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Public acceptance of sustainable energy innovations in the European Union: A multidimensional comparative framework for national policy

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ABSTRACT

Public acceptance of sustainable energy innovations and policies is of crucial importance in enabling the transition to decarbonized energy systems necessary to meet the key climate targets of the Paris Agreement. This is particularly important in the context of the European Union, which is the third largest energy-related greenhouse gas emitter in the world. However, achieving acceptance is complex and requires improved understanding of the underlying conditions that are likely to motivate it. To contribute to this understanding and overcome common shortcomings in the literature, this paper presents a multidimensional and cross-national framework for the factors that have the potential to motivate both dimensions of acceptance, namely adoption and support. The innovations of interest are numerous and include electric vehicles, residential solar panels, energy-efficient home insulation, environmental taxes and incentives. The paper employs multilevel regression analysis and combines individual and contextual data from all the European Union nations to demonstrate the significance of various types of predictors in motivating acceptance. It is found that citizens' personal capabilities and attitudes towards life satisfaction, climate change and the environment influence both dimensions of acceptance. Attitudes towards broader socio-political dimensions such as representation, equity and transparency primarily influence support, whereas national environmental and energy policy indicators primarily influence adoption. Overall, this paper provides evidence suggesting governments should simultaneously address both dimensions of acceptance, through a combination of different means: enhancing support through strategies that target attitudes and preferences, and market-based environmental policies that promote adoption at the household level.

1. Introduction

Emissions of carbon dioxide (CO_2) and other greenhouse gases (GHGs) are triggering climate change (Intergovernmental Panel on Climate Change (IPCC), 2014) and other phenomena that negatively affect human health and the environment (Bernard et al., 2001). Reducing these emissions is therefore an urgent challenge for humanity, especially as their concentrations in the Earth's atmosphere are now among the highest in human history (Arning et al., 2021). As the energy sector is of the largest emitters globally, the large-scale transition to sustainable and decarbonized energy systems becomes an important prerequisite for combating climate change and meeting the goals of the Paris Agreement (Kern and Rogge, 2016). Governments aim to achieve this transition through low-carbon technological innovations, such as variable renewable energy and energy efficiency, and economic innovations in the form of Pigovian taxes (i.e., taxes on environmental externalities) (Carattini et al., 2018) or incentives that encourage pro-environmental energy management. Such efforts are of key importance in achieving cleaner and more sustainable production and consumption of energy in the European Union (EU), the world's third largest contributor to GHG emissions-a large part of which is associated with energy use (World Resources Institute (WRI), 2020). However, sustainable energy (SE) and decarbonization transitions are socio-technical transitions and require public participation and acceptance (Čábelková et al., 2021) to be successful. This is not always the case, as SE innovations often face difficulty gaining public acceptance (Rand and Hoen, 2017; Umit and Schaffer, 2020). Examples in Europe include public resistance to renewable energy projects and carbon tax initiatives in nations such as Ireland (Brennan and Van Rensburg, 2016; Clinch and Dunne, 2006), France (Douenne and Fabre, 2019) and the United Kingdom (UK) (Carattini et al., 2018).

To meet this challenge, it is crucial to gain a holistic understanding of how policies can be appropriately designed to increase the acceptance of

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Abbreviations

SE	sustainable energy
EV	electric vehicle
ABC	Attitude Behavior Context
TPB	Theory of Planned Behavior
VBN	Value Belief Norm
NIMBY	not in my backyard
GHG	greenhouse gases
EU	European Union
UK	United Kingdom
UNSD	United Nations Statistics Division
ICC	Intra-class Correlation Coefficient

SE innovations in various settings. However, this understanding is hindered by certain gaps observed in the scholarly literature that supports policy-making. Although SE innovations acceptance has two different manifestations, namely support (the willingness to support measures in relation to an innovation) and adoption (the decision to purchase an innovation for own use), relevant studies commonly focus only on one or the other. As there is no solid evidence that support always leads to adoption, understanding the underlying factors that influence support and simultaneously those that influence adoption is of significant importance for a holistic approach to increasing SE acceptance. Moreover, SE innovation acceptance studies commonly focus exclusively on technological innovations or on economic innovations. On the other hand, there is limited evidence of the factors that motivate specific populations in specific settings to accept innovations of either type. This can be problematic when the aim is to design energy decarbonization strategies based on mixes of technology deployment and economic reforms. Moreover, as an expression of energy-saving behavior, citizen acceptance of SE innovations is complex and may depend on a variety of characteristics and preferences of the decision-makers, including self-interest and altruistic considerations. It is therefore necessary to examine the role of characteristics that have received less attention in the past in the context of SE innovation acceptance, such as attitudes towards broader socio-political dimensions of a state. Finally, other shortcomings in the literature include the generally limited number of nations from which evidence pertaining to SE innovation is drawn (see subsection *2.2*).

The aim of this paper is to improve the understanding of the phenomena relevant to SE innovation acceptance, while overcoming the aforementioned shortcomings in the literature. Achieving this understanding can assist governments in increasing national levels of acceptance of SE-enabling policies. In turn, increased SE innovation acceptance can significantly contribute to nations' cleaner production via increased efficiencies in energy generation and increased consumer responsibility and sustainability in energy use. To achieve its aim, the paper provides the first large-scale and comprehensive international analysis of the underlying factors that potentially affect: i) citizen adoption of SE technology; ii) citizen support for SE technology; and iii) citizen support for SE-relevant economic reforms. Based on established social psychology models that link environmentally significant behavior with attitudinal variables and the context in which people live (Stern, 2000), the factors examined herein include individual (micro-level) factors, such as citizen capabilities and attitudes, as well as contextual (macro-level) factors that reflect the performance of national environmental and energy policies. In particular, the SE technologies examined include applications that are central to the decarbonization plans of several governments: energy efficiency applications, such as electric vehicles (EVs) and improved home insulation, and renewable energy applications, such as household-scale solar panels. The economic reforms examined include environmental taxes and incentives as well as public funding for clean energy transitions. The empirical analysis of the paper consists of estimating multilevel regression econometric models using a novel dataset on energy-related trends and attitudes of approximately 52,000 citizens from the EU-28 nations (the 27 current EU member states and the UK). This additionally allows for the investigation of nation-level and European subregion-level effects. To the best of the authors' knowledge, no other study has systematically examined all these different dimensions of public acceptance of SE innovations, and across the entire EU-28 group, including trends in locales that have received relatively less attention in the extant literature.

The results suggest that citizens' personal capabilities and attitudes towards climate change and the environment play an important role in both the adoption and support dimensions of acceptance. On the other hand, personal attitudes to broader socio-political dimensions such as representation, equity and transparency primarily influence support, while national indicators and market-based policies primarily influence adoption. Finally, the examination of nation-level effects reveals a greater variation of technology adoption and support from one EU nation to another, and a smaller variation of support for economic reforms. The overall results justify the need to distinguish between adoption and support, and call for the development of policies to encourage both of them, especially in nations aiming to facilitate the energy decarbonization transition via a combination of technological and economic innovations.

The remainder of this paper is structured as follows. Section *2* provides a literature review in the form of defining key aspects of SE innovation acceptance as well as providing an overview of previous studies and the most dominant theoretical models in the field. Critical gaps in the literature are identified and the paper's approach to overcome them is introduced. In Section *3*, the paper's methods are detailed, including a conceptual framework, ten research hypotheses and the description of the data and the econometric models employed. In Section *4*, the results of the analyses are presented. Subsequently, Section *5* discusses the findings and their implications for policy. Finally, Section *6* provides closing remarks and the overall conclusions derived from this study.

2. Background and literature review

2.1. SE innovation adoption and support

In the context of SE policy, the term "innovations" often refers to technological innovations, i.e., advances in renewable energy and energy efficiency technology. Nevertheless, this term has also been used to refer to economic innovations (Ashworth et al., 2006), i.e., novel market-based policies, such as efficiency-enhancing environmental taxes (Carattini et al., 2018; Klenert et al., 2018) and incentives, which aim to encourage pro-environmental behaviors, including the sustainable production and consumption of energy. In this regard, the general term "public (social) acceptance" of SE innovations is employed to describe societal decisions of different natures, falling into two broad categories. The category of "adoption" decisions refers to citizens' behavioral responses that entail the purchase and direct use of an innovation (Huijts et al., 2012) (most often a technological system) in their daily life. Purchasing an EV, installing a home solar panel, conducting a deep energy efficiency home retrofit and participating in energy community projects are examples in that category. Such decisions constitute a behavioral change and have a visible effect on the life, finances and habits of the decision-makers. On the other hand, the category of "support" decisions refers to citizens' willingness to support (or express no opposition against) governmental decisions on technology and pecuniary measures, such as: the building of new solar and wind energy farms, the introduction of stricter energy efficiency standards for buildings and appliances, as well as the implementation of various types of environmental or carbon taxes. Such support decisions may have a smaller or greater effect on the life of the decision-makers, depending on

Table 1
Summary of decision factors commonly reported in the literature as influential in public acceptance of SE innovations.

Public acceptance of sustainable energy (SE) innovations dimension	Decision factors commonly reported as influential	Examples of studies (locations of major focus in parentheses)
Adoption: technological innovations		
Electric vehicles, biodiesel/hydrogen/hybrid vehicles	Vehicle price and performance, battery charging time, distance driven on full battery, incentives, environmental impacts	(Rezvani et al., 2015) (Belgium, China, Denmark, Germany, Netherlands, UK, USA) (Jansson et al., 2017), (Langbroek et al., 2016) (Sweden) (Peters et al., 2018) (Netherlands)
Home micro-generation of renewable energy (e.g., solar, micro-wind, heat pumps, micro-hydro, biomass)	Installation and maintenance costs, system performance and reliability, risk of disruption in energy service, risk of losing personal comfort, visual impact, availability of information, environmental benefits, social approval	(Balcombe et al., 2014) (UK) (Heiskanen and Matschoss, 2017) (20+ European nations) (Yuan et al., 2011) (China)
Home energy efficiency (insulation, efficient boilers, efficient lighting and appliances)	Energy price concerns, expected savings, availability of information, trust, environmental concerns, moral and social norms	(Urban and Ščasný, 2012) (Australia, Canada, Czech Republic, France, Italy, South Korea, Netherlands, Norway, Sweden) (Fornara et al., 2016), (Testa et al., 2016) (Italy)
Community renewable energy, micro-grids and energy storage	Economic feasibility, ownership concerns, data exchange concerns, concerns on incentives, business model, intermediary organizations, social benefits	(Müller and Welpe, 2018) (Australia, Germany) (Koirala et al., 2018) (mainly Germany, Netherlands) (Ruggiero et al., 2014)(Finland, Germany, Ireland, Norway, Sweden, UK) (Warneryd et al., 2020) (mainly Australia, China, Germany, Japan, Netherlands, Singapore, South Korea, Sweden, Taiwan, USA)
Support: technological innovations		
Green electricity, renewable energy farms and power plants (e.g., solar, wind, gas, biomass)	Effects on electricity prices, landscape modification, environmental impact, distance from residence, effect on house prices near the facilities, design and physical characteristics of the facilities, equity in distribution of costs and benefits	(Harold et al., 2021) (Ireland, Germany, USA) (Langer et al., 2018), (Bertsch et al., 2016), (Meyerhoff, 2013), (Andor et al., 2018) (Germany) (Mirasgedis et al., 2014) (Greece) (Hall et al., 2013) (Australia) (Jones and Eiser, 2010) (UK) (Ladenburg and Dahlgaard, 2012) (Denmark) (Molnarova et al., 2012) (Czech Republic) (Strazzera et al., 2012) (Italy) (Firestone et al., 2018) (USA) (Enevoldsen and Sovacool, 2016) (France) (Walter, 2014) (Switzerland) (Strazzera and Statzu, 2017) (Spain, Italy, Tunisia, Egypt, Jordan, Lebanon) (Wolsink, 2007) (mainly Denmark, Germany, Greece, Netherlands, Spain, Sweden, UK)
Support: economic innovations		
Environmental and energy-related taxes	Personal effects, effects on economy, equity and fairness in procedures and in distribution of benefits	(Kallbekken and Sælen, 2011) (Norway) (Baranzini and Carattini, 2017) (Switzerland) (Povitkina et al., 2021) (USA) (Jagers et al., 2021) (USA, Canada, Germany) (Hammerle et al., 2021) (Australia) (Mehleb et al., 2021) (France) (Umit and Schaffer, 2020), (Levi, 2021) (20+ European nations)

circumstances such as the physical distance between their home and the technology facility, the specific tax liability that their lifestyle subjects them to, or the necessity to pay for internalizing possible environmental damages induced by the facility; in the latter case, the people's willingness to pay (Andor et al., 2018; Stigka et al., 2014) becomes a proxy parameter for support. For a holistic approach towards a sustainable future, governments need to focus on both dimensions simultaneously, as the adoption counterpart is the essence of deep deployment of a technology, whereas the support part is equally important in ensuring that there will be no political costs due to certain SE policies.

2.2. Previous studies

Several reviews have focused on public acceptance of specific energy technology applications. Stigka et al. (2014) and Heiskanen and Matschoss (2017) review national-level and household-level renewable energy, respectively. Rezvani et al. (2015) review public acceptance of EVs, while Cowan and Daim (2011) examine the literature on lighting energy efficiency. Warneryd et al. (2020) discuss trends pertaining to energy community microgrids and Arning et al. (2021) examine acceptance of CO_2-derived building materials. Other reviews-such as the one by Upham et al. (2015)- examine an umbrella of different energy technologies. Regarding innovations of economic nature, public acceptance of environmental or carbon taxes is more commonly examined than that of incentives, as taxes naturally create public opposition, thus more effort is needed to identify the circumstances that would make them appealing. Kallbekken and Sælen (2011), Carattini et al. (2018), Maestre-Andrés et al. (2019) and Umit and Schaffer (2020) provide detailed overviews of research in that direction.

Table 1 provides examples of the parameters found to play a role in citizen decisions to adopt or support an innovation. This information is acquired through a brief literature review that was conducted following standard procedures to obtain a representative sample of papers in this research field (Heiskanen and Matschoss, 2017; Karlin et al., 2015; Spandagos et al., 2021): in brief, English-language reviews and original research papers were sought for in electronic databases such as Web of Science and Scopus by using combinations of keywords that include: "public/social/societal acceptance", "adoption", "support", "energy innovations", "energy solutions", "energy policies", "renewable energy", "energy efficiency", "sustainability", "solar", "wind", "electric vehicles", "environmental taxes", "carbon taxes", "carbon pricing" and "incentives". Refining the results through multiple title/abstract reviews yielded a final sample of papers. As the subject of public acceptance of SE policies is vast and has been analyzed in numerous papers, information in Table 1 is not intended to be exhaustive, but rather to provide an illustrative snapshot of dominant trends.

2.3. Theoretical models: self-interest, altruism, attitudes and context

Acceptance of SE innovations can be considered an expression of energy-saving behavior, which, in turn, is a subset of pro-environmental, or environmentally significant behavior. Stern (2000) describes several types of the latter behavior, including environmental activism, non-activist behaviors in the public sphere, and private-sphere environmentalism: the adoption part of SE innovation acceptance, as described in *2.1*, fits with Stern's description about private-sphere environmentalism; similarly, and according to the level of one's activism, the support for SE innovations and policies can fit with the description of either non-activist behaviors or environmental activism. This connection between acceptance of SE measures and pro-environmental behavior has enabled research on the former to be developed on the basis of several consumer behavior models that explain the latter. Kollmuss and Agyeman (2002) provide a detailed overview of theoretical models of such behavior, while Wilson and Dowlatabadi (2007) do likewise specifically for energy use. Upham et al. (2015) provide a relatively more recent review on the social acceptance of energy technology. That work distinguishes between the more general line of research based on the diffusion and innovation models for technology adoption (Rogers, 2010) and the heuristic approach that involves disciplines such as economics, behavioral economics and social psychology.

Established behavioral models, such as the ones based on the Rational Choice theory, approach energy-saving behaviors through the traditional economics notions of self-interest and rational evaluation of self-centered benefits and consequences. This "selfishness" had been originally identified as the driving force behind the "not in my backyard" (NIMBY) phenomenon, where citizens support innovations in general, but object to them when their direct vicinity is affected. However, behavioral economics and social psychology challenge these notions and demonstrate that human decisions are also driven by emotions, allegiances and normative social values. Normative approaches such as Ajzen's Theory of Planned Behavior (TPB) (Ajzen I., 1991; Dhir et al., 2021) and Stern's Value-Belief-Norm (VBN) (Stern, 2000) theory extend beyond self-utility maximization to include social norms and other concerns. In particular, TPB suggests that personal attitudes, subjective norms and perceived behavior control shape intentions, which, in turn, shape behaviors. Moreover, VBN explores the relationship among values, beliefs and moral norms as antecedents of environmentally significant behavior. In that regard, energy-saving behavior can often be explained from the perspective of altruism, where pro-social considerations (such as protecting people's rights and the environment) are of central importance. Therefore, NIMBY phenomena can be attributed to the need for equity and fairness, rather than to selfish motives (Wolsink, 2007). The consensus in the literature is that examining exclusively either selfish or selfless motives is not enough to unlock the complexity of energy-saving behavior and SE acceptance. Therefore, newer theoretical models (Huijts et al., 2012) follow more mixed approaches, recognizing the importance of both types of motives (Bamberg and Möser, 2007). Hence why, and as Table 1 highlights, the list of the most examined decisions factors in SE acceptance studies includes both self-interest factors (risk for own financials, distance from residence) and altruistic factors (equity, environmental and social benefits).

Independently of decision factors being altruistic or not, the literature indicates that a holistic understanding of the phenomena behind pro-environmental behaviors can be achieved when attitudes, values beliefs and other "internal" determinants of behavior are explored together with "external" determinants, i.e., situational and contextual factors. Hence, even though VBN and TPB have been acknowledged for their ability to explain pro-environmental behaviors (Spandagos et al., 2020), they have also been criticized for overlooking contextual or other factors that may be key in the behavior-shaping process (Okumah et al., 2020). In one of the most critical efforts to overcome the "internal--external" dichotomy, Guagnano, Stern and Dietz (Guagnano et al., 1995; Stern, 2000) developed the Attitude Behavior Context (ABC) theory, according to which one's behavior (B) is the result of multifaceted interactions between one's personal attitudes (A) and the surrounding context (C). Based on that notion, Stern (2000) further suggests that an integrated model of environmentally significant behavior would consist of factors that are categorized into: i) personal capabilities; ii) personal attitudes; iii) personal habits or routines; and iv) contextual factors. Testa et al. (2016) find this typology useful in exploring the predictors of energy-saving behaviors, while Devine-Wright (2007) provide a similar typology for the predictors of public acceptance of renewable energy technologies. Regarding economic innovations, as Kallbekken and Sælen (2011) indicate, even though very few studies on the public support for environmental taxes are based on theoretical models, Stern's social psychology-based theoretical foundations are relevant to this type of acceptance as well.

2.4. Gaps and the current paper

Some gaps in the literature remain. (1) There is a need to inform policy concerning a holistic approach towards decarbonization that ensures an optimal mix (Rogge and Reichardt, 2016) of technology deployment and economic measures. However, and as Table 1 indicates, acceptance of technology is most often explored separately from acceptance of economic measures. (2) While there is a need to guide policy towards motivating adoption and support simultaneously, comparisons between adoption and support preferences of the same groups of citizens ((Strazzera and Statzu, 2017) is an example) are limited. (3) Providing policy with realistic insights concerning actual adoption of technology is hindered (Nisa et al., 2019) by the fact that studies often measure "intentions to adopt" as a proxy for actual adoption (Rezvani et al., 2015). (4) While citizen attitudes are of key importance in innovation acceptance studies, these are predominately measured explicitly in relation to energy-relevant concepts or to the specific innovation in question only. Examples include attitudes towards energy security (Knox-Hayes et al., 2013), attitudes towards the costs/distributional equity of specific technological (Andor et al., 2018) and economic (Kallbekken et al., 2010) innovations. On the other hand, relatively fewer studies have focused on citizen attitudes towards a state's broader socio-political dimensions, such as representation, transparency, equity and fairness in rules and laws. However, broader socio-political dimensions become extremely relevant when the target is to achieve large-scale acceptance (Enevoldsen and Sovacool, 2016), especially as the transition to smart and distributed energy systems creates new societal and institutional concerns (Warneryd et al., 2020). (5) Studies often report heterogeneous results concerning which factors most adequately influence acceptance, and findings from one single location cannot easily be applied to another (Heiskanen and Matschoss, 2017). Thus, a holistic understanding of the conditions that favor SE acceptance can only be achieved by gathering evidence from as many locations as possible. In practice, however, this is rarely achieved. As Table 1 indicates, research in the European context is often concentrated in the UK, the Netherlands, Germany and the Nordic nations. In general, the number of original research studies that provide comparisons of trends across all, or at least most, of the European nations is limited ((Levi, 2021; Sierzchula et al., 2014; Umit et al., 2019; Umit and Schaffer, 2020) are some examples in that direction). This emphasizes the urgent need to create more representative and cross-national pools of evidence.

In view of the above, and to provide a valuable theoretical and policy contribution, this paper develops a multidimensional and comparative framework of the conditions that potentially influence SE innovation acceptance. The framework is built by combining micro-level (citizen characteristics) and macro-level (national characteristics) data from all the EU-28 nations, and advances the literature in several critical aspects: i) it explores the factors that shape acceptance of various types of innovations, including technological and economic reforms; ii) it compares the support and adoption dimensions of technology acceptance, with parameters that reflect actual adoption trends being measured pertaining to the latter dimension, instead of intentions to adopt; iii) it examines the role of several acceptance predictors that have received little attention in the literature thus far, such as the citizens' attitudes towards broader socio-political dimensions; and iv) it provides insights from a large number of European nations (some of which rarely feature in the literature), while exploring nation-level and European subregion-level effects. Developing a single framework for simultaneously exploring all these dimensions of public acceptance of SE innovations on a large scale is a new departure, and creates insights that can assist governments in identifying the optimal conditions to increase citizen acceptance of SE innovations.

3. Methods and data

3.1. Conceptual framework and research hypotheses

This paper's conceptual framework is built through the theoretical lens of the ABC theory and Stern's categorization of predictors of environmentally significant behavior into personal capabilities, personal attitudes and contextual factors (Stern, 2000).[1] This choice is dictated by: (a) the connection between SE innovation acceptance and environmentally significant behavior discussed in *2.3*; (b) the fact that the ABC theory has been used in the past to provide insights on how attitudes and contextual factors are linked to behaviors; (c) the relevance of Stern's integrated model to previous energy-saving behavior studies (Devine-Wright, 2007; Testa et al., 2016), as discussed in *2.3*. Regarding the ABC theory, the current conceptual framework is drawing on the notion that attitudes ("internal" factors) and the surrounding context ("external" factors) jointly shape environmentally significant behaviors. As for Stern's typology, it is used to formulate this paper's research hypotheses, as described in the following subsections.

3.1.1. Personal capabilities

Personal capabilities refer to the resources a person requires to take an action and are often measured by socio-demographic variables. Regarding SE innovation acceptance, socio-economic or socio-demographic variables such income, age and education have been found to have an effect (Heiskanen and Matschoss, 2017). While Stern's integrated model distinguishes personal capabilities from contextual factors, other scholars consider them part of the context in which people live. For instance, Šćepanović et al. (2017) treat income and gender as contextual factors behind energy-saving behaviors. In this way, such variables can become relevant to the ABC theory as well. Yet, governments are often unobservant of citizens' capabilities, and this is believed to constrain the design of optimal strategies for innovation deployment (Mirrlees, 1971). Motivated by this, this paper aims to provide additional information on the effects of capabilities on acceptance, through the following hypotheses:

H1-2. Citizens' personal capabilities affect their SE innovation adoption (1) and support (2) decisions.

3.1.2. Attitudes towards life satisfaction

Behaviors related to energy use have been linked to attitudes towards life satisfaction (Poortinga et al., 2004), as access to reliable and affordable energy contributes to human well-being (Brand-Correa and Steinberger, 2017; Pasten and Santamarina, 2012). The correlation between innovation and well-being has also been demonstrated (Dolan and Metcalfe, 2012), it can thus be argued that people who are satisfied with their life might be more eager to accept an innovation. On the other hand, it could be possible that people who are not satisfied with theirs might also accept innovations, if they believe that the innovations will improve their well-being. As SE innovations aim to improve people's lives by decreasing the environmental and health hazards of fossil fuel energy, it is intriguing to further explore how people's attitudes towards life satisfaction affect their acceptance of these novelties. This leads to the following hypotheses:

H3-4. Citizens' attitudes towards life satisfaction affect their SE innovation adoption (3) and support (4) decisions.

3.1.3. Attitudes towards climate change and the environment

There is an increased interest in how a particular set of these attitudes influences environmental policy acceptance, i.e., the attitudes that express one's own moral responsibility in protecting the environment and tackling climate change. For instance, it has been indicated that citizens more often take action to reduce those environmental problems they have personally caused, something that discourages them from accepting solutions that delegate the task to others (Jakob et al., 2017). To further explore the role of such attitudes, the following hypotheses are formulated:

H5-6. Citizens' attitudes towards climate change and the environment affect their SE innovation adoption (5) and support (6) decisions.

3.1.4. Attitudes towards socio-political dimensions

As mentioned in *Section 2*, procedural and distributional equity are important considerations in SE innovation acceptance. However, equity has been given relatively little attention in sustainability studies compared to other citizen considerations (Chapman et al., 2016; Tol, 2001), and is hence less understood. A probable cause for this gap is the fact that different terms are often employed to describe equity in energy research, such as "fairness" and "justice" (Forman, 2017). Such terms are ambiguous, and stakeholders of an energy project may disagree on their exact meaning or measurement (Been, 1993). Furthermore, equity and fairness have several dimensions that exceed the boundaries of energy innovation and become relevant to the general functions and operations within a state. As Enevoldsen and Sovacool indicate (Enevoldsen and Sovacool, 2016), large scale acceptance involves broader socio-political dimensions; whereas SE innovation studies often examine people's attitudes towards equity, fairness and trust that the subjects are in agreement on what these terms measure. This creates limitations in understanding the influence of their broader dimensions on acceptance. Pertaining to technology, it is also intriguing to investigate attitudes towards representation, as distributed and smart energy advancements increase the community engagement of energy users, giving rise to the novel concept of grid democratization (Warneryd et al., 2020). Furthermore, improved understanding of how citizens perceive their socio-political environment may determine which economic strategies are more likely to succeed (Klenert et al., 2018). For instance, positive attitudes to representation, transparency and lack of discrimination may increase general trust in the socio-political system, which is hinted to increase acceptance of environmental taxation (Klenert et al., 2018). The above motivate this paper to examine how acceptance is influenced by citizen attitudes towards broader socio-political dimensions that reflect fairness, justice and trust, through the following hypotheses:

[1] The category of personal habits or routines was omitted in the current paper, due to lack of suitable data to represent it. Devine-Wright (2007) also omits habits and follows a broader "personal, socio-psychological, contextual" factors typology (which is analogous to the personal capabilities, personal attitudes and contextual factors typology).

H7-8. Citizens' attitudes towards broader socio-political dimensions affect their SE innovation adoption (7) and support (8) decisions.

3.1.5. National environmental and energy policy aspects

While household-level characteristics are important in shaping energy-relevant behaviors, their examination is insufficient without simultaneously considering national-level characteristics. Hence, and in line with the ABC theory, the national context is often examined in relation to citizens' energy-saving behavior (Šćepanović et al., 2017) and acceptance of technological innovations (Heiskanen and Matschoss, 2017). Pertaining to the acceptance of economic innovations, however, Levi (2021) points out that even the most comprehensive studies often ignore the nation-level conditions, including governance and climate policies (Umit and Schaffer (2020) is one of the recent examples of exceptions to that rule). Overall, the heterogeneity of trends across acceptance studies (Heiskanen and Matschoss, 2017) can perhaps be better understood when these trends are examined within the environmental and energy policy context of the location studied. Indeed, policies can either encourage or hinder innovation acceptance, and scholars have recently highlighted the need to consider not only the current number of supporting policies in each state, but also aspects such as the number of years each policy has been implemented (Heiskanen and Matschoss, 2017). The above formulates the following hypotheses:

H9-10. National environmental and energy policy aspects affect citizens' SE innovation adoption (9) and support (10) decisions.

Fig. 1 provides a graphic illustration of the conceptual framework. Each category of predictors is linked with the adoption and support dimensions through the corresponding research hypotheses. For instance, the illustration indicates that personal capabilities are linked with adoption through **H1** and with support through **H2**. Testing the ten hypotheses is performed on the basis of applying the appropriate econometric models (described below in *3.3*) and examining the resulting sign and significance of relationships between the dependent and predictor variables described in *3.4* and *3.5*.

3.2. Data

This study combines individual citizen (micro-level) data from two recent Eurobarometer (EB) surveys with contextual (macro-level) data from two EU-wide statistics databases. The first survey is the *Special EB survey 91.3* (GESIS- Leibniz Institute for the Social Sciences, 2019a) ("Survey 1") and the second one is the *Special EB survey 92.4* (GESIS-Leibniz Institute for the Social Sciences, 2019b) ("Survey 2"). Each survey involves approximately 1,000 respondents from each one of the current EU nations and the UK, providing this study with a dataset of approximately 55,000 respondents. The EB employs a multistage random probability design to select respondents, and collects data via face-to-face interviews (Duijndam and Beukering, 2021). Detailed descriptions of the sampling and conduction methods of Survey 1 and Survey 2, together with their questionnaires are provided by the GESIS platform of the Leibniz Institute for the Social Sciences (GESIS Leibniz Institute for the Social Sciences, 2021). The contextual factors data are extracted from the Eurostat (European Commission, 2021) and the Odyssee-Mure (2020) databases. Combining the surveys and databases allows the examination of hypotheses **H1–H10** across the EU-28 nations, thus providing a comprehensive and cross-national pool of evidence on public acceptance of innovations within the EU.

3.3. Clustering and econometric models

The purpose of this paper's analysis is to estimate the odds that a citizen will adopt or support particular SE innovations. The EB datasets contain thousands of individual citizen responses with a potential nested structure within and across several nations, therefore it is important to estimate these odds while considering the dependency of the data (i.e., the fact that citizens are nested within nations) (Sommet and Morselli, 2017). Furthermore, past research shows that regression models using data from various levels (e.g., nations or geographical areas) can have stochastic error terms (Secondi et al., 2015) that correlate between and within the levels. To investigate that in relation to the current data, and to allow for a higher degree of flexibility of how a model's stochastic error terms may be allocated across nations, this study employs multilevel logistic regression modeling (Hedeker, 2008).

To apply multilevel modeling, at least two levels are necessary, with "level 1" concerning the citizens and "level 2" the 28 European nations. Furthermore, a third level concerning European subregions ("level 3") is added to explore possible effects due to a nation belonging to a specific subregion. To cluster the nations into subregions, this paper employs the geoscheme system of the United Nations Statistics Division (UNSD), according to which Europe consists of the following 4 subregions (United Nations Statistics Division, 2021): Northern Europe: Denmark (DK), Estonia (EE), Finland (FI), UK (GB), Ireland (IE), Latvia (LV), Lithuania (LT), Sweden (SE); Southern Europe: Greece (EL), Spain (ES), Croatia (HR), Italy (IT), Malta (MT), Portugal (PT) and Slovenia (SI); Western Europe: Austria (AT), Belgium (BE), Germany (DE), France (FR), Luxembourg (LU), Netherlands (NL) and; Eastern EU: Bulgaria (BG), Czech Republic (CZ), Hungary (HU), Poland (PL), Romania (RO) and Slovakia (SK). A modification is made for Cyprus (CY), which is placed in West Asia by the UNSD, but is added in Southern Europe herein, together with the other Mediterranean nations.

Adding the subregional level creates the requirement for a three-level logistic regression model, which is defined herein based on Raman and Hedeker (2005). In brief, assuming that there are $k = 1, \ldots, n_{ij}$ level 1 units nested within $j = 1, \ldots, n_i$ level 2 units nested within $i = 1, \ldots, n$ level 3 units, the model can be expressed mathematically as:

$$y_{ijk} = \boldsymbol{x}'_{ijk}\,\beta + \upsilon_{ij} + \upsilon_i + \varepsilon_{ijk} \quad (1)$$

where y_i is the dependent variable (representing a citizen decision to adopt/support an SE innovation), $\boldsymbol{x}_{ijk}$ is the covariate vector, $\boldsymbol{\beta}$ is the regression parameter vector to be estimated (odds ratio in this study), ε_{ijk} are the residuals and υ_{ij} and υ_i are the random effects at level 2 and level 3, respectively. Due to the presence of fixed and random effects, the model is characterized as a mixed-effects model. The level 3 subscript i is present in both υ_{ij} and υ_i, thus not all level 3 units are assumed to contain the same number of level 2 units, which in turn are not assumed to contain the same number of level 1 units (Raman and Hedeker, 2005). This fits well with the available datasets, as not all subregions contain the same number of nations and not all nations contain the same number of citizen responses.

In this study, the dependent variables that represent EV adoption, solar panel installation, home insulation, support for environmental taxes and support for environmental incentives are dummies. The probability of y_{ijk} becoming equal to unity is therefore modeled as:

$$P(y_{ijk} = 1) = \Psi(\boldsymbol{x}'_{ijk}\boldsymbol{\beta} + \upsilon_{ij} + \upsilon_i) = \frac{\exp\left(\boldsymbol{x}'_{ijk}\boldsymbol{\beta} + \upsilon_{ij} + \upsilon_i\right)}{1 + \exp\left(\boldsymbol{x}'_{ijk}\boldsymbol{\beta} + \upsilon_{ij} + \upsilon_i\right)} \quad (2)$$

where $\Psi(\bullet)$ is the logistic cumulative distribution function (Hedeker, 2008). The probability can be written in terms of the cumulative logit as:

$$log\frac{P(y_{ijk} = 1)}{1 - P(y_{ijk} = 1)} = \boldsymbol{x}'_{ijk}\boldsymbol{\beta} + \upsilon_{ij} + \upsilon_i \quad (3)$$

Furthermore, the dependent variables that represent support for renewable energy targets and support for clean energy funding are categorical. In this case, and assuming that there are $c = 1, \ldots, C$ ordered categories, equation (2) needs to be modified to provide the probability that $y_{ijk} \leq c$ as follows:

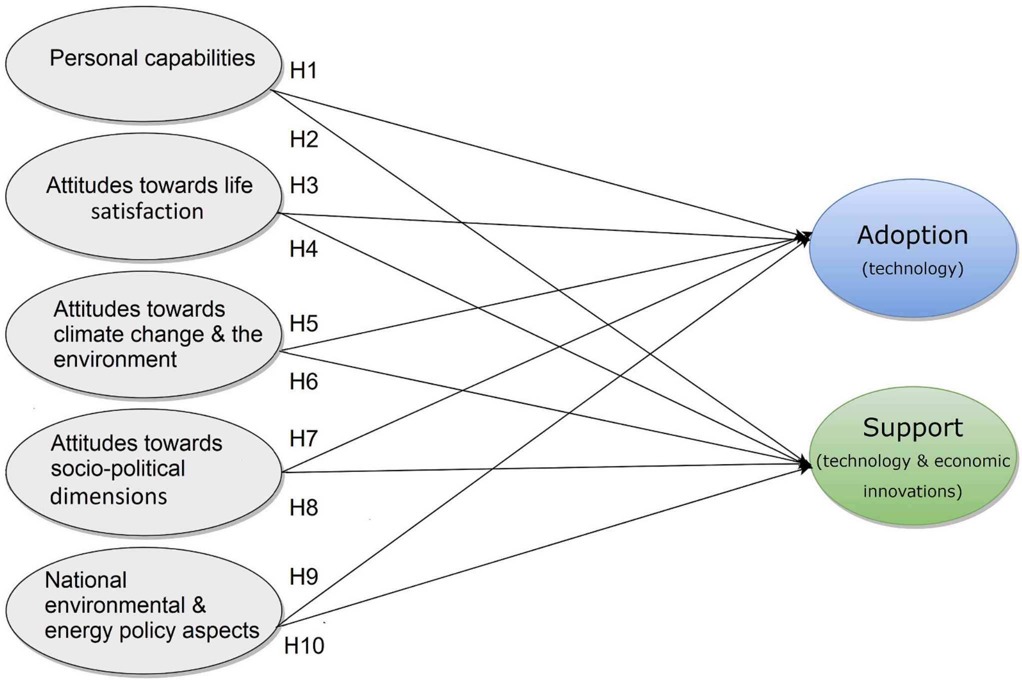

Fig. 1. Conceptual framework and research hypotheses H1–H10.

$$P(y_{ijk} \leq c) = \Psi\left(\gamma_c - \left[x'_{ijk}\boldsymbol{\beta} + \upsilon_{ij} + \upsilon_i\right]\right) = \frac{\exp\left(\gamma_c - \left[x'_{ijk}\boldsymbol{\beta} + \upsilon_{ij} + \upsilon_i\right]\right)}{1 + \exp\left(\gamma_c - \left[x'_{ijk}\boldsymbol{\beta} + \upsilon_{ij} + \upsilon_i\right]\right)} \quad (4)$$

with C-1 increasing model thresholds γ_c (i.e., $\gamma_1 < \gamma_2 < \ldots < \gamma_{C\text{-}1}$) (Hedeker, 2008). The latter probability can also be written in terms of the cumulative logit as:

$$log \frac{P(y_{ijk} \leq c)}{1 - P(y_{ijk} \leq c)} = \gamma_c - \left(x'_{ijk}\boldsymbol{\beta} + \upsilon_{ij} + \upsilon_i\right) \quad (5)$$

Finally, three model specifications are constructed for each dependent variable, with each specification containing certain sets of predictor variables: Model 1 contains only personal capabilities, Model 2 maintains personal capabilities while adding personal attitudes and Model 3 maintains all the previous variables while adding contextual factors (see *5.4*).

3.4. Dependent variables

Table 2 summarizes all this study's dependent variables. The two EB surveys are chosen because they provide the most recent data concerning European citizens' adoption and support decisions for various technological and economic innovations; these are used to shape this study's six dependent variables. Technology adoption is measured by three variables, which derive from answers to Survey 1 questions that asked the subjects whether they have purchased an EV, installed a home solar panel, or installed home insulation. Given the binary nature of these answers, dummy variables are used, with a value of 1 indicating that the particular technology has been adopted, and a value of 0 indicating the opposite. Technology support is measured by one variable, derived from answers to a Survey 1 question that assessed whether citizens support the idea that their governments set ambitious renewable energy targets. Answers to that question were given in the form of 5-value Likert scales, are thus shaped into ordered dependent variables for this study. Support for economic innovations is measured by three variables, one deriving from answers to Survey 1 and two more from answers to Survey 2. Specifically, a Survey 1 question explored whether citizens supported more public funding for the clean energy transition, and the corresponding 5-value Likert scale answers are similarly shaped into ordered dependent variables. Finally, a Survey 2 question presented twelve measures and asked the respondents to choose the ones they deem most effective in tackling environmental problems, with a maximum of three choices. Among the measures, two are relevant to this study's scope: financial incentives to people who "take measures to protect the environment", and taxation on "environmentally harmful activities". The latter generalized description in the questionnaire allows this study to consider answers to that question as a proxy indicator for support for carbon or energy taxes. Answers to this question are shaped into dummies, where a value of 1 denotes that the respondents included

Table 2
Summary of the study's dependent variables.

Variables	Source	Coding
Dependent variables		
EV purchase	Survey 1	'1' purchased, '0' not purchased.
Solar panel installation	Survey 1	'1' installed, '0' not installed.
Home insulation	Survey 1	'1' home is insulated, '0' not insulated.
Support for ambitious renewable energy targets	Survey 1	How important is that the government sets ambitious targets to increase renewable energy by 2030; 5-point Likert scale, where '5' indicates the highest attributed importance.
Support for public funding for clean energy	Survey 1	Level of agreement with the statement that more funding should be given to the clean energy transition; 5-point Likert scale, where '5' indicates the highest level of agreement.
Support for environmental taxes	Survey 2	'1' if environmental taxation is one of the 3 most effective measures in tackling environmental problems, '0' if it is not.
Support for environmental incentives	Survey 2	'1' if financial incentives to people who take action to protect the environment is one of the 3 most effective measures in tackling environmental problems, '0' if it is not.

the corresponding measure to their top three, taken as an indication for support, and 0 otherwise.

3.5. Predictor variables

Table A of the Appendix provides a summary of the study's predictor variables. The EB surveys provide data on citizen demographics and attitudes towards life, the environment and socio-political dimensions. Together with contextual information for each nation extracted from the Eurostat (European Commission, 2021) and Odyssee-Mure (2020) databases, they are used to shape this study's predictor variables. Regarding individual variables, Surveys 1 and 2 provide information on the respondents' age, gender, education, self-declared social class, political orientation and location or residence. Furthermore, Survey 1 provides data on the number of citizens who believe that: it is their own responsibility to tackle climate change; climate change is a serious problem, and; adapting to climate change is beneficial to citizens. These are used as examples of attitudes to climate change. Finally, the survey provides information about the number of citizens who believe that their voice counts within their state and that it is important for: rules and laws to apply equally to all; public authorities to be transparent when they make decisions; governmental decisions to be taken with the purpose of serving the public interest; governmental decisions to be taken without any discrimination; for corruption to be punished, and for the media to be able to criticize the government without any fear. The above are used as examples of attitudes to socio-political dimensions. Similar to Survey 1, Survey 2 also assesses the citizens' demographic information and their level of life satisfaction. In addition, it assesses their beliefs whether climate change is a serious problem and whether protecting the environment is important. Moreover, the survey assesses citizen beliefs whether their voice counts, together with their attitudes towards the current performance of their governments in the fields of environmental protection, corruption and social class inequality. These are used as proxy variables for citizen attitudes towards their socio-political environment. In terms of contextual factors, GHG emissions (in tonnes per capita) are included as an indicator of environmental performance, while the energy prices index (2015 = 100) and household environmental taxes (in Euros per capita) are included as key market-based environmental policies.[2] Finally, three indicators are chosen from the Odyssee-Mure database to reflect three different aspects of a nation's energy policy performance: the average number of active residential energy policies, the number of years each policy has been implemented on average, and the overall energy efficiency score-an aggregated indicator that reflects each nation's achieved level of energy efficiency in 2020.

4. Results

4.1. Descriptive statistics

Table 3 provides descriptive statistics for all the variables of the study, in the form of means and standard deviations for the whole sample. The table indicates that the means and standard deviations of age, female gender, tertiary education level completed, lower social class, right political orientation and rural location of residence in Survey 1 are similar to the corresponding ones in Survey 2. The same is true for the variables concerning life satisfaction, the belief that climate change is a serious problem and the belief that the respondents' voice counts within their state. Furthermore, Table 3 demonstrates that, while most respondents seem to believe that climate change is a serious problem, they do not necessarily believe it is their own responsibility to tackle it. Furthermore, most respondents seem to be unsatisfied with their life. On the other hand, the majority believes that their voice counts within their state. In terms of other attitudes to socio-political aspects, the vast majority of citizens in all nations believe that equality, transparency and media freedom are important, together with tackling discrimination and corruption. Tables B and C of the Appendix provide nation-level information on the respondents' attitudes, while Table D summarizes nation-level information on the paper's contextual factors.

4.2. Dependent variable trends

Fig. 2 illustrates how the Survey 1 responses pertaining to the dependent variables are distributed across the EU-28 group. Among the three technology solutions, the penetration of home insulation appears to be the highest, with percentages above 20% in most of nations. Moreover, most nations are associated with a solar panel adoption of up to 6%, and an EV adoption of up to 1%. In terms of technology adoption trends of individual nations, the highest percentages of solar panel adoption appear in the Mediterranean nations of Greece, Cyprus and Malta, and also in the Netherlands. As for EV adoption, the highest percentages are reported in Sweden and the Netherlands. Furthermore, the highest percentages of home insulation adoption are observed in France, the United Kingdom, Ireland, Estonia, Denmark, Belgium, the Netherlands, Slovenia and Bulgaria. Pertaining to support rates for renewable energy, they exceed 90% in most nations, while support rates for clean energy funding are also high, yet somewhat smaller than the former. While the differences among nations are generally small, highest support for renewables is reported in Greece, Cyprus, Hungary, Denmark, Portugal, Spain and Ireland, and highest support for clean energy funding in Greece and Cyprus. Similarly, Fig. 3 illustrates how the Survey 2 responses pertaining to the dependent variables are distributed across the 28 nations. In individual nation terms, a support for taxes rate of over 24% is reported only in Bulgaria, and support for incentives rates of over 30% are found only in Sweden and Latvia.

4.3. Correlation among dependent variables

Table 4 provides a correlation among the dependent variables of each survey. The table demonstrates a statistically significant but weak correlation among the three technology adoption actions, indicating that citizens who have performed one action have not necessarily performed the other two. Interestingly, the table demonstrates that supporting renewable energy has a statistically significant but weak correlation with purchasing a solar panel (a home renewable energy unit). Moreover, Table 4 indicates statistically significant correlations between the elements of each of the two pairs of support decisions (renewable energy-clean energy funding and taxes-incentives); these correlations are not strong in absolute terms, but stronger relative to the other relationships reported.

4.4. Multilevel model results

Table 5 summarizes the results of this paper's multilevel regression analysis, based on comparing the effects of individual and contextual factors on adoption decisions; Table 6 does likewise pertaining to support decisions. The tables report odds ratios estimated via the equations described in subsection *3.3*. An odds ratio value greater than 1 is equivalent to a positive sign for the corresponding relationship between predictors and dependent variables. As mentioned earlier, for each dependent variable and on both tables, the Model 1 specification consists of predictors that fall into the category of personal capabilities only. In Model 2 and Model 3, personal attitudes and contextual factors are respectively added as predictors. Gradually adding new predictors in the regressions and examining possible changes in terms of the significance and the sign (positive or negative) of the relationships serves as a

[2] The income inequality ratio (the ratio of the total income received by the top quintile to that received by the lowest quintile) was also initially examined as a key economic indicator but was excluded from further analysis as it was not found to form any statistically significant relationships.

Table 3
Descriptive statistics of all the variables used in this study.

Variables	EB Survey 1 (EU-28)				EB Survey 2 (EU-28)			
	Mean	St.d.	Min	Max	Mean	St.d.	Min	Max
Dependent variables:								
EV purchase	0.01	0.11	0	1				
Solar panel installation	0.06	0.24	0	1				
Home insulation	0.26	0.44	0	1				
Support for ambitious renewable energy targets	3.36	0.85	0	4				
Support for public funding for clean energy	3.08	1.13	0	4				
Support for environmental taxes					0.16	0.36	0	1
Support for environmental incentives					0.20	0.40	0	1
Predictor variables:								
Personal capabilities								
Age	51.68	18.23	15	98	51.83	18.20	15	98
Gender = female	0.54	0.50	0	1	0.53	0.50	0	1
Education level = tertiary	0.35	0.48	0	1	0.35	0.48	0	1
Social class = lower	0.45	0.50	0	1	0.45	0.50	0	1
Political orientation = right	0.30	0.46	0	1	0.26	0.44	0	1
Location of residence = rural	0.33	0.47	0	1	0.33	0.47	0	1
Attitudes to life satisfaction								
I am satisfied with my life	0.26	0.43	0	1	0.27	0.44	0	1
Attitudes to climate change								
Climate change is a serious problem	0.84	0.36	0	1	0.80	0.40	0	1
Climate change adaptation is beneficial to citizens	0.69	0.46	0	1				
It is my personal responsibility to tackle climate change	0.35	0.47	0	1				
Protecting the environment is important					0.94	0.24	0	1
Attitudes to socio-political dimensions								
My voice counts in my state	0.59	0.49	0	1	0.60	0.49	0	1
It is important that rules/laws apply equally to all	0.91	0.28	0	1				
It is important that gov. decisions are transparent	0.93	0.24	0	1				
It is important that gov. decisions are taken in the public interest	0.93	0.24	0	1				
It is important that gov. decisions are taken under no discrimination	0.94	0.23	0	1				
It is important that the media are free to criticize the authorities when necessary	0.88	0.32	0	1				
It is important that corruption is investigated and punished	0.94	0.22	0	1				
Corruption is widespread in my state					0.72	0.45	0	1
Social class inequalities are serious in my state					0.83	0.37	0	1
The government does enough to protect the environment					0.99	0.07	0	1
	Eurostat and Odyssee-Mure (EU-28)							
National environmental and energy policy aspects	Mean	St.d.	Min	Max				
Energy prices index	108.11	4.46	102	118				
Log household environmental taxes per capita	2.43	0.33	1.57	3.02				
Log GHG emissions per capita	0.94	0.12	0.73	1.30				
Log number of residential energy policies	0.77	0.33	0	1.46				
Log average number of years since residential energy policies have been implemented	1.04	0.23	0	1.36				
Energy efficiency score	0.46	0.17	0.21	0.80				

validation of the robustness of each model (Colagrossi et al., 2019).

As Table 5 indicates, personal capabilities are significantly associated with technology adoption. Having completed tertiary education is positively associated with adopting each one of the three innovations, while being younger, female of belonging to a lower social class is negatively associated with it. Belonging to the political right is positively associated with EV adoption and home insulation, while living in a rural area is positively associated with home insulation and solar panel installation. In terms of personal attitudes to life and climate change, only the belief that climate change is one's own responsibility significantly affects the adoption of all three innovations. For other attitudes, differences among the adoption of the innovations are reported. For instance, the effects of life satisfaction and of believing climate change is a serious problem are significant only for solar panels and home insulation, but not for EVs. Moreover, the effect of believing that climate change adaptation is beneficial is significant only for solar adoption and home insulation. As for attitudes to socio-political concepts, they appear to affect only home insulation. All the aforementioned observations are consistent across Models 1, 2 and 3. When contextual variables are added in Model 3, certain factors appear to be positively and significantly associated with the adoption of certain innovations. Pertaining to market-based policies, energy prices positively affect EV adoption and home insulation, and environmental taxes positively affect EV and solar panel adoption. Furthermore, the number of years for which residential energy policies are implemented and the energy efficiency score are positively associated with EV adoption and home insulation, respectively. Finally, it is observed that there is sufficient variation across nations pertaining to the adoption of each technology, but not across subregions. This is evident by comparing the variance across different levels in Table 5, where the highest nation-level variation concerns solar panels, followed by EV adoption and home insulation. The same trend is revealed by examining the intra-class correlation coefficient (ICC), a composite measure of variability that detects the existence of systematic differences among levels (Wang and Kim, 2018). An ICC value above 5% is considered to indicate sufficient variation (Muthén, 1994), and based on that standard too, solar panel adoption appears to have the highest variation across nations, followed by EV adoption and home insulation.

Similarly to shaping adoption trends, citizens' personal capabilities have a significant effect in shaping support for innovation, as Table 6 indicates. Having completed higher education is positively associated with support for all innovations, while being younger or belonging to the lowest social class is negatively associated with it. Being female is positively associated with supporting ambitious renewable energy targets, but negatively associated with supporting any of the economic

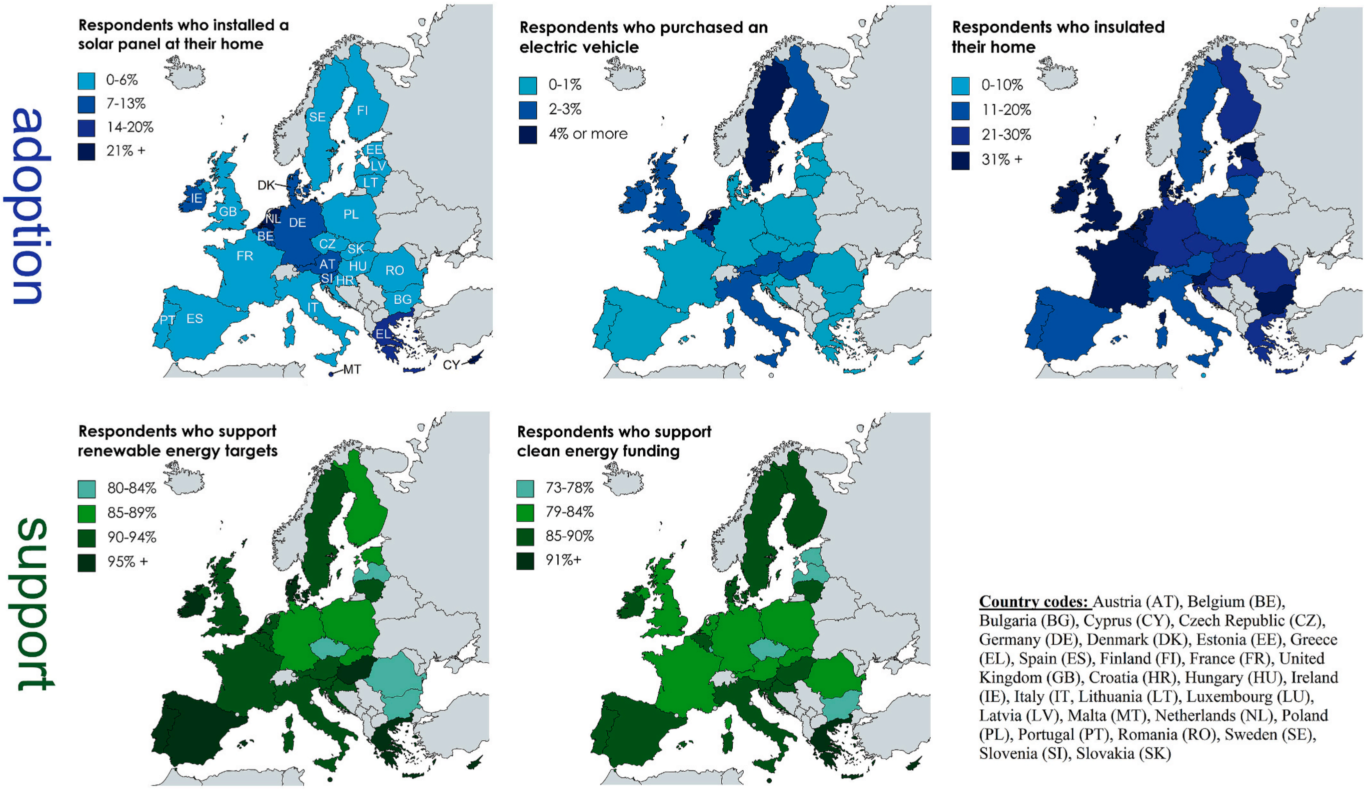

Fig. 2. Summary of adoption (technology) and support (technology and economic innovation) percentages in each EU-28 nation, as derived by answers to Survey 1 questions. The percentages pertaining to the support for renewable energy and clean energy funding reflect the percentages of citizens who responded to the corresponding questions with the 2 highest values of the Likert scale.

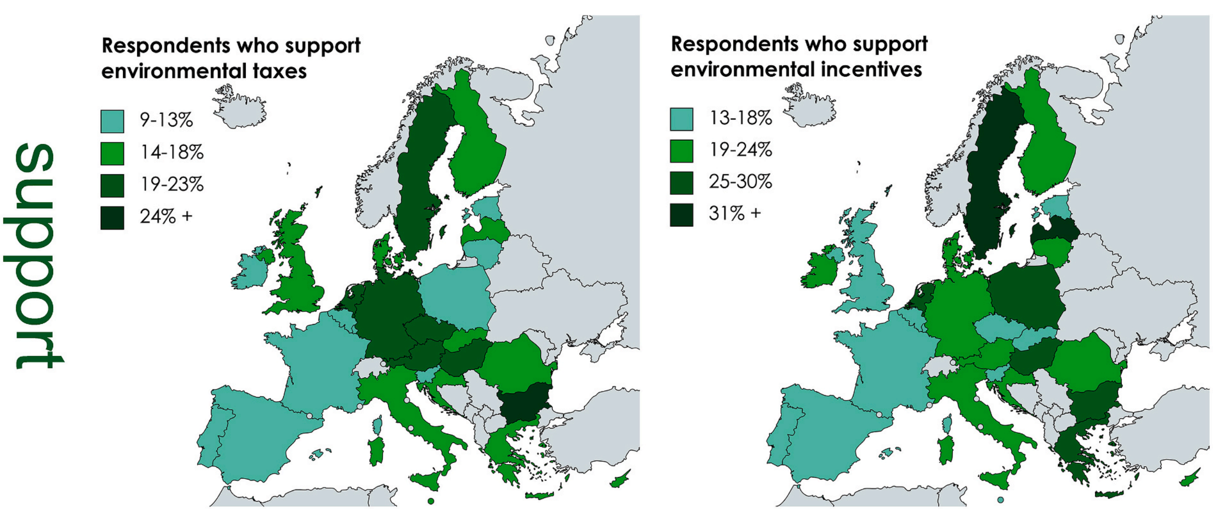

Fig. 3. Summary of support (economic innovations) percentages in each EU-28 nation, as indicated by answers to Survey 2 questions.

innovations. Belonging to the political right creates a positive relationship with supporting incentives, and a negative one with supporting any other innovation. Living in a rural area is negatively associated with support for clean energy funding. Pertaining to citizen attitudes to life and climate change, they are all positively and significantly associated with support for renewables and clean energy funding. Moreover, the belief that climate change is a serious problem is positively associated with support for taxes, while the belief that protecting the environment is important has a similar effect with support for incentives. In terms of attitudes to socio-political concepts, they are all positively associated with support for renewables and clean energy funding, while the belief that class inequalities are serious in one's nation is positively associated with support for taxes and incentives. On other hand, the belief that corruption is widespread in one's state is negatively associated with support for the two aforementioned economic measures. Finally, the contextual factors in Model 3 seem to have less effect on support, compared to their relationship with adoption. Only household environmental taxes appear to be positively associated with support for renewables, while the number and duration of policies influence support for clean energy funding and environmental incentives, respectively. Overall, the strongest predictor for support for renewables and of environmental taxes is the belief that climate change is a serious

Table 4
Correlations among the dependent variables of Survey 1 (A) and Survey 2 (B).

A. Dependent variables- Survey 1 (EU-28)					
Adoption	(1)	(2)	(3)	(4)	(5)
(1) EV purchase	1.000				
(2) Home insulation	0.036***	1.000			
(3) Solar panel installation	0.094***	0.158***	1.000		
Support					
(4) Support for renewable energy targets	0.016***	0.065***	0.045***	1.000	
(5) Support for clean energy funding	0.023**	0.042***	0.040***	0.307***	1.000
B. Dependent variables- Survey 2 (EU-28)					
Support	(6)	(7)			
(6) Support for environmental taxes	1.000				
(7) Support for environmental incentives	0.028***	1.000			

p < 0.01, **p < 0.05, *p < 0.1.

problem. Furthermore, the strongest predictor for support for clean energy funding is the belief that climate change adaptation is beneficial, while the strongest predictor for support for environmental incentives is the average number of years since a residential energy policy has been implemented. As in the case of adoption, examining the national-level and subregional-level variations for support reveals significant results only for the former level. However, only support for renewables is associated with a nation-level ICC value that exceeds the 5% threshold, something that is not true for the support for economic measures. Finally, all the nation-level variations for support are smaller compared to the ones for adoption.

5. Discussion

The dependent variable trends observed in Figs. 2 and 3 are plausible and consistent with behavioral economics concepts and observations in the literature. The technology penetration trends illustrated in Fig. 2 are consistent with the degree of difficulty and change each technology introduces to one's lifestyle: home insulation, which is associated with the highest penetration percentage, is a one-off investment that does not entail major disruption in habits; the latter is true to some extent for solar panel installation, which remains however a more complex decision. On the other hand, a shift from an internal combustion engine to an EV (the penetration of which is the lowest among the three technologies) requires a behavioral change, that of charging the vehicle. The above can be explained through the (popular in behavioral economics) status quo bias concept, according to which people tend to avoid change, especially when it concerns complicated decisions (Frederiks et al., 2015). As for Fig. 3, it indicates that environmental taxes are generally supported less compared to incentives across the EU; this is not surprising, as the unpopularity of taxes is well-documented in the literature- for instance, in Carattini et al., 2018. It is interesting to note, however, that support for environmental incentives in Survey 2 (Fig. 3) is smaller compared to the corresponding support for clean energy funding in Survey 1 (Fig. 2). This can be explained by the different way the corresponding question was asked in each survey. The Survey 2 approach (to present taxes and incentives as two of several potentially effective measures) has the advantage of identifying the respondents who strongly believe that taxes or incentives are good solutions, but also the disadvantage of excluding respondents who may think of them as good solutions but would not necessarily place them in their top choices. While this is a limitation, it is useful to include both surveys in this paper, as subsection *4.4* has indicated that this comparison reveals statistically significant trends that are consistent with the support for all the economic innovations, independent of the survey used. The significant consistency in terms of the two surveys' sample populations (indicated by the means and standard deviations of socio-demographics in Table 3) add further confidence to this paper's choice to analyze the surveys together.

Moreover, the correlation and regression results illustrated in Tables 4–6 provide interesting insights pertaining to the adoption and support of SE innovations across the EU. The insights may guide policy-making in the EU-28 nations, especially those interested in facilitating the transition to a cleaner, sustainable and decarbonized energy economy through a combination of technological and economic innovations. In particular, the observed correlations between the dependent variables in Table 4 justify the need for exploring the specific circumstances that may motivate the adoption of each technology. In particular, the weak relationship between supporting renewable energy and having purchased a solar panel demonstrated in Table 4 can be partly attributed to the fact that purchasing a solar panel is only one of the several ways to contribute towards renewable energy targets. Nevertheless, this observation indicates the gap between simply declaring one's support for a technology and actually adopting it for everyday use. In certain settings, support can be the first decision in the acceptance process. However, encouraging support will not necessary lead to adoption without additional measures. This argument is further reinforced by observing the regression model results in Tables 5 and 6: not every predictor that explains support necessarily explains adoption as well, and vice versa. The major policy implication of these observations is that governments need to simultaneously implement strategies to stimulate citizen decisions in both directions. To achieve this, a combination of factors should be considered: in all cases, Model 3 (which contains all types of predictors) is associated with a higher log-likelihood value and thus more explanatory power compared to the other two specifications. In turn, this indicates that adoption and support across the EU may be better influenced when the following individual and contextual factors are jointly considered:

Personal capabilities: Based on the significance of the odds ratios in Tables 5 and 6, the regression analysis provides evidence which links citizens' personal capabilities with each one of the adoption and support decisions. This supports research hypotheses **H1** and **H2** and confirms past studies (Heiskanen and Matschoss, 2017) concerning the importance of demographic characteristics in shaping SE acceptance. Older age appears to be positively associated with adopting and supporting SE innovations; this hints that the positive link between young age and climate change concern reported elsewhere (Duijndam and Beukering, 2021) does not necessarily lead to acceptance of SE innovations. As for political orientation, it is interesting to observe that belonging to the political right is negatively associated with supporting innovations, but at the same time positively associated with adopting innovations. This reinforces the argument for distinguishing between the adoption and support dimensions. Furthermore, and contrary to studies concerning specific European states (Ziegler, 2017), this analysis did not reveal a significant relationship between political orientation and support for environmental taxes. This suggests that at least some environmental actions can be pursued in a non-partisan manner across the political spectrum. On the other hand, social class and education level are among the strongest predictors of acceptance in this category: a key observation from Tables 5 and 6 is that belonging to the lower social classes is a barrier in accepting innovations. This requires particular attention, and measures such as the 15 energy efficiency obligation schemes that are currently active in the EU (Fawcett et al., 2019) and aim to facilitate energy savings at low costs (Moser, 2017) can perhaps pave the way for future programs to facilitate access to SE innovations for lower income households. On the other hand, Tables 5 and 6 indicate that having completed tertiary education is positively associated with accepting the innovations. This positive effect of education can be linked with observations in the literature about a positive relationship between education

Table 5
Summary of results of the multilevel mixed effects logistic regression analysis of the dependent variables relevant to adoption. Odds ratios are reported, errors are in parentheses. Odds ratios greater than 1 and significant are boldfaced.

ADOPTION: EU-28	**Technological innovations**								
	EV purchase			**Solar panel installation**			**Home insulation**		
	Model 1	**Model 2**	**Model 3**	**Model 1**	**Model 2**	**Model 3**	**Model 1**	**Model 2**	**Model 3**
Predictors									
Personal capabilities									
- Age	0.99** (0.00)	0.99** (0.00)	0.99** (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00*** (0.00)	1.00*** (0.00)	1.00*** (0.00)
- Gender: female	0.79** (0.08)	0.79** (0.08)	0.79** (0.08)	0.87** (0.04)	0.86*** (0.04)	0.86*** (0.04)	0.86*** (0.02)	0.85*** (0.02)	0.85*** (0.02)
- Education level: tertiary	**1.43*** (0.15)**	**1.43*** (0.16)**	**1.38*** (0.15)**	**1.60*** (0.09)**	**1.54*** (0.09)**	**1.54*** (0.09)**	**1.49*** (0.05)**	**1.42*** (0.04)**	**1.41*** (0.04)**
- Social class: lower	0.57*** (0.07)	0.57*** (0.07)	0.58*** (0.07)	0.62*** (0.04)	0.65*** (0.04)	0.65*** (0.04)	0.69*** (0.02)	0.74*** (0.02)	0.74*** (0.02)
- Political orientation: right	**1.29** (0.14)**	**1.29** (0.14)**	**1.28** (0.14)**	1.07 (0.06)	1.08 (0.06)	1.07 (0.06)	**1.14*** (0.03)**	**1.11*** (0.03)**	**1.12*** (0.03)**
- Location of residence: rural	0.78** (0.09)	0.77** (0.09)	0.78** (0.09)	**1.40*** (0.08)**	**1.39*** (0.08)**	**1.39*** (0.08)**	**1.30*** (0.03)**	**1.30*** (0.04)**	**1.30*** (0.04)**
Attitudes to life satisfaction									
- I am satisfied with my life		1.09 (0.12)	1.23 (0.13)		**1.33*** (0.08)**	**1.32*** (0.08)**		**1.30*** (0.04)**	**1.30*** (0.04)**
Attitudes to climate change									
- Climate change is a serious problem		1.01 (0.15)	1.04 (0.15)		**1.20*** (0.10)**	**1.20** (0.10)**		**1.19*** (0.05)**	**1.19*** (0.05)**
- Climate change adaptation is beneficial to citizens		**1.24* (0.15)**	**1.27* (0.16)**		**1.12* (0.07)**	**1.12** (0.07)**		1.01 (0.03)	1.01 (0.03)
- It is my personal responsibility to tackle climate change		**1.26** (0.13)**	**1.23* (0.13)**		**1.32*** (0.07)**	**1.32*** (0.07)**		**1.18*** (0.03)**	**1.18*** (0.04)**
Attitudes to socio-political dimensions									
- My voice counts in my state		0.95 (0.11)	0.93 (0.11)		0.97 (0.06)	0.96 (0.06)		**1.15*** (0.04)**	**1.15*** (0.04)**
- It is important that rules/laws apply equally to all		1.14 (0.24)	1.15 (0.24)		1.00 (0.11)	1.00 (0.11)		**1.24*** (0.07)**	**1.24*** (0.07)**
- It is important that gov. decisions are transparent		0.46*** (0.09)	0.45*** (0.09)		0.83 (0.11)	0.83 (0.11)		**1.18** (0.09)**	**1.18** (0.09)**
- It is important that gov. decisions are taken in the public interest		1.31 (0.33)	1.30 (0.33)		0.83 (0.11)	0.83 (0.11)		1.10 (0.09)	1.10 (0.09)
- It is important that gov. decisions are taken under no discrimination		0.52*** (0.12)	0.52*** (0.12)		0.84 (0.12)	0.83 (0.12)		1.03 (0.09)	1.03 (0.09)
- It is important that the media are free to criticize the authorities when necessary		1.01 (0.18)	0.99 (0.18)		1.11 (0.11)	1.12 (0.11)		**1.17*** (0.06)**	**1.17*** (0.06)**
- It is important that corruption is investigated and punished		1.17 (0.32)	1.16 (0.32)		1.12 (0.18)	1.12 (0.18)		**1.34*** (0.12)**	**1.34*** (0.12)**
National environmental and energy policy aspects									
- Energy prices index			**1.06*** (0.02)**			1.01 (0.03)			**1.03* (0.01)**
- Log household environmental taxes per capita			**1.75* (0.58)**			**3.17** (1.80)**			0.70 (0.18)
- Log GHG emissions per capita			1.65 (1.20)			**10.04** (10.35)**			**5.40*** (3.20)**
- Log number of residential energy policies			0.57 (0.20)			1.45 (1.89)			0.89 (0.24)
- Log average number of years since residential energy policies have been implemented			**2.99* (1.70)**			0.82 (0.67)			0.88 (0.38)
- Energy efficiency score			0.69 (0.40)			0.65 (0.64)			**4.72*** (2.24)**
Summary									
Nation-level variance	0.37*** (0.10)	0.34** (0.13)	0.14** (0.07)	0.66*** (0.20)	0.61*** (0.19)	0.36*** (0.12)	0.26*** (0.08)	0.28*** (0.08)	0.14*** (0.04)
Subregion-level variance	0.01 (0.06)	0.01 (0.06)	0.00 (0.00)	0.08 (0.13)	0.08 (0.13)	0.10 (0.17)	0.00 (0.03)	0.00 (0.00)	0.00 (0.00)
Nation-level ICC	**10.9%**		**17.6%**	**6.9%**					
Subregion-level ICC	**1.3%**		**2.7%**	**0.7%**					
Log-likelihood	−1967	−1950	−1942	−5884	−5848	−5842	−15188	−15044	−15034
Observations	27,655	27,655	27,655	27,655	27,655	27,655	27,655	27,655	27,655

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

and climate change concern (Duijndam and Beukering, 2021). This provides a new rationale for investment in education, that of improving the acceptability of SE innovations of both technological and economic nature.

Attitudes: Citizens' life satisfaction is found to be significantly associated with most adoption and support decisions, but not with all of them; this supports **H3** and **H4** but only partially. The strongest positive effect of life satisfaction appears to occur on the support for renewable energy targets. Once again, these observations can be linked to the positive relationship between life satisfaction and climate change concerns (Duijndam and Beukering, 2021). This provides a rationale for governments to identify which quality of life indicators relevant to

Table 6
Summary of results of the multilevel mixed effects logistic regression analysis of the dependent variables relevant to support. Odds ratios are reported, errors are in parentheses. Odds ratios greater than 1 and significant are boldfaced.

SUPPORT: EU-28	Technological innovation						Economic innovations					
	Renewable energy targets			Clean energy funding			Environmental taxes			Environmental incentives		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Predictors												
Personal capabilities												
- Age	0.99*** (0.00)	0.99*** (0.00)	0.99*** (0.00)	0.99*** (0.00)	0.99*** (0.00)	0.99*** (0.00)	0.99*** (0.00)	0.99*** (0.00)	0.99*** (0.00)	0.99*** (0.00)	0.99*** (0.00)	0.99*** (0.00)
- Gender: female	**1.07*** (0.03)**	**1.04* (0.02)**	**1.04* (0.02)**	0.88*** (0.02)	0.87*** (0.02)	0.87*** (0.02)	0.95 (0.03)	0.93* (0.03)	0.94* (0.03)	0.90*** (0.03)	0.90*** (0.03)	0.90*** (0.03)
- Education level: tertiary	**1.33*** (0.04)**	**1.16*** (0.03)**	**1.16*** (0.03)**	**1.29*** (0.03)**	**1.15*** (0.03)**	**1.15*** (0.03)**	**1.28*** (0.05)**	**1.25*** (0.05)**	**1.24*** (0.05)**	**1.19*** (0.04)**	**1.17*** (0.04)**	**1.17*** (0.04)**
- Social class: lower	0.76*** (0.02)	0.85*** (0.02)	0.84*** (0.02)	0.75*** (0.02)	0.84*** (0.02)	0.84*** (0.02)	0.88*** (0.03)	0.90*** (0.03)	0.91** (0.03)	0.86*** (0.03)	0.88*** (0.03)	0.89*** (0.03)
- Political orientation: right	0.83*** (0.02)	0.78*** (0.02)	0.78*** (0.02)	0.90*** (0.02)	0.86*** (0.02)	0.86*** (0.02)	0.98 (0.04)	0.98 (0.04)	0.99 (0.04)	**1.17*** (0.04)**	**1.17*** (0.04)**	**1.17*** (0.04)**
- Location of residence: rural	0.98 (0.02)	1.02 (0.03)	1.02 (0.03)	0.90*** (0.02)	0.94** (0.02)	0.94** (0.02)	0.94 (0.03)	0.94 (0.03)	0.94 (0.03)	0.98 (0.03)	0.98 (0.03)	0.99 (0.03)
Attitudes to life satisfaction												
- I am satisfied with my life		**1.50*** (0.05)**	**1.50*** (0.05)**		**1.19*** (0.03)**	**1.18*** (0.03)**		1.04 (0.04)	1.06 (0.04)		1.03 (0.04)	1.04 (0.04)
Attitudes to climate change												
- Climate change is a serious problem		**2.90*** (0.10)**	**2.90*** (0.10)**		**2.03*** (0.06)**	**2.03*** (0.06)**		**1.29*** (0.06)**	**1.28*** (0.06)**		0.98 (0.04)	0.98 (0.04)
- Climate change adaptation is beneficial to citizens		**1.41*** (0.04)**	**1.41*** (0.04)**		**2.97*** (0.08)**	**2.97*** (0.08)**						
- It is my personal responsibility to tackle climate change		**1.36*** (0.04)**	**1.36*** (0.04)**		**1.30*** (0.03)**	**1.30*** (0.03)**						
-Protecting the environment is important								1.06 (0.08)	1.07 (0.08)		**1.20*** (0.08)**	**1.21*** (0.08)**
Attitudes to socio-political dimensions												
- My voice counts in my state		**1.20*** (0.03)**	**1.20*** (0.03)**		**1.22*** (0.03)**	**1.22*** (0.03)**		1.03 (0.04)	1.04 (0.04)		1.05 (0.03)	**1.06* (0.04)**
- It is important that rules/laws apply equally to all		**1.27*** (0.06)**	**1.27*** (0.06)**		**1.47*** (0.07)**	**1.47*** (0.07)**						
- It is important that gov. decisions are transparent		**1.50*** (0.09)**	**1.50*** (0.09)**		**1.28*** (0.07)**	**1.28 *** (0.07)**						
- It is important that gov. decisions are taken in the public interest		**1.20*** (0.07)**	**1.20*** (0.07)**		**1.19*** (0.07)**	**1.19*** (0.07)**						
- It is important that gov. decisions are taken under no discrimination		**1.60*** (0.10)**	**1.60*** (0.10)**		**1.39*** (0.08)**	**1.39*** (0.08)**						
- It is important that the media are free to criticize the authorities when necessary		**1.59*** (0.06)**	**1.59*** (0.06)**		**1.75*** (0.07)**	**1.74*** (0.07)**						
- It is important that corruption is investigated and punished		**1.64*** (0.10)**	**1.64*** (0.10)**		**1.15** (0.07)**	**1.15** (0.07)**						
-Corruption is widespread in my state								0.93 (0.04)	0.93* (0.04)		0.89*** (0.03)	0.90*** (0.03)
-Social class inequalities are serious in my state								**1.12** (0.05)**	**1.12** (0.05)**		**1.09** (0.04)**	**1.08* (0.05)**
- The government does enough to protect the environment								1.00 (0.00)	1.00 (0.00)		1.00 (0.00)	1.00 (0.00)
National environmental and energy policy performance aspects												
- Energy prices index			0.99 (0.02)			0.98 (0.01)			0.99 (0.01)			1.00 (0.01)

(continued on next page)

Table 6 (*continued*)

SUPPORT: EU-28	**Technological innovation**						**Economic innovations**					
	Renewable energy targets			**Clean energy funding**			**Environmental taxes**			**Environmental incentives**		
	Model 1	**Model 2**	**Model 3**	**Model 1**	**Model 2**	**Model 3**	**Model 1**	**Model 2**	**Model 3**	**Model 1**	**Model 2**	**Model 3**
- Log household environmental taxes per capita			**1.75*** **(0.50)**			1.02 (0.20)			0.86 (0.18)			0.93 (0.16)
- Log GHG emissions per capita			0.74 (0.50)			0.51 (0.23)			0.48 (0.24)			0.46* (0.19)
- Log number of residential energy policies			1.21 (0.38)			**1.43*** **(0.30)**			0.99 (0.23)			0.66** (0.13)
- Log average number of years since residential energy policies have been implemented			0.68 (0.34)			0.93 (0.31)			0.71 (0.26)			**1.80*** **(0.55)**
- Energy efficiency score			1.04 (0.56)			0.53* (0.19)			0.91 (0.03)			0.74 (0.25)
Summary												
Nation-level variance	0.25*** (0.07)	0.20*** (0.06)	0.18*** (0.05)	0.14*** (0.04)	0.08*** (0.02)	0.08*** (0.00)	0.09*** (0.03)	0.09*** (0.03)	0.09*** (0.03)	0.09*** (0.02)	0.09*** (0.02)	0.06*** (0.02)
Subregion-level variance	0.04 (0.05)	0.02 (0.03)	0.00 (0.00)	0.04 (0.05)	0.03 (0.03)	0.00 (0.00)	0.02 (0.02)	0.02 (0.02)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Nation-level ICC	**7.4%**		**4%**	**2.8%**		**2.9%**						
Subregion-level ICC	**1.4%**		**1%**	**0.3%**		**0%**						
Log-likelihood	−27066	−25495	−25493	−32054	−30096	−30093	−11849	−11825	−11429	−13801	−13790	−13346
Observations	27,655	27,655	27,655	27,655	27,655	27,655	27,498	27,498	27,498	27,498	27,498	27,498

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

energy innovations are valued most highly by their citizens, and to create the surrounding conditions that would improve them. Some potential applications include a comprehensive list of 22 quality of life indicators linked to personal motives for sustainable consumption, compiled by Poortinga et al. (2004). Furthermore, citizen attitudes to climate change and the environment are found to significantly affect each one of the adoption and support decisions; thus, **H5** and **H6** are supported. This is consistent with past studies that suggested a link between personal attitudes to climate change and the environment and behaviors such as residential energy-saving (Gadenne et al., 2011; Karlin et al., 2014), technology adoption (Decker et al., 2009; Michelsen and Madlener, 2011) and tax acceptance (Kallbekken and Sælen, 2011). The above make it critical for public policy to reinforce altruistic environmental attitudes, such as the notion that battling climate change and protecting the environment is the citizens' own moral responsibility. This can be facilitated through provision of environmental knowledge (Pothitou et al., 2016), and also, through "nudges" and programs that capitalize on social influence (Spandagos et al., 2021) to motivate energy savings. This is particularly relevant to support for environmental taxes, whose strongest predictor in this study is the attitude that climate change is a serious problem. As an additional benefit, appropriately designed taxes may reinforce the belief that environmental burdens are delegated to the ones who are responsible for equal amounts of environmental damage, something that may not hold for cap-and-trade mechanisms (Jakob et al., 2017). As for attitudes to socio-political dimensions, they appear to significantly affect most of the support decisions, but only one of the adoption decisions. In particular, the beliefs concerning corruption, discrimination, freedom of press and equality in laws create some of the strongest relationships with support decisions. Therefore, **H8** is supported but **H7** is supported only partially. Once again, this is particularly important pertaining to support for environmental taxes and incentives, which are negatively associated with the belief that corruption in one's state is widespread. This hints that respondents may believe that taxes and incentives will not provide real benefit in a state that is already corrupted. On the other hand, the positive relationship between supporting taxes and believing that social class inequality is serious within a nation hints that environmental taxation may be viewed by respondents as a measure to combat inequalities. It is of great importance to take advantage of that relationship, and a key consideration of governments in that direction is to identify which revenue recycling mechanism is the most equalitarian. Klenert et al. (2018) suggest that uniform lump-sum recycling is favorable in most circumstances, even though direct payments to poorer households and tax cuts might be more suitable in certain settings. The aforementioned observations indicate the urge for policy-makers to reinforce support for environmental taxes and the other SE-enabling innovations by clearly communicating information about the objectives of the innovations, together with a strong sense of fairness and transparency across all state procedures. In parallel with engineering and cost-effectiveness improvements that increase the safety, reliability and positive impact of SE innovations, the promotion of a general sense of equity, fairness and trust from the side of governments is crucial in strengthening citizen confidence in shared sustainability targets. This is in line with past observations that the appropriate informational campaigns increase the acceptability of such innovations (Carattini et al., 2017).

Overall, it is observed that personal attitudes create a greater number of significant and stronger relationships with the support decisions, compared to what is observed for the adoption decisions. This confirms Stern's suggestion that the more difficult and expensive the behavior, the weaker its dependence on attitudes (Stern, 2000). Supporting an innovation does not entail bearing the monetary and/or comfort costs associated with adopting an innovation. This becomes relevant to the comparison among the three technologies, as home insulation (an one-off action, as discussed in above) is associated with the greater number of significant relationships with attitudes, while EV adoption (which requires behavioral change) is associated with the smallest number.

Contextual factors: National environmental and energy policy indicators create a greater number of significant relationships with all adoption decisions, compared with the support decisions. Therefore, **H9** is fully supported and **H10** is only partially supported. Interestingly, the number of energy policies does not significantly affect any of the adoption decisions. On the other hand, the average number of years since the policies have been implemented is the strongest predictor of EV adoption. This demonstrates that nations with a long legacy of institutionalized residential energy policies are already having an advantage in EV penetration, compared to nations with shorter history in that direction. Furthermore, of particular interest is the positive relationship of energy prices and household environmental taxes with the technology adoption decisions, which hints that the particular instruments are possibly motivating citizens to meet their energy needs through low-carbon solutions. This observation bolsters the case for market-based environmental policies as instruments to facilitate the SE transition. This is particularly intriguing for environmental taxation, which, while remaining an unpopular measure across Europe, seems to positively affect environment-related technological innovation, not only in terms of the number of new patterns (as observed, for instance, in (Karmaker et al., 2021)), but also in terms of public adoption. Interestingly, the amount of current environmental taxation implemented within a state is not found to significantly affect support for taxes, which suggests that households that invest in SE innovations may be responding to the financial incentive from environmental taxation rather than a behavioral nudge. As it is understood that searching for the most appropriate taxation level remains a key tax design consideration (Carattini et al., 2018), this observation should not distract policy-makers from pursuing that goal; instead, it is an alert that setting the optimal amount of taxation should not be the only priority, and that the aforementioned relationships between support for taxes and citizen attitudes to climate change, corruption and inequality should be taken under serious consideration in tax development and communication plans.

Reflecting upon this study's ten research hypotheses, most of them are supported, while the directions and significance levels of the odds ratios in the regressions do not change noticeably, indicating the robustness of the models and of the results across the three specifications. The above confirm that the choice of employing Stern's model of environmentally significant behavior to explore factors that potentially influence SE innovation acceptance was appropriate. At the same time, it can be argued that the lack of significant subregion-level variations in this analysis is linked with the generally ambiguous way such subregions are defined. The European subregions do not have strict "borders", but can instead be defined to include different nations, based on different interpretations of their characteristics. The UNSD clusters European nations into subregions based on geographic criteria, but other sources do likewise by considering institutional and cultural dimensions as well. Dictated by this ambiguity, an alternative clustering[3] was tested following Colagrossi et al. (2019), but the same observation held true: the regression model results did not indicate any noteworthy variation at the subregional level. Nevertheless, the choice to apply multilevel modeling becomes well-justified by the fact that the nation-level clustering explains significant parts of the observed variations. This is more evident for adoption decisions, and especially for solar panel installation, and less evident for support decisions. The latter is plausible, as Tables 5 and 6 indicate that national (contextual) factors are associated primarily with adoption, and to a lesser extent with support. A significant policy implication of this observation is that future support for environmental taxes, incentives and clean energy funding may be strengthened to some extent by common, EU-wide strategies. On the other hand, future policies aiming to strengthen adoption of EVs, solar panels and home insulation, and support for renewables, may be required to be nation-specific at greater extent, and take into greater account the unique characteristics of each nation.

[3] The difference between the clustering by Colagrossi et al. (2019) and the one by the UNSD is that the former places Estonia, Latvia, Lithuania, Slovenia and Croatia to Eastern Europe.

6. Conclusions

This paper presented a comprehensive framework for understanding the factors that potentially influence acceptance of SE innovations across all the EU-28 nations. The framework was designed to examine various dimensions of public acceptance and thus contribute towards addressing several shortcomings in the literature: firstly, it simultaneously considered both adoption and support of innovations; secondly, it explored decision factors that are relevant to technological and economic innovations alike; thirdly, it considered decision factors that have received less attention in the extant literature, such as citizen attitudes towards broader socio-political concepts; finally, it compared trends based on a large pool of international data, while exploring the extent of national-level and subregional-level effects. The empirical analysis was based on multilevel logistic regression models, which were fed with academically unexploited individual (micro-level) and contextual (macro-level) data from reputable sources of EU statistics.

The adoption decisions of interest concerned EVs, home solar panels and home insulation, while the support decisions concerned renewable energy targets, environmental taxes and incentives, and the allocation of public funding to clean energy transitions. Overall, this paper demonstrates the need to distinguish among the conditions that drive adoption, those that drive support, and those that drive both. At the same time, the paper provides evidence that each one of the adoption and support decisions are affected by combinations of individual-level capabilities and attitudes, and national-level contextual factors. Citizen capabilities and attitudes to life satisfaction generally affect both adoption and support; attitudes to climate change and the environment also affect both adoption and support, with certain variables in that category being the strongest predictors for most support decisions; attitudes to socio-political dimensions primarily affect support; contextual factors in the form of environmental and energy policy indicators primarily affect adoption, with variables in that category being the strongest predictors for all adoption decisions.

Several implications can be stipulated for policy-makers in the EU-28 nations, where increased citizen acceptance of SE-enabling policies may contribute to cleaner, more sustainable and more responsible energy management. Firstly, it is important to simultaneously address the adoption and support dimensions of acceptance, while considering possible trade-offs in measures that increase technology adoption but are unpopular. Of particular interest are energy prices, which are observed to be associated with increased adoption of EVs and home insulation, and environmental taxes, which are observed to positively affect adoption of EVs and solar panels- indicating that such market-based policies may be motivating citizens to increasingly rely on low-carbon technology for their energy needs. Secondly, these policies need to be appropriately designed and accompanied by instruments that target to satisfy citizens' considerations about the quality of their life, climate change and the environment, and broader socio-political dimensions such as lack of corruption and discrimination. Energy policy should be communicated in a manner that highlights the transparency of certain measures, as well as the egalitarian and inclusive way the state operates, forging the citizens' sense of being represented in an ethical and unprejudiced society. These measures, among others, may contribute to SE innovation acceptance. This is in line with recent lessons on innovation acceptability from behavioral economics, according to which policies need to be complemented by information instruments targeted towards understanding and satisfying citizen preferences (Shogren and Taylor, 2008; Spandagos et al., 2020). Finally, the noteworthy nation-level variations pertaining to the adoption of technological innovations in the EU suggest the requirement for future approaches targeting technology acceptance to be more nation-specific, something that may be less necessary for approaches targeting support for economic measures.

Most observations pertaining to citizen capabilities and attitudes towards the environment are consistent with several studies on energy-saving behaviors. On the other hand, fewer SE acceptance studies have focused explicitly on attitudes towards life satisfaction and broad socio-political dimensions (such as (Klenert et al., 2018)), thus more research is needed to fully evaluate the results under that perspective. Moreover, the large pool of data from 28 nations and the robustness of the models developed in this paper add confidence to the results and their implications for European policy. Nevertheless, and as Table 1 indicates, the interest in motivating public acceptance of SE innovations spans across several continents, and concerns nations such as the United States and China (Cheng et al., 2021) that surpass Europe in energy-related emissions (World Resources Institute (WRI), 2020). Therefore, it is intriguing to explore to what extent the present research hypotheses and models will apply in these locales. Furthermore, in line with the recent suggestions of Steg et al. (2021), it is intriguing to employ the framework presented in this paper to understand whether the predictors of acceptance differ between early and later adopters of innovations (Noppers et al., 2015). In that regard, data that reflect citizens' habits or routines relevant to innovations would expand and possibly strengthen the framework by integrating into it the fourth type of predictors of Stern's model (a type of predictors that was omitted in the current framework version due to unavailability of suitable data). Finally, another future direction for the framework is to integrate variables that measure the citizens' awareness of SE innovations, and their level of confidence towards their own assessments. Characteristics of that type may have a large impact on acceptance, but data that could possibly fit this purpose (for instance (European Union- Eurobarometer, 2007)) need to be updated in order to reflect responses to the latest technological trends.

CRediT authorship contribution statement

Constantine Spandagos: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Miguel Angel Tovar Reaños:** Methodology, Data curation, Supervision. **Muireann Á. Lynch:** Conceptualization, Writing – review & editing, Supervision, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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APPENDIX

Table A
Summary of the study's predictor variables.

Predictor variables	Source	Coding
Personal capabilities		
Age	Surveys 1,2	Age of the respondent.
Gender = female	Surveys 1,2	Gender of the respondent, '1' for female.
Education level = tertiary	Surveys 1,2	Age >20 years when finishing full-time education.
Social class = lower	Surveys 1,2	2 lowest values of a 5-point scale of self-declared social class, from the working class to the higher class.
Political orientation = right	Surveys 1,2	5 highest values on a 10-point scale about political orientation, from left to right.
Location of residence = rural	Surveys 1,2	Rural area as location of residence.
Personal attitudes to life		
I am satisfied with my life	Surveys 1,2	2 highest values on a 5-point scale about self-declared satisfaction with life.
Personal attitudes to climate change		
Climate change is a serious problem	Surveys 1,2	5 highest values on a 10-point scale about whether climate change is a serious problem, where '10' indicates the highest level of seriousness.
Climate change adaptation is beneficial to citizens	Survey 1	2 highest values on a 5-point scale level of agreement with the statement that climate change adaptation is beneficial to citizens.
It is my personal responsibility to tackle climate change	Survey 1	'1' for tackling climate change being one's personal responsibility.
Protecting the environment is important	Survey 2	2 highest values on a 5-point scale level of how important for the respondent personally is to protect the environment.
Personal attitudes to socio-political dimensions		
My voice counts in my state	Surveys 1,2	2 highest values on a 5-point scale level of agreement with the statement that the respondent's voice counts within his/her state.
It is important that rules/laws apply equally to all	Survey 1	2 highest values on a 5-point scale level of importance of rules and laws being applied equally to all.
It is important that gov. decisions are transparent	Survey 1	2 highest values on a 5-point scale level of importance of the government communicating clearly the reasons behind their decisions.
It is important that gov. decisions are taken in the public interest	Survey 1	2 highest values on a 5-point scale level of importance of governmental decisions being made in the public interest.
It is important that gov. decisions are taken under no discrimination	Survey 1	2 highest values on a 5-point scale level of importance of governmental decisions being made under no discrimination.
It is important that the media are free to criticize the authorities when necessary	Survey 1	2 highest values on a 5-point scale level of importance of the media being able to criticize the government without any consequences.
It is important that corruption is investigated and punished	Survey 1	2 highest values on a 5-point scale level of importance of corruption is being investigated and punished.
Corruption is widespread in my state	Survey 2	2 highest values on a 6-point scale level of corruption being widespread in the respondent's state.
Social class inequalities are serious in my state	Survey 2	2 highest values on a 5-point scale level of importance of class inequalities in the respondent's state.
The government does enough to protect the environment	Survey 2	2 highest values on a 4-point scale level of how much the government is doing to protect the environment.
National environmental and energy policy aspects		

(*continued on next page*)

Table A (*continued*)

Predictor variables	Source	Coding
Energy prices index	Eurostat	Energy prices index (100 = 2015).
Household environmental taxes per capita	Eurostat	Household environmental taxes in Euros per capita.
GHG emissions per capita	Eurostat	GHG emissions in tonnes per capita.
Number of residential energy policies	Odyssee-Mure	Number of national residential energy policies.
Average number of years since residential energy policies have been implemented	Odyssee-Mure	Average number of years since national residential energy policies have been implemented.
Energy efficiency score	Odyssee-Mure	Aggregated indicator (0–1) reflecting achieved level of energy efficiency.

Table B
Summary of EU citizens' attitudes towards life satisfaction, climate change and socio-political aspects, as derived by answers to Survey 1.

% of respondents											
Nations	**Attitude towards life satisfaction**	**Attitudes towards climate change**			**Attitudes towards socio-political aspects**						
	I am satisfied with my life	Climate change is a serious problem	I am responsible to tackle climate change	Climate change adaptation is beneficial to citizens	It is important that …						My voice counts in my state
					rules/ laws apply equally to all	gov. decisions are transparent	gov. decisions are taken in the public interest	gov. decisions are taken under no discrimination	the media are free to criticize the authorities	corruption is investigated and punished	
AT	41	79	46	67	89	88	90	90	91	86	82
BE	25	84	54	79	90	95	95	94	96	90	64
BG	6	88	37	60	95	96	96	95	97	89	47
CY	32	88	45	73	97	99	99	97	99	97	31
CZ	20	80	33	51	87	89	90	89	91	72	52
DE	29	86	51	59	97	97	98	98	99	95	77
DK	76	87	58	83	91	95	95	94	95	92	94
EE	13	67	38	34	92	96	96	95	94	83	44
EL	5	95	52	70	98	99	98	98	99	95	22
ES	26	93	56	83	93	94	96	95	96	90	42
FI	38	80	54	59	97	97	97	97	96	92	89
FR	21	87	57	63	91	93	94	92	95	90	64
GB	44	81	59	82	91	96	96	95	97	89	46
HR	22	82	47	77	89	91	91	90	91	84	71
HU	9	91	41	77	93	92	93	92	92	87	47
IE	42	86	62	88	94	97	97	96	98	89	61
IT	12	97	49	67	97	97	98	98	99	96	45
LT	16	79	42	63	87	93	94	94	93	87	32
LU	45	86	57	65	87	93	94	92	95	89	62
LV	14	71	35	55	77	93	94	92	93	83	41
MT	20	94	54	85	94	95	95	95	95	95	60
NL	57	82	61	78	96	98	99	99	99	96	89
PL	15	80	40	70	89	91	91	91	90	86	59
PT	4	93	56	86	95	98	98	97	99	93	56
RO	8	79	45	70	82	81	82	80	81	77	34
SE	27	84	54	78	90	95	95	94	96	90	66
SI	29	86	43	71	90	94	95	94	95	87	61
SK	16	87	48	73	92	92	93	92	94	84	67

Table C
Summary of EU citizens' attitudes towards life satisfaction, climate change and the environment and socio-political aspects, as derived by answers to Survey 2.

% of respondents							
Nations	**Attitude towards life satisfaction**	**Attitudes towards climate change & the environment**		**Attitudes towards socio-political aspects**			
	I am satisfied with my life	Climate change is a serious problem	Protecting the environment is important	My voice counts in my state	Corruption is widespread in my state	The government does enough to protect the environment	Social class inequalities are serious in my state
AT	37	67	87	77	60	42	78
BE	26	85	95	61	67	23	87
BG	10	90	92	46	83	12	92
CY	31	79	95	38	93	31	83

(continued on next page)

Table C (*continued*)

% of respondents							
Nations	**Attitude towards life satisfaction**	**Attitudes towards climate change & the environment**		**Attitudes towards socio-political aspects**			
	I am satisfied with my life	Climate change is a serious problem	Protecting the environment is important	My voice counts in my state	Corruption is widespread in my state	The government does enough to protect the environment	Social class inequalities are serious in my state
CZ	25	64	93	52	83	38	61
DE	32	79	94	77	55	28	88
DK	71	80	96	94	37	48	70
EE	12	60	93	42	65	38	78
EL	11	91	97	34	95	14	90
ES	26	93	97	43	92	10	93
FI	33	73	95	83	26	41	82
FR	21	89	96	66	70	12	93
GB	41	85	95	50	67	20	80
HR	23	84	92	78	96	15	84
HU	13	82	94	50	87	37	87
IE	38	84	93	67	70	19	89
IT	11	95	99	45	91	24	89
LT	17	73	94	33	93	23	91
LU	42	86	97	67	45	41	88
LV	16	68	90	38	86	18	82
MT	22	79	97	59	79	31	76
NL	57	85	96	84	51	35	82
PL	15	82	88	61	64	36	79
PT	9	77	98	60	90	20	87
RO	12	82	87	54	83	27	86
SE	28	85	95	60	67	24	87
SI	26	75	94	61	88	14	79
SK	19	84	95	70	88	21	90

Table D
Contextual (environmental and energy policy aspects) indicators across the EU (Sources: Eurostat and Odyssee- Mure).

Nations	Energy prices index (2015 = 100)	Household environmental taxes (Euros/capita)	GHG emissions (tonnes/capita)	Number of residential energy policies	Average number of years since policies have been implemented	Energy efficiency score (0–1)
AT	105	537	9	6	23	0.37
BE	117	548	11	11	17	0.43
BG	108	66	8	9	11	0.52
CY	105	427	11	8	11	0.23
CZ	109	82	12	0	0	0.23
DE	105	376	11	13	14	0.64
DK	102	1070	9	3	11	0.66
EE	113	136	15	3	8	0.32
EL	108	307	9	7	10	0.48
ES	104	241	8	7	10	0.42
FI	111	580	11	10	19	0.36
FR	117	375	7	29	15	0.72
GB	113	349	8	7	16	0.80
HR	102	207	6	3	9	0.43
HU	108	149	7	6	12	0.21
IE	108	547	13	9	17	0.78
IT	105	525	7	7	12	0.32
LT	105	161	7	9	10	0.50
LU	111	187	20	1	8	0.35
LV	108	190	6	1	12	0.61
MT	102	263	6	5	9	0.25
NL	111	910	12	5	14	0.41
PL	105	133	11	3	8	0.29
PT	106	250	7	11	12	0.54
RO	109	38	6	8	13	0.77
SE	118	466	5	5	14	0.36
SI	108	487	9	8	9	0.53
SK	104	164	8	7	10	0.46

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