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SOLAR PANEL INVESTMENT DETERMINANTS

Exploring the determinants to invest in solar panel (PV) energy on a Dutch household level

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Abstract

This study embarks on an in-depth exploration of the factors influencing solar panel adoption in Dutch households, utilising data from the WoOnonderzoek 2021 survey. Through binary logistic regression analysis and a comprehensive literature review, key determinants impacting the decision to adopt solar panels were identified. The research underscores the significance of sustainability-related factors, household characteristics and socio-demographic factors as primary influencers in the decision-making process for solar panel adoption.

The analysis categorises influential factors into five groups: economic factors, socio-demographic factors, housing characteristics, sustainability-related factors and location-specific factors. Among these, the presence of electric vehicles, house size, and the age of the household head were identified as notable determinants. Contrary to common assumptions, economic factors such as disposable income and monthly electricity costs emerged as having a less pronounced impact, providing new insights into the dynamics of solar panel adoption in the Dutch context.

This thesis contributes valuable perspectives to the academic discourse on renewable energy adoption and offers practical insights for policy-making and sustainability initiatives. By pinpointing the factors that facilitate or hinder solar panel adoption, this study aids in formulating targeted strategies to accelerate the transition to sustainable energy sources within Dutch households.

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1. Introduction

1.1. Background and context

The urgency of addressing climate change and transitioning to sustainable energy sources cannot be overstated. The consequences of inaction are becoming increasingly evident, with rising global temperatures, extreme weather events, and ecological disruptions posing significant threats to human societies. In this context, the adoption of solar panels within Dutch households carries profound social relevance. One of the most significant social drivers for solar panel adoption is the potential to reduce carbon emissions and mitigate climate change. Solar panels produce electricity with virtually no greenhouse gas emissions, making them a vital tool in reducing the carbon footprint of energy production (Jacobson and Delucchi, 2011). As the Netherlands seeks to meet its climate targets and reduce its reliance on fossil fuels, encouraging the adoption of solar panels is a critical step toward a more sustainable future.

Furthermore, solar panel adoption can enhance energy security and independence at both the household and national levels. By generating electricity from sunlight, households can reduce their reliance on external energy sources, providing a measure of resilience in the face of energy supply disruptions. At the national level, a distributed network of solar panels contributes to a more robust and diversified energy infrastructure, reducing vulnerabilities associated with centralised power generation.

Moreover, solar panel adoption carries significant economic benefits for Dutch households. By generating their electricity, homeowners can lower their electricity bills, providing financial relief. Additionally, various government incentives and subsidy programs are available to support solar panel installations, further enhancing their economic attractiveness. By installing and maintaining solar panels, households become part of the broader innovation ecosystem driving improvements in solar technology. This participation

in technological advancements contributes to the overall progress of sustainable energy solutions.

1.2. Scientific status quo

The existing body of research on solar panel adoption has made significant strides in identifying key factors that influence adoption decisions.

1.2.1. Economic

Economic factors, including income levels, have been thoroughly examined in various studies. For instance, Ahmar et al. (2022) found that higher income levels were associated with a greater inclination to invest in solar panels. On the other hand, Best and Esplin (2023) noted that the effect of income on solar panel adoption in the United States was limited and context-dependent.

1.2.2. Socio-demographic

Socio-demographic variables have also been recognized as influential factors. Ahmar et al. (2022) observed that household age played a significant role in solar panel adoption, with older households being more likely to invest in solar energy. Contrary, Best and Esplin (2023) found that household age had a non-linear relationship with adoption, highlighting the complexity of age-related factors.

1.2.3. Housing characteristics

Housing characteristics, such as household size and available space, have been acknowledged as contributing to adoption choices. Ahmar et al. (2022) identified these factors as key determinants in solar panel adoption decisions in rural Pakistan, where the availability of adequate space was crucial for installation.

1.2.4. Sustainability-related

Sustainability-related factors, rooted in the Value-Belief-Norm theory (Stern et al., 1999), have been identified as significant determinants but require further exploration. Vasseur and Marique (2019) highlighted the role of environmental consciousness in determining energy-saving investments, such as solar panels, among households.

1.2.5. Location-specific

Location-specific dynamics have also been studied, revealing regional variations in adoption patterns. Zhang, Ballas and Liu (2023) explored how the physical features of homes, such as house size, can affect the propensity of households within a neighbourhood to adopt solar panels in the Netherlands.

1.2.6. Limitations and research gap

Despite the progress made, there are limitations within the existing research landscape. First, there is a need to deepen the understanding of the depth to which these identified factors influence solar panel adoption. While these factors have been recognized, the extent of their impact remains a subject of exploration. For instance, while income has been identified as a factor, the precise degree to which income influences adoption decisions in diverse contexts requires further investigation.

Second, the research conducted primarily in global contexts may not fully capture the unique socio-economic, environmental, and policy factors shaping adoption in the Netherlands. Dutch-focused research has provided valuable insights, but limitations persist in offering a comprehensive view of the depth of influence of these factors in the Dutch setting. Therefore, a research gap exists in assessing the magnitude to which these determinants operate within the specific socio-economic and environmental context of Dutch solar panel adoption.

1.3. Research problem

This study addresses a critical research problem: understanding the key determinants that influence the adoption of solar panels in Dutch households. The research question thus is as follows: *What are the key determinants influencing the decision to invest in solar panels at the household level in the Netherlands?*

It does so with both social and scientific relevance, as the adoption of solar panels carries significant implications for mitigating climate change, enhancing energy security, and fostering economic growth. Moreover, the research contributes to the academic discourse on renewable energy adoption by filling knowledge gaps and providing tailored insights for the Dutch context. By embarking on this journey, we aim to unravel the intricacies of solar panel adoption and pave the way for a more sustainable and resilient energy future.

2. Theoretical Framework

2.1. Literature review

The pursuit of a comprehensive resolution to the research inquiry necessitated a thorough and meticulous exploration of the existing body of literature. This exploration served a dual purpose: firstly, to identify determinants that have previously been associated with the adoption of solar panels, and secondly, to unveil the underlying behavioural and determinative factors entwined with environmental consciousness and the proclivity towards embracing sustainability initiatives at the grassroots level of citizenry.

2.1.1. Identifying determinants

Broadly, the identified determinants can be categorised into five distinct factor groups, each bearing significance in understanding the dynamics of solar panel adoption. These categorizations serve as a valuable framework for dissecting the multifaceted landscape of determinants shaping households choices regarding sustainable energy solutions.
The five pivotal factor groups encompass economic factors, socio-demographic factors, housing characteristics, sustainability-related factors, and location-specific factors. This classification framework, drawn from the extensive review of literature, serves as a guide for identifying variables within the Woononderzoek 2021 dataset that can be used as proxies for these determinants and factors.

2.1.2. Factors in Germany

The framework for classification employed in this study is inspired by the research of Rausch and Suchanek (2021) as they provide valuable insights into the various factors influencing investment decisions in solar power technologies.

By systematically organising the diverse determinants into these factor groups, this review seeks to provide a perspective on the interplay of factors that guide individuals' choices in the realm of solar panel adoption, thereby enhancing the depth of understanding in this critical domain of sustainability and renewable energy, all by doing a statistical analysis of quantitative data.

The study's conclusions reveal a hierarchy of factors that wield varying degrees of influence on decision-making at the household level in Germany. Quality of life emerges as

the foremost determinant, exerting the most substantial impact on individuals' choices. Following closely, the presence of renters within a specific locality also plays a significant role, although its relevance may be limited in the context of the current research, which exclusively focuses on the investment decisions of homeowners in the Netherlands.

Moreover, regional disparities stand out as another influential factor, particularly in Germany, where marked regional differences are observed and the south seems to be outstanding, particularly in rural areas. However, this factor's importance may be less pronounced in the Netherlands due to the relatively reduced regional disparities compared to Germany, apart from the Dutch rural-urban division. Finally, proximity to industrial areas emerges as a notable factor, although it lies outside the scope of the present study, which does not investigate this aspect.

2.1.3. Determinants in rural Pakistan

A recent study in Pakistan that was executed using surveys and a statistical analysis of quantitative data found that several factors influence households' decisions to invest in solar photovoltaic technology in rural areas. Specifically, higher income levels, the age of households, education levels, household size, and the availability of adequate space were identified as key determinants (Ahmar et al., 2022).

Income levels emerged as crucial determinants, indicating that households with higher incomes are more inclined to invest in solar panels. Secondly, socio-demographic factors, like education levels, exerted a considerable influence on adoption decisions, confirming the notion that educated people tend to be more environmentally conscious (Meyer, 2015). Lastly, housing characteristics, like household size and available space, also played roles in shaping households' choices regarding solar panel investments (Ahmar et al., 2022).

2.1.4. Insights from U.S. research

The findings of the research conducted by Ahmar et al. (2023) exhibit similarities with an American study conducted by Best and Esplin (2023) which analyses the factors influencing the adoption of solar panels in American households. In terms of economic factors, contrary to the Pakistan-based study, the American study indicated that the effect of income was limited and not always significant for solar panel adoption. This difference suggests that the role of income may be contingent on specific regional contexts and policy measures.

Regarding socio-demographic factors, both studies identified household age as a relevant determinant. However, while the Pakistan-based research demonstrated that older households were more likely to invest in solar energy, the American study found a non-linear relationship between age and adoption. This contrast highlights the complexity of age-related factors and suggests that cultural and socio-economic contexts may play a role and underscore the need for region-specific research. The American study was conducted with statistical analyses and used data from the U.S. Housing Survey, a dataset akin to the Woononderzoek 2021 employed in this research.

2.1.5. Rural Poland

Research conducted by Klepacka, Florkowski, and Meng (2018) about Poland focused on rural household investment in solar panels, aiming to understand the reasons behind participation in an EU-funded subsidy program for solar panels. The study collected data through surveys conducted among passive solar panel owners in rural areas of Poland. Analytical methods including correlation coefficients and ordered logit techniques were employed to analyse the probability changes in the importance of certain investment reasons. Notably, economic factors such as subsidies, total installation costs and socio-demographic factors including household incomes distributed across various income categories emerged as significant determinants. Additionally, housing characteristics, such as average living space and concerns about future energy costs, played a role in influencing investment decisions. Regionally, the interest in the solar panel program was widespread across four provinces, indicating a regional inclination toward sustainable energy investments.

2.1.6. Dutch rebound effect

Aydın et al. (2019) conducted a study in Texel that demonstrated a significant 7.7% increase in total electricity consumption as households adopted solar panels. The concept of the "solar PV rebound effect," challenges traditional assumptions about the negative relationship between solar energy adoption and energy consumption. It suggests that households may perceive higher energy usage as a beneficial outcome of their solar panel investment, potentially making solar energy more attractive as a viable and sustainable energy source. Furthermore, the observed shift in consumption patterns towards periods of higher solar electricity production indicates that Dutch households are actively adapting their energy usage behaviours in response to solar energy availability. This adaptability may

reflect an increased awareness of the potential cost savings and environmental benefits associated with solar energy adoption or just a desire to consume more electricity and thus finding cheaper alternatives. Thus, the study's findings underscore the importance of considering not only the initial cost of solar panel installation but also the dynamic nature of energy consumption when evaluating the determinants for households to invest in solar energy. It prompts further exploration into the intricate motivations and decision-making processes that underlie Dutch households' choices regarding sustainable energy investments in a changing energy landscape.

2.1.7. Sustainability focus

Within the realm of sustainability and its relationship with investments in energy saving measures in Dutch households, the study by Vasseur and Marique (2019) unveils a compelling narrative. It highlights the role of environmental consciousness in determining energy saving investments, such as solar panels as well as a link to sustainable transport like using electric cars. Dutch households with a strong sustainability ethos are more inclined to embrace energy-saving measures in or outside of their house, including solar panels and electrical cars. The usage of electrical cars could thus be a determinant for the presence of solar panels in a Dutch household. Employed using a research methodology involving descriptive and binary logistic regression analyses, the study delves into the web of factors influencing these investment decisions; it mostly confirms all of the aforementioned studies and their important factors like socio-demographic and economical ones, but it emphasises the environmental consciousness and thus gives us another factor to think about as mentioned before; the sustainability-factor.

The sustainability factor is rooted in the Value-Belief-Norm (VBN) theory by Stern et al. (1999), which suggests that the intrinsic values and environmental beliefs of individuals shape their personal norms, thereby influencing their decisions towards sustainable practices like investing in solar panels and using electric vehicles. The 'sustainability-factor' essentially encapsulates how commitment to sustainability transcends socio-demographic and economic considerations, driving households towards environmentally responsible choices. This factor plays a critical role in understanding the motivations behind Dutch households' inclination to adopt solar energy and electric vehicles, adding a nuanced dimension to the discourse on sustainable energy investments.

2.1.8. Dutch neighbourhood level solar impact

A study by Zhang, Ballas and Liu (2023) provides an in-depth analysis of the factors influencing the adoption of residential solar photovoltaic (PV) systems at the neighbourhood level in the Netherlands. This research is particularly interesting as it has its focus on a neighbourhood-level perspective. One of the key aspects of this study is its emphasis on housing characteristics as a crucial factor. They explore how the physical features of homes can affect the propensity of households within a neighbourhood to adopt solar panels. This approach acknowledges that the physical attributes of a house can significantly influence the feasibility and desirability of installing solar panels. Furthermore, the study delves into location-specific factors, particularly the role of population density in renewable energy adoption. They argue that the density of a neighbourhood can have a substantial impact on solar panel adoption, potentially due to factors such as social norms, visibility of solar panels, and peer influence. This insight is crucial as it underscores the importance of the social and physical environment surrounding a household in the decision-making process for renewable energy adoption. They employ rigorous research methodologies, including detailed data collection and sophisticated spatial analysis techniques. By focusing on neighbourhood-level determinants, the study differs slightly from this one. It highlights the importance of considering spatial factors and local contexts in understanding and promoting solar energy adoption.

2.1.9. Age

Research on sustainable investment preferences among robo-advisor clients by Faradynawati and Söderberg (2022) align with previous research conducted by Ahmar et al. (2022). Faradynawati and Söderberg's findings suggest that age may also play a significant role in sustainable investment preferences, showing that older people are more inclined to prefer sustainability. This provides a more comprehensive understanding of which socio-demographic factors in particular influence the adoption of sustainable technologies like solar panels.

2.3. Framework for analysing Dutch context in different factors

The amalgamation of insights gleaned from diverse international studies has provided us with a theoretical framework, conceptualised in Figure 1, tailored to address our research question.

Economic factors, such as income levels and subsidies, have consistently emerged as pivotal determinants in various studies (Klepacka et al., 2018; Best and Esplin, 2023). In the Dutch context, a thorough examination of these economic factors is crucial, particularly regarding the effectiveness of government subsidies and incentives in shaping investment choices.

Socio-demographic factors, encompassing variables like age, education, and household size, have consistently shown their influence on solar panel adoption decisions (Ahmar et al., 2022; Faradynawati and Söderberg, 2022). Our research will delve into how these socio-demographic factors manifest in the Netherlands.

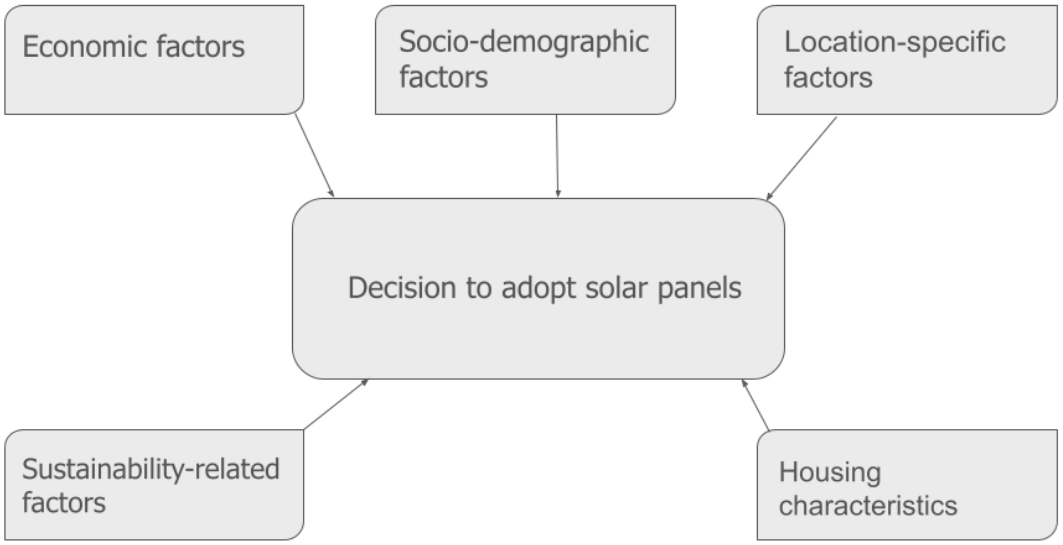
Housing characteristics, including things like house size, have also emerged as significant determinants, with implications for the feasibility of solar panel installation (Ahmar et al., 2022; Zhang et al., 2023; Klepacka et al., 2018).

Sustainability-related factors, rooted in the Value-Belief-Norm (VBN) theory (Stern et al., 1999), emphasise the role of environmental consciousness and personal beliefs in shaping sustainable energy choices (Vasseur and Marique, 2019).

Location-specific factors, including population density and peer influence, have been identified as determinants in the adoption of solar panels within specific local contexts (Zhang et al., 2023).

Integrating these determinant factors into this research helps fill a crucial gap in the existing literature. While prior studies have provided insights into solar panel adoption worldwide, there is a specific need to examine these factors at the Dutch household level. Notably, much of the Dutch research has focused on the neighbourhood level, leaving a gap in understanding individual household decisions. By synthesising insights from international and Dutch-specific studies, this framework guides our investigation into the intricate motivations and decision-making processes guiding Dutch households' choices regarding sustainable energy investments. Our aim is to offer a nuanced understanding of these factors within the Dutch context, potentially
informing targeted policies and initiatives promoting solar panel adoption in the country.

Figure 1: Conceptual model



2.4. Hypothesis

Thus the hypothesis is that solar panel adoption in Dutch households is influenced by a complex interplay of economic, socio-demographic, housing-characteristic, sustainability-related, and location-specific factors. Specifically, we hypothesise that variations in income levels, household age, household size, education, house size, environmental consciousness, and neighbourhood characteristics, including population density, collectively contribute to the likelihood of solar panel adoption in the Netherlands.

3. Methodology

3.1. Binary Logistic Regression

Binary logistic regression is the fundamental statistical approach employed in this study to investigate the determinants of solar panel adoption within Dutch households. This section provides an outline of the regression specification, notation definitions and the manner in which a multitude of independent variables encompassing the five factor groups discussed in the literature review and theoretical framework exert influence on the dependent variable.

3.2. Regression specification

At the core of our analysis lies binary logistic regression, a statistical method to model the binary dependent variable, representing the presence (coded as 1) or absence (coded as 0) of solar panels in Dutch households. This is a widely employed statistical technique when dealing with dichotomous dependent variables. In our context, it allows us to explore the factors that influence whether households adopt solar panels. The essence of this methodology lies in estimating the probability of an event occurring, in our case, the adoption of solar panels, based on a set of independent variables. The model is as follows:

$$P(Y = 1) = \frac{1}{1 + e\text{^}-(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_k X_k)}$$

This equation represents the probability (P(Y = 1)) of Dutch households adopting solar panels (Y=1). It is shaped by a set of coefficients (β_0,β_1,β_2,...β_k) associated with independent variables (X_1,X_2,....,X_k). These coefficients capture the impact of various factors on the likelihood of solar panel adoption. Through careful analysis of the coefficients (β) and their corresponding independent variables (X), we aim to gain an understanding of the determinants of solar panel adoption.

3.3. Dependent variable

The dependent variable in this study is binary, representing the presence or absence of solar panels in Dutch households. It is denoted as "Solar Panel Adoption" with values coded as 1 (presence) or 0 (absence).

3.4. Independent variables

A diverse range of independent variables are incorporated that may influence the likelihood of solar panel adoption. These variables fall into several categories.

3.4.1. Economic factors

Within this category, we examine two key variables. First, we consider "Disposable income," which is quantified in thousands of euros, providing insight into household income

levels. Second, we investigate "Monthly electricity costs," denoting the monthly expenses in euros related to electricity consumption.

3.4.2. Socio-demographic factors

This category encompasses several variables that shed light on the demographic composition of households. We begin with "45+ of age (respondent)", a binary variable indicating whether the household's respondent is older than 45. "Higher educated" is another binary variable, signifying higher education attainment, in this case whether the respondent has at least attended HBO (University of Applied Sciences) or University. We also include "Number of children", which is an ordinal categorical variable representing the number of children in the household, ranging from 1 to 4, where 4 indicates 4 or more children, a similar variable called "Household size" is a categorical variable reflecting the total number of individuals in the household, with categories ranging from 1 to 5, where 5 indicated more than 5 number of people in the household.

3.4.3. Housing characteristics

This category involves variables related to the housing environment. "Year of construction" provides information on the construction year of the house. "Number of rooms" indicates the quantity of rooms within the house. "House size" is a binary variable, with a value of 1 indicating a house size exceeding 120 square metres. Additionally, “Farm” denotes whether or not the house of the respondent is a farmstead. Lastly, "Property value" represents the value of the property (WOZ-waarde in Dutch, the worth of the real estate dictated by the Dutch municipality, mostly for taxation), this one is measured in 100.000s of euros.

3.4.4. Sustainability-related factors

In this category, we explore variables that pertain to sustainability and eco-conscious behaviours within households. "Electrical cars present" is a binary variable, with a value of 1 denoting ownership of electric vehicle(s). "Water usage" reflects the household's water consumption, while "Electricity use" quantifies the household's electricity consumption in 1000s of kWh.

3.4.5. Location-specific factors

This category focuses on the geographical and/or spatial contexts of households. "Population Sparsity" indicates the urban or rural nature of the neighbourhood, with values

ranging from 1 (very urbanised) to 5 (very sparsely populated/rural). "Livability score" measures the level of livability and quality of life. Finally, "Rural residence" is a binary variable, with a value of 1 indicating residence in a rural area or village.

3.5. Explanation of variables

The dependent variable 'Solar Panel Adoption' is inherently binary, capturing a straightforward presence or absence scenario. In contrast, the suite of independent variables encompasses binary, continuous, and categorical formats. Binary variables like 'Higher education' and 'Electrical cars present' are dichotomous, taking values of 0 or 1. Continuous variables, such as 'Disposable Income' and 'Monthly electricity costs', are represented on continuous scales, indicating varying levels of income and expenses. Categorical variables like 'Household size' and 'Number of children' adopt ordinal groupings but function similarly to continuous variables in our model, providing discrete, ordered categories of analysis.

3.6. Explaining variation in the dependent variable

The binary logistic regression analysis employed aims to show the factors contributing to the presence or absence of solar panels in Dutch households. By systematically examining the relationships between various independent variables and solar panel adoption, our objective is to uncover the key determinants influencing households' decisions to adopt solar energy systems. Within this analytical framework, the logistic regression model is used to estimate the probabilities of households having solar panels, providing insights into the direction and significance of these associations. Additionally, the model yields odds ratios, which offer valuable information on how changes in independent variables affect the likelihood of solar panel adoption.

4. Data

4.1. Data overview

The primary data source integral to this research is the "WoOnonderzoek 2021" survey, in English known as the "Housing Survey Netherlands 2021." This nationwide survey is conducted triennially and is overseen by the Dutch Ministry of the Interior and Kingdom Relations. The principal objective of this survey is to collect robust statistical data concerning the housing situations, preferences, and requisites of the Dutch populace. Its domain encompasses a broad spectrum of housing-related facets, encompassing household composition, housing conditions, living expenditures, housing preferences, and residential mobility. This survey prioritised ethical considerations, including data privacy, participant consent, confidentiality, and anonymity, with handling of sensitive data to safeguard individual rights and privacy.

4.2. Institutional background

The "WoOnonderzoek" survey represents a crucial component of the Netherlands' extensive housing research tradition. It was initiated in 2006, succeeding the "Woningbehoefteonderzoek" (Housing Needs Survey), which had been conducted since 1981. The survey is triennially administered and has undergone administrative changes, with various entities, including ABF Research and the Central Bureau of Statistics (CBS), assuming responsibility for its execution over the years. Since 2009, the CBS, in partnership with the Ministry of the Interior and Kingdom Relations, has been entrusted with the survey's implementation (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties & CBS, 2021).

4.3. Data cleaning procedure

To ensure data reliability and consistency, a meticulous data cleaning process was implemented. The key steps included the exclusion of renters, since narrowing it to homeowners seemed to be a more logical choice considering investments are almost solely done by homeowners. There was also an exclusion of specific housing types: households

residing in apartments, homes with shared kitchens, and those classified under the "other" category were omitted based on predefined criteria, this because they have a high probability of shared roofs. The illogical outliers were also removed in variables like water and electricity usage, as well as disposable income for instance, where there were some negative responses.

Table 1: Data descriptives

Independent Numeric Variable	Description	Factor	Minimum	Maximum	Mean	Std. Deviation	Mode
Water usage	Average monthly water usage	Sustainability-related	59	363	123.840	36.058	
Electricity use (1000 kWh)	Annual electricity usage in thousands of kWh	Sustainability-related	0.01	11.250	3.358	1.579	
Household size	Number of people residing in the household	Socio-demographic	1	5			2
Number of children	Number of children in the household	Socio-demographic	0	3			0
Property value (thousands of €)	Property value in 100.000s of euros	Housing characteristics	0.26	48.75	3.586	1.891	
Number of rooms	Total number of rooms in the house	Housing characteristics	1	5			4
Year of construction	Year in which the house was constructed	Housing characteristic	1005	2021	1970.210	40.450	
Monthly electricity costs	Average monthly costs for electricity	Economic	26	235	88.97	28.985	
Disposable income	Annual disposable income in thousands of euros	Economic	0.04	1306.18	62.419	55.146	
Livability-Score	Score indicating the livability of the area	Location-specific	3.56	4.76	4.1623	0.118	
Population sparsity	Measure of population sparsity in the area (1-5)	Location-specific	1	5			2

Independent Binary Variable	Description	Factor	Percent (Yes)

Electrical cars present	Presence of electric cars	Sustainability-related	6.6%
45+ of age (Respondent)	Age of the respondent is 45 years or older	Socio-demographic	73.2%
Higher educated	Respondent has completed higher Dutch education (HBO/University)	Socio-Demographic	42.7%
House >120m2	House size greater than 120 square metres	Housing characteristics	64.8%
Farm	The residence is a farm	Housing characteristics	1.7%
Rural-area or a village	Residence in a rural area or a village	Location-Specific	51.6%

Dependent Binary Variable	Description	N	Percent (Yes)
Solar Panel Presence	Presence of solar panels in a household	21803	30.2%

5. Results

5.1. Research implementation

The results of the binary logistic regression analysis are shown in Table 2, conducted on a comprehensive dataset comprising 21,803 households. This dataset distinctly categorises households based on the presence or absence of solar panels, setting the stage for a nuanced exploration of the determinants influencing solar panel adoption.

The analysis encompasses 15,219 households without solar panels and 6,584 with solar panels. This diverse sample allows for a robust assessment of the factors contributing to solar panel adoption among Dutch households.

Central to our analysis are two key statistical measures: the odds ratios (Exp(B)) and Wald statistics (Wald). The odds ratios offer insights into the impact of each predictor variable on the likelihood of adopting solar panels. An odds ratio greater than 1 suggests a positive influence on adoption likelihood, while a value less than 1 indicates a negative impact. The Wald statistics further provide a measure of the significance of these predictor variables, highlighting their relative importance in the model.

Table 2 presents the detailed outcomes of this analysis. It lists the coefficients, standard errors, Wald statistics, significance levels, and odds ratios for each variable considered in the study. This table is pivotal in understanding the intricate dynamics at play

in the decision-making process of households regarding solar panel adoption. The following discussion will interpret these results, shedding light on the most influential factors driving or hindering the adoption of solar panels in the Dutch context.

Table 2: Factors influencing Solar Panel adoption

Variable	B	S.E.	Wald	Sig.	Exp(B)	Factor
Monthly electricity costs	0.028	0.012	4.979	0.026	1.028	Economic
Disposable income (1000s of €)	0.001	0.000	6.279	0.012	1.001	Economic
Property-value (100.000s of €)	0.070	0.011	39.273	<.001	1.073	Housing characteristics
House >120m2	0.520	0.039	181.454	<.001	1.681	Housing characteristics
Farm	0.119	0.132	0.809	0.369	1.126	Housing characteristics
Number of rooms	0.071	0.012	33.109	<.001	1.073	Housing characteristics
Year of construction	0.009	0.001	275.940	<.001	1.009	Housing characteristics
Population sparsity	0.148	0.017	71.701	<.001	1.159	Location-specific
Rural-area or a village	-0.040	0.043	0.866	0.352	0.960	Location-specific
Livability-score	-0.127	0.160	0.625	0.429	0.881	Location-specific
Household size	0.704	0.054	171.457	<.001	2.022	Socio-demographic
45+ of age (Respondent)	0.425	0.040	112.264	<.001	1.530	Socio-demographic
Higher educated	0.243	0.034	52.106	<.001	1.276	Socio-demographic
Number of children	-0.722	0.047	237.812	<.001	0.486	Socio-demographic
Electrical cars present	0.872	0.062	197.862	<.001	2.392	Sustainability-related
Water usage	0.006	0.001	25.904	<.001	1.006	Sustainability-related
Electricity use (1000kWh)	-0.954	0.229	17.294	<.001	0.385	Sustainability-related

Constant	*-21.377*	*1.391*	*236.164*	*0.0011*	*0.0*

5.2. Different factors

In the subsequent subsections, various factors that exert influence on the adoption of solar panels are examined. These factors encompass sustainability-related, socio-demographic, housing characteristics, economic and location-specific factors. By dissecting each factor's role and significance, the aim is to provide an insight into the intricate landscape of solar panel adoption determinants. This comparative approach helps shed light on both the consistency and divergence between our findings and prior research, providing a comprehensive perspective on this topic.

5.2.1. Sustainability-related

A distinctive trend emerges among Dutch households, particularly among electric car owners. This group demonstrates a markedly higher propensity for solar panel adoption, evidenced by a 138.5% increased likelihood compared to those without electric vehicles. This phenomenon is particularly noteworthy given the overall low ownership rate of electric cars at 6.6%. Such findings suggest a committed subset of the population who, despite broader trends of reluctance towards high-cost sustainable solutions, are actively pursuing sustainable living practices, integrating both advanced transportation and renewable energy technologies. This confirms the study by Vasseur and Marique (2019), highlighting a subgroup of 1.6% that is actively engaged in advanced sustainable practices, owning both electric cars and solar panels.

Higher water usage seems to correlate with a slightly bigger chance of the presence of solar panels, however this effect, as shown by a low Wald statistic of 25.904, is nearly negligible. On top of that, a higher electricity use seems to correlate with a lower likelihood of having solar panels, contrary to the ‘Dutch rebound effect’ which has told us that people tend to use 7.7% more electricity when they have solar panels, as shown in the study done on Texel (Aydın et al., 2023). This phenomenon can be elucidated by considering that individuals who exhibit greater environmental consciousness tend to manifest this commitment in their daily activities, as indicated by studies conducted by Stern et al. (1999) and Vasseur and Marique (2019).

5.2.2. Socio-demographic

Increased household size significantly correlates with a higher likelihood of installing solar panels, a relationship that holds true even after accounting for the presence of children. Interestingly, having more children within a household tends to decrease the likelihood of solar panel installation. This nuance suggests that while larger households typically have greater energy needs and may see more value in solar energy, the specific demands and priorities associated with child rearing can offset this trend.

Moreover, the analysis sheds light on the influence of household age: respondents aged 45 or older are 53% more likely to have solar panels, supporting Faradynawati and Söderberg's (2022) observation that older people are more inclined towards sustainability investments, controlling for other variables, the only explanation of this phenomenon might be that they tend to have a more long term view on solar panel investments and they see it as a wise investment with potential long-term benefits, both financially and environmentally. In addition, higher education levels increase the probability of adoption by 27.4%, this is similar to the study done by Ahmar et al. (2022) where each year of education increases the likelihood by 42%, however, this difference can be explained by the cultural and educational differences between rural Pakistan and the Netherlands. This trend may reflect the general observation that individuals with higher education are more environmentally conscious, as supported by the findings of Meyer (2015) among Europeans.

5.2.3. Housing characteristics

People living on a farm is insignificant at the 0.05 level thus we cannot refute the German study which shows an indirect link between rurality and higher solar panel-adoption rates by their suggestion that rurality may influence solar panel adoption, through the correlation between political tendencies, industrialisation, and solar panel investment (Rausch and Suchanek, 2021). Every 100.000 euros of extra property value (WOZ) of the house increases the likelihood of having solar panels by 7.3%, this implies that a higher property value correlates with a greater propensity for solar panel installation, though concerns about increased property taxes due to higher WOZ values might moderate this inclination, severely limiting the sustainability choices for Dutch households by this governmental taxation (Vereniging Eigen Huis, 2024).

Houses over 120 square metres have a 68.1% higher likelihood of having solar panels, and each additional room increases this likelihood by 7.3%. In comparison, the Pakistani study by Ahmar et al. (2022) shows a coefficient of 0.8358 for 'space available,'

indicating a positive correlation between space availability and solar panel adoption but without specific percentages related to house size or room number, which have coefficients of 0.52 and 0.071 in our analysis respectively. Together they confirm a link between more space and higher solar panel adoption, albeit measured differently, confirming the necessity for space availability when installing solar panels (Ahmar et al., 2022).

The year of construction emerges as a significant determinant, demonstrating a yearly increase of 0.9% in the likelihood of solar panel adoption. This approach further expands upon research by Zhang et al. (2023), which primarily classified houses into binary categories based on construction year. It is important to note that our findings reveal a larger positive effect (0.9%) associated with each additional separate year and is continuous, compared to their observed 0.4% reduction in likelihood for houses built before 2000, which is done in binary categories.

5.2.4. Economic

Monthly electricity costs with a significance of 0.026 and a mere Wald statistic of 4.979 seems to be nearly negligible. Similarly, disposable income, with a low significance of 0.012 and a Wald statistic of 6.279, is associated with a marginal 0.1% increase in the likelihood of solar panel adoption for each additional 1000 euros. These factors play a relatively minor role in influencing solar panel adoption decisions, however it is still interesting and quite similar to the research results by Best and Esplin (2023) noting that household incomes of the highest quantiles are associated with around 0.7 percent of extra solar uptake probability. On the other hand, compared to Klepacka et al. (2018), which indicated that higher-income households had a 4.1% lower probability of considering the total cost of solar panels as significant in their adoption decisions, this disparity highlights the nuanced relationship between income and perceived cost sensitivity, suggesting that while affluent individuals may express a reduced concern for economic costs, the practical adoption of solar panels may not align with these verbalised preferences, reinforcing the importance of assessing actual behaviour alongside stated intentions and therefore contrasting with the Value-Belief-Norm theory (Stern et al., 1999).

5.2.5. Location-specific

The most striking revelation was the minimal significance of location-specific factors. Contrary to expectations informed by a study by Rausch and Suchanek (2021), a higher quality of life and livability score does not exhibit a significant correlation with an increase

in solar panel adoption at the 0.05 level. This insignificance also extends to the effect of residing in rural areas or villages. Intriguingly, an inverse relationship is observed with population density: a lower population density is associated with a 15.9% increase in the likelihood of solar panel adoption for each ascending category. This trend contrasts with findings in the Netherlands from Zhang et al. (2023), where an opposite correlation is reported, indicating that a 1% increase in population density results in a 0.203% increase in solar panel adoption.

6. Conclusion

This thesis provides a thorough investigation into the determinants of solar panel adoption in Dutch households, utilising data from the WoOnonderzoek 2021 survey. Through a detailed literature review and subsequent binary logistic regression analysis, we have identified several key factors that influence this adoption process.

The findings of this study primarily highlight the importance of sustainability related-, household characteristics and socio-demographic factors in driving the decision to adopt solar panels. Interestingly, our research indicates that economic and location-specific factors, contrary to prevailing scientific consensus, play a less significant role than expected in this context.

Despite these insights, the research encountered notable limitations. The WoOnonderzoek 2021 survey, while comprehensive, does not provide data on the costs of return on investment for solar panels. This gap limits our understanding of how economic considerations, particularly long-term financial benefits, influence household decisions regarding solar panel adoption since it was often mentioned in the literature. Also, the role of government subsidies was also mentioned quite often in the literature review, but could not be researched by us.

For future research, two critical areas emerge. Firstly, the exploration of government subsidies, a factor frequently mentioned in the literature but not directly measurable in the WoOnonderzoek data, presents a significant avenue for investigation. Understanding how these subsidies interact with other determinants and their direct impact on adoption rates could provide deeper insights into effective policy measures. Secondly, a focus on the economic aspects, especially the costs of return on solar panel investments, is essential. This includes assessing how perceptions of financial viability influence adoption decisions and

how these perceptions are shaped by external factors such as market trends and policy changes.

The implications of this research are pivotal for policy development, particularly in crafting strategies that align with sustainability, household characteristics, and socio-demographic factors, the key drivers of solar panel adoption. Policies should be customised to connect with different demographic segments, taking into account their varying levels of interest in sustainability. This could involve targeted campaigns that emphasise not only the environmental benefits but also the practical advantages of solar panels to appeal to those less engaged in sustainability. Effective communication strategies, tailored to the unique needs and motivations of diverse households, can lead to more effective and inclusive approaches in promoting solar energy adoption, moving beyond generic policy models.

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