1	1,138	22,896.68	20,946	16,328.56	52	154,233		
Median age	35.56	36	5.08	19	65	41.70	42	5.93	22	64	-6.14	0.000
Education[a]	4.06	4.04	0.47	1	6	3.52	3.50	0.47	2.07	5.56	0.54	0.000
Median income[b]	387.28	373.55	59.99	286.12	865.92	499.82	479.29	72.64	365.30	1,006.90	-112.54	0.000
Gender (prop.[c] male)	0.35	0.35	0.09	0	1	0.49	0.49	0.01	0.42	0.64	-0.14	0.000
Prop. Black	0.01	0	0.03	0	0.39	0.02	0	0.05	0	0.43	-0.01	0.000
Prop. Asian	0.03	0.01	0.06	0	0.75	0.05	0.01	0.09	0	0.74	-0.02	0.000
Prop. White	0.94	0.97	0.09	0.18	1	0.92	0.97	0.13	0.11	1	0.03	0.000
Prop. Mixed	0.02	0.01	0.02	0	0.5	0.02	0.01	0.02	0	0.26	0.00	0.132

Notes: This table compares the postcode district means between the internet-based personality survey and UK Census 2011 by socio-demographic variables for 2,590 postcode districts. [a]1 (No qualification), 2 (Level 1 qualification), 3 (Level 2 qualification), 4 (Apprenticeship), 5 (Level 3 qualification), 6 (Level 4 qualification and above). [b]GBP per week measured at the higher local authority district (LAD) level since income data are not available for postcode districts in the Census 2011 data. [c]Proportion. [d]p-value of the two-sided Wilcoxon matched-pairs signed-ranks test.

Table C.2 Summary statistics solar PV installations, Big Five personality traits and control variables for the large postcode district sample

Variables	Mean	SD	Min	Max	Source
Number of domestic solar PV installations per number of dwellings by postcode district	0.01	0.01	0	0.13	OFGEM[d]
Big Five personality traits (5-item Likert scale)					
Openness to Experience	3.67	0.06	3.52	4.05	UoC/BBC[e]
Conscientiousness	3.66	0.05	3.38	3.77	UoC/BBC
Extraversion	3.23	0.05	3.06	3.48	UoC/BBC
Agreeableness	3.75	0.03	3.61	3.84	UoC/BBC
Neuroticism	2.97	0.04	2.77	3.12	UoC/BBC
Dwelling type[a]	2.33	0.51	1.05	3.98	UoC/BBC
Median income (GBP per week measured at the local authority district)	500.00	72.50	365.30	910.20	ONS/NRS[f]
Median age	41.68	5.94	22	64	ONS/NRS
Gender (prop.[b] of male population)	0.49	0.01	0.42	0.64	ONS/NRS
Education[c]	3.52	0.47	2.07	5.49	ONS/NRS
Commuting population (prop.)	0.91	0.06	0.43	0.99	ONS/NRS
Feed-in tariff (p/kWh)	24.15	13.66	10.35	41.58	OFGEM

Notes: Each variable has 122,928 observations, where an observation is a postcode district month.

[a] 1 (Detached house/bungalow), 2 (semi-detached house/bungalow), 3 (terraced and end terraced house/bungalow), 4 (purpose-built block of flats/maisonettes or equivalent), 5 (caravan or other mobile or temporary structure).

[b] Proportion.

[c] 1 (No qualification), 2 (Level 1 qualification), 3 (Level 2 qualification), 4 (Apprenticeship), 5 (Level 3 qualification), 6 (Level 4 qualification and above).

[d] Office of Gas and Electricity Markets. [e] University of Cambridge/British Broadcasting Corporation. [f] Office for National Statistics/National Records of Scotland.