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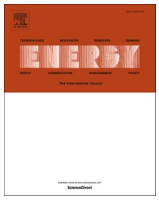

Attitudes toward climate change to demand-driven energy mitigation: A machine-learning approach

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ABSTRACT

Promoting mitigation behaviors among the public is a fundamental step in addressing climate change, yet such efforts have achieved uneven success across demographic groups. This paper surveys the literature on the relationship between personal attitudes toward climate change and mitigation behaviors, with a particular focus on demand-side energy consumption reductions. An interpretative framework for understanding the key drivers of and barriers to common mitigation strategies is provided. Applying a machine-learning approach to survey data from 23 European countries to disentangle the relative importance of attitudinal predictors, the analysis finds that perceived personal responsibility for climate change is the single most powerful predictor of energy-conscious behavior. This paper thus offers a useful guide to understanding successful approaches to incentivizing climate-friendly action within this regional context.

1. Introduction

More than 50 years after the Stockholm Declaration [1], climate change is now widely recognized as one of the most significant challenges of our time. Despite a broad, though not universal, consensus on the necessity of preventing further environmental deterioration, policymakers' efforts to curb emissions have remained largely insufficient to meet the scientific community's recommendations [2,3]. According to the UN Environment Programme, greenhouse gas emissions need to be more than halved by 2035 to put the world back on track to meet the Paris Agreement's goal of limiting global warming to 1.5°C above pre-industrial levels (UNEP, 2024)[4]. This goal was recently reaffirmed at COP30 2025, held in Belém in 2025, where the "Belém Declaration" (High-Level Champions for Climate Action, 2025)[5,6] emphasized that closing the emissions gap requires immediate and unprecedented action on demand-side mitigation. Similarly, the latest UNEP Emissions Gap Report [7] highlights that, without a significant shift in individual energy consumption patterns, the 1.5°C pathway will become structurally unattainable. At the root of this underperformance is the misalignment between polluting behavior and its costly repercussions, which creates what economists call a "public good problem". Fundamentally, the global nature of climate change means that a lack of coordination leads to suboptimal outcomes for all parties involved. Similar misalignments of incentives are found at both the national and international levels (OECD et al., 2024)[8]. When individual actors prefer to free-ride on others' efforts rather than bear the costs of mitigation, the outcome is overconsumption and excessive pollution at the aggregate level. The scale and persistence of the negative externalities have led some authors to describe the issue as a "super-wicked problem" [9]. On the one hand, mounting time pressure and the absence of a central authority demand active engagement from everyone. On the other hand, conflicting incentives and bounded rationality stifle individuals' willingness to unilaterally adopt mitigation behaviors.

Despite the complexity of the issue, solutions do exist. In particular, an approach that has gained prominence in public discourse is the implementation of individual behavioral changes. Recent assessments suggest that closing the mitigation gap requires not only supply-side decarbonization but also faster progress in end-use demand reduction [10,11]. The 2025 World Energy Outlook explicitly identifies public engagement as a critical pillar of the next phase of the energy transition. Despite pushback from small but vocal segments of the population, public recognition of climate change as a real and serious threat has strengthened over the past decades [12]. Therefore, changes in consumers' lifestyles could yield considerable benefits while avoiding some

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of the pitfalls of coordination. While the costs of combating climate change may not be borne evenly across populations, harnessing intrinsic motivation to forgo short-term welfare to prevent future environmental degradation is believed to be a promising avenue for intervention. This paper focuses on demand-side energy mitigation strategies, a term that encompasses decisions by private households and individuals to reduce energy consumption.

However, reducing energy demand is not straightforward [13]. Private efforts are often insufficient to achieve a sustainable development path; therefore, policymakers must devise interventions to support and incentivize such behaviors. Misperceptions about individual energy consumption and the potential benefits of energy mitigation may prevent gains from materializing [14,15]. The extent of belief distortion is even greater among individuals with lower numeracy and weaker pro-environmental beliefs [16], who are often considered more resistant to climate engagement. Existing studies often struggle to clearly map attitudes toward mitigation onto observed behaviors, failing to identify best practices for addressing the issue [17,18]. At the root of these unresolved questions are the scarcity of large-scale studies, especially cross-country and longitudinal ones, and a clear lack of credible causal estimation strategies to account for unobserved confounding variables.

This paper contributes to the literature on climate change mitigation strategies in three ways. First, the paper reviews the theoretical evidence explaining how attitudes and beliefs regarding climate change translate into mitigation actions. Because sustainable behaviors are inherently the product of individuals' deliberate decisions to address a problem deemed real and urgent, identifying obstacles to personal engagement can provide valuable insights into the most promising avenues for intervention. Second, a classification of known factors influencing both climate beliefs and private energy-saving behaviors is proposed to identify which personal characteristics serve as catalysts for curtailment behaviors. Finally, the paper contributes to the debate on the relationship between climate attitudes and mitigation behaviors by proposing a machine-learning algorithm, applied to survey data from 23 European countries, to identify the most powerful predictors of pro-environmental attitudes and behaviors.

The rest of the paper is structured as follows: Section 2 examines how the public perceives climate change, including the recent rise in skepticism and the reasons for its concentration among specific demographic groups. Section 3 then examines in greater depth how beliefs and attitudes translate into practical action, considers potential obstacles, and elucidates the links between climate change beliefs and one solution: demand-side energy mitigation. Section 4 offers a more detailed analysis of the main predictors of engagement with environmental issues and reviews the strengths and weaknesses of existing studies. Section 5 presents a machine-learning approach to identify the most important predictors of energy curtailment and efficiency improvements. Finally, Section 6 provides concluding remarks.

2. Environmental beliefs and climate change skepticism

A pivotal question is whether the public regards climate change as an established reality or as a majority opinion explicitly challenged by others. As current environmental goals appear to be increasingly insufficient to tackle accelerating climate change [19] and issue fatigue plays a significant role in discouraging sustained engagement [20,21], it is imperative to understand when and why engagement with mitigation actions fails to mobilize certain sections of the population. To do so, a necessary step is to understand how people conceptualize environmental matters. In recent years, a substantial surge in skepticism has been observed [22], despite the scientific community reiterating that significant changes in consumption and production trajectories remain necessary to mitigate the adverse consequences of climate change. How can this surprising surge in denialism be reconciled with the ever-growing body of objective evidence contradicting it, even more so considering that scientific data are becoming increasingly accessible thanks to faster and more pervasive internet connections?

The first crucial distinction is between climate change denial and skepticism. Despite media attention, the former is recognized as a fringe view [23,24] and is associated with small percentages of respondents in representative surveys. Using Round 8 of the European Social Survey as an indicator of environmental opinions among Europeans (shown in Fig. 1), outright denial is rarely observed: only 0.83% of the sample explicitly identifies with the statement “I don't think climate change is happening.” This is unsurprising: people tend not to behave in deliberately irrational ways, and while scientific evidence may be partially disputed (particularly concerning the interpretation of the rise in average temperatures), there is little doubt that the climate has markedly changed in recent decades. On the other hand, varying degrees of skepticism about the anthropogenic nature of climate change and its threat to everyday life are increasingly prevalent across demographic groups [25]. Turning again to the survey, the level of consensus regarding human responsibility for the root causes of climate change is at best moderate. The distribution is approximately bell-shaped, with its mode falling equally between human activity and natural forces, while displaying only slight skewness toward the former. This suggests that although some recognize that humans are solely responsible for climate change, this view is not widely shared. Instead, it appears common to regard environmental transformations as at least partly natural (see Fig. 2).

Notably, the heterogeneity among climate skeptics warrants exploration. For instance, pro-environmental beliefs are not entirely absent among these groups, as they report concerns about air and water quality. However, their support appears to decline significantly when the focus shifts to climate change-related issues, such as global warming [27]. In light of these results, Haltinner and Sarathchandra [28] argue that a more nuanced description of attitudes might be warranted. By accounting for uncertainty in responsibility attribution and thereby characterizing skepticism as a continuum, it may be possible to achieve greater explanatory power. In other words, a core idea in this new approach to climate skepticism is the necessity of recognizing the complex nature and significance of this social phenomenon. Rather than treating skeptics as a monolithic group of people holding common beliefs, they should be understood as an internally heterogeneous contrarian movement that finds in opposition to science a way to affirm its identity and express its discontent with the current state of affairs.

At the root of climate skepticism there appears to be a gap between the perceived magnitude and urgency of the issue and the scientific evidence [29]. Accurate information regarding climate change does appear to be less available to doubters [30,31], perhaps as a result of selective consumption of content, either voluntarily (as a result of biased selection and retention of information) or involuntarily (through exposure to unreliable or partisan media outlets). However, the phenomenon is not solely, or even predominantly, linked to a higher degree of misinformation [25]. Numerous studies suggest that providing accurate information is insufficient to address the discrepancy and that belief updating remains aligned with prior opinions on the issue [32,33]. Indeed, identity-affirming information seems to receive preferential treatment, especially among those who are more culturally polarized to begin with. Critically, the role of partisan newspapers [34,35], fossil fuel companies [36], and other politically motivated groups and individuals [37,38] has been found to significantly shape individual opinions, possibly hindering the learning process. In turn, the belief gap translates into differences in support for environmental action, with strong correlations between partisanship and preferred mitigation approaches [39].

At this point, the question naturally arises: what distinguishes climate doubters from the rest of the population? There is a rich literature examining predictors of skepticism, which identifies demographic and ideological variables that correlate with weaker environmental beliefs and attitudes (for relevant meta-analyses, see Hornsey et al. [40] and Cipriani et al. [41]). Indeed, these attitudes are not equally common

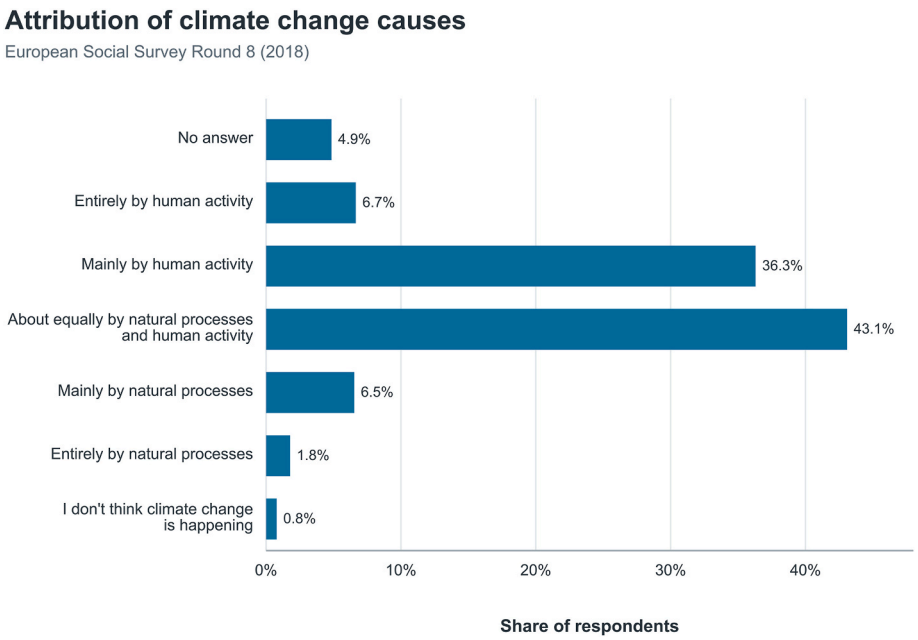

Fig. 1. Relative frequency of beliefs regarding the origin of climate change. Source: Authors' elaboration on Round 8 of the European Social Survey (collected in 2018).

across demographics. In many English-speaking countries, distrust of scientific evidence appears prevalent among politically conservative strata of the population, particularly among males [42–45]. Politics seems to correlate strongly with climate skepticism: McCrea et al. [46] show that, in the wake of an election, voting behavior influences climate change beliefs more than the other way around, reinforcing the idea that political ideology plays a pivotal role in explaining the rejection of climate concerns. The importance of political identity seems to have increased over time [47], consistently ranking among the most powerful predictors of climate skepticism [41], especially in wealthier countries [48]. Interestingly, in contexts where no party explicitly supports climate skepticism, political participation declines among those who hold these unconventional beliefs [49]. More fundamentally, there appears to be a difference in how different groups conceptualize the implications of the phenomenon. For instance, perceiving global warming as a personal rather than a planetary threat is associated with greater reported concern about the issue [50].

To understand why these demographics are more susceptible to climate skepticism, it is imperative to examine the motivations that make such a contrarian position appealing. An explanation for the increasing traction it has gained over the years has been formalized by Kahan [32] and Kahan et al. [51] as the "Cultural-Identity-Protective Risk Perception Thesis." The conceptual framework is rooted in the cultural theory of risk perception [52–54] and identity-protective cognitions [55,56], Intuitively, when reality, or the closest approximation of it through scientific evidence, clashes with widely held beliefs that constitute a core part of one's identity and membership in a social group, people may prefer to dismiss new information altogether rather than revise such core beliefs [57]. This decision serves to shield the group's interests from the effects of climate change and the behavioral changes that recognizing its existence entails, not to mention of the direct responsibility it attributes to developed societies. Accepting that climate change is a direct consequence of a long-held consumerist lifestyle would threaten not only their living standards, forcing them to reconsider the implications of their behavior, but also the ethical connotations associated with the nostalgic ideal of society, which constitutes the romantic core of many conservative platforms.

The view of environmental skepticism as a consequence of motivated reasoning by those who see climate change action as a threat to society is also a central theme in the "anti-reflexivity thesis," as presented by McCright [58] and McCright and Dunlap [59]. According to this theory, mobilization to defend industrialized society against the threats posed by social movements and the scientific community results from the perceived undesirability of the radical government interventions that their claims entail. Therefore, by fundamentally opposing the idea that the current state of society is flawed and politicizing the claim that a transformation is required, culturally conservative groups and economically motivated enterprises have joined forces to push their agenda on the public. Their success is explained by their ability to address a general sense of dissatisfaction among the American middle class, which then expanded into a worldwide phenomenon.

Taken together, these perspectives suggest that the seemingly irrational rejection of scientific evidence is most likely not a failure of reasoning, but rather a mechanism designed to shield individuals from the attacks of a world that is changing around them. In many respects, this view of climate skepticism complements the "cultural backlash" hypothesis of Inglehart and Norris [60]. As society's core values shift toward greater progressivism, once-dominant groups may perceive ongoing social and cultural change as threatening to their status or values. The natural response is then to oppose the institutions that underpin modern society; among these, science is one of the most notable. While the critical rethinking of the ethical implications of our consumption patterns undermines their foundations, these individuals find a new identity and a sense of belonging as "climate change skeptics". Whether this transition would have occurred without the assistance of economically and politically motivated groups remains an open question.

Although this analysis of climate skepticism is essential to our understanding of mitigation inaction, researchers are also interested in when and under what conditions individuals with pro-environmental attitudes are willing to engage personally with the issue. Given the scale of the projected consequences of climate change, it seems evident that, among those who accept this narrative, it is of the utmost importance to act to prevent further environmental deterioration. However, evidence shows a strong disconnect between green beliefs and mitigation action [61]. In the next section, the paper addresses the fundamental question: why are those who believe in climate change not always ready to act to mitigate it?

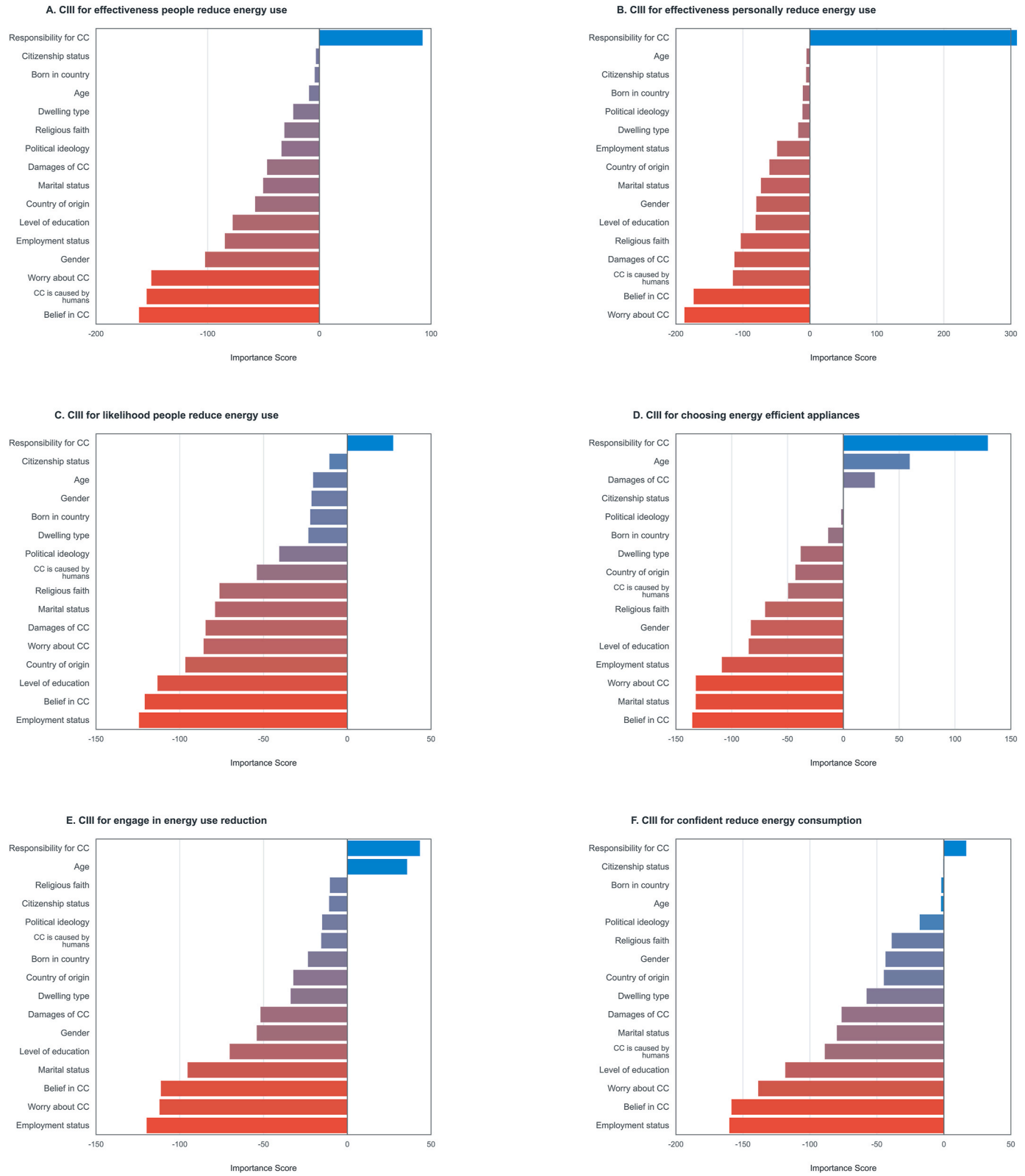

Fig. 2. Variable-importance scores for the main environmental variables among European respondents (n = 37,255), using Altmann et al. [26] AIR scores. The outcome variables for each graph are as follows. In the left column from the top: Effectiveness of people reducing energy use; Likelihood of people reducing energy use; Engage in energy use reduction. In the right column from the top: Effectiveness personally reduces energy use; Choosing energy efficient appliances; Confidently decreasing energy consumption. A complete description of these variables is provided in Table 1.

3. Energy consumption reduction as a mitigation strategy

3.1. Understanding how beliefs become behaviors

Despite our current understanding of what predicts concern for the environment, translating beliefs into action remains a nontrivial task. According to the Theory of Planned Behavior and its extension, the Theory of Reasoned Action [62–64], the decision to engage in a specific behavior is the result of the interaction between two core components. On the one hand, there is intention, which depends on perceiving the issue as worthy of effort and socially desirable. On the other hand, perceived behavioral control, that is, the extent to which individuals believe their behavior is feasible and can effectively influence the outcome, is fundamental to catalyzing action. This framework is a powerful tool for understanding the pathways to and obstacles to personal engagement. Several studies have applied this perspective to climate change research [65–67]. Crucially, because actions are conceptualized as deliberate choices to pursue a goal, how individuals understand and evaluate the importance of the problem and how they assess the most desirable approach to address it, will be key to predicting engagement in mitigating environmental damage. Indeed, evidence supporting a link between climate change beliefs and mitigation behaviors is abundant [68–71].

However, attitudes are a necessary but not sufficient condition for action [40]. Engagement in mitigation behaviors often requires more than merely reporting concern for the environment. Especially significant is the degree of personal responsibility that individuals feel toward the climate issue [72]. This is not necessarily inconsistent with strong concern about global warming: individuals might view private energy conservation negatively because they believe collective action, pursued through political and policy efforts, to be more effective [73]. Moreover, personal attitudes should not be treated as exogenous or immutable. Evidence suggests that social consensus on climate change, particularly among friends and family, helps explain respondents' reported opinions [74]. Finally, it must be noted that concepts related to climate change mitigation are often interrelated in nontrivial ways [75], so results may vary considerably depending on the measures of environmental beliefs and mitigation behavior used.

To provide a systematic assessment of the drivers of engagement, it is informative to consider the specific barriers and enabling factors that make some individuals willing to intervene, whereas others remain inactive despite similar views on climate risk. There appear to be several barriers to personal engagement with climate change, ranging from psychological to social [71,76,77]. As such, environmental beliefs do not directly translate into greater engagement in mitigation efforts [67,78]. Following Dechezleprêtre et al. [79], three key concepts appear to underlie support for energy mitigation strategies: the perceived effectiveness of these measures in reducing emissions; their distributional impacts on lower-income households (inequality concerns); and their effects on respondents' households (i.e., self-interest). According to the authors, the most widely studied factor is the former. Consistent with the literature, this paper will focus on this dimension in the subsequent discussion. A related psychological literature discusses perceived effectiveness, both at the individual and collective levels, as a function of efficacy, namely the ability to implement substantive behavioral and policy changes, and outcome expectancy, which captures the extent of damage reduction associated with the behavior. Along with collective outcome expectancy, self-efficacy and personal outcome expectancy are positively associated with pro-environmental behaviors, while collective efficacy is not [80]. These results support the idea that individual views of personal and collective action are not simply a function of climate-conscious beliefs. While some people may be willing to translate their attitudes into action when they feel personally committed to making changes, this is less likely when coordination costs and political issues reduce expectations of successfully implementing large-scale behavioral changes. The literature has examined other psychological markers of greater engagement in mitigation actions. In particular, feelings of worry about the consequences of climate change, personal responsibility for causing it, and a moral obligation to fight it display strong explanatory power [81,82]. More generally, personal involvement in mitigation behaviors appears to be associated with this conceptualization of climate change as a challenge worth addressing, and one that calls for direct involvement from private citizens. This link between attitudes and behavior is also shaped by individual capacity for follow-through: self-control, for instance, has been shown to strengthen the relationship between pro-environmental attitudes and actual behavior [83].

Personal concern also influences the preferred type of behavioral response. People with higher levels of worry and susceptibility to environmental threats are more responsive to mitigation framing than to adaptation framing [84]. By contrast, adaptation-oriented responses appear to depend more strongly on the availability of information about climate change [85]. In other words, results may vary considerably depending on the level of individual concern, the specific solution, and the individual's ability to commit to its implementation.

A related strand of research points to the importance of policy understanding. Energy literacy appears to be a key dimension of climate engagement [86]. However, Savin and van den Bergh [87] find that greater reported awareness of available policy tools among respondents is negatively, rather than positively, associated with the precision of recommended mitigation strategies. Therefore, the observed overconfidence suggests that standard measures of policy engagement fail to capture genuine understanding of the problem and the available solutions. As policy reforms are perceived as increasingly ambitious or difficult to implement, support tends to decline [88], highlighting the role of perceived feasibility and policy comprehension in shaping environmental action.

3.2. Tackling energy consumption to mitigate climate change

The following discussion will focus on a specific approach to addressing climate change: demand-driven energy mitigation strategies. The term refers to changes in individuals' consumption decisions that account for the environmental implications of energy use. This family of solutions encompasses a range of approaches, from purchasing more efficient appliances to using existing ones more conscientiously (e.g., turning off lights, reducing heating and cooling during transitional seasons). Limiting private energy consumption aims to reduce carbon emissions and promote more sustainable lifestyles.

This bottom-up approach offers practical advantages over alternative solutions, such as carbon taxes and regulatory policy. First, since it results from a personal decision to follow a greener lifestyle, it reduces the need for external enforcement and monitoring mechanisms to ensure compliance with formal regulations. At the same time, it does not require political support, the pursuit of which can create complex situations where environmental policies are bundled with other (typically left-wing) ideological agendas that may not be appealing to the opposite end of the political spectrum [89]. Finally, even small reductions in energy demand and improvements in energy efficiency, when replicated across large populations, can generate substantial aggregate effects. As such, complementing technological advancements and policy reforms with individual mitigation efforts has been suggested as a prerequisite for achieving current environmental goals [90,91].

Despite the potential benefits of this route, various sources suggest that substantial reductions in energy demand have not yet been achieved [92,93]. Indeed, the scope for energy demand reduction measures appears considerable: Eerma et al. [94] estimate that behavioral changes could reduce final energy consumption in Germany by up to 20.5%. Similarly, policymaker-led, demand-focused net-zero scenarios are projected to reduce energy demand by 18–45% by 2050 [95]. According to Belaïd and Joumni [96], the sluggish pace of the green transition may primarily be due to insufficient understanding of how attitudes and

behaviors influence energy demand. In fact, a central condition for energy curtailment is the individual's willingness to make conscious consumption choices while considering the environmental repercussions of these choices. Sustainable consumption is typically more financially costly due to the higher ex-ante investment in newer, more advanced appliances and greener goods. It also adds a layer of complexity to the decision-making process that people may be unwilling to bear. Therefore, recognizing that climate change has the potential to significantly alter their way of life is a prerequisite for promoting engagement.

As mentioned, energy mitigation does not refer to a single class of solutions but rather serves as an umbrella term encompassing a range of approaches to the same problem. A crucial dichotomy is between energy curtailment behaviors and energy-efficiency behaviors. While the former refers mostly to reducing unnecessary energy use and favoring less impactful behaviors capable of producing comparable outcomes (e.g., choosing a more sustainable transportation method), the latter consists of investments in more efficient appliances, typically for use in one's home, which reduce energy consumption at source. It is generally understood that consumers prefer energy curtailment over efficiency improvements [16,97]. Such a tendency to favor curtailment-oriented lifestyle changes has been observed to increase over the years [98], although more recent data are unavailable. This reflects the idea that small behavioral changes can produce benefits without requiring significant investments or the phasing out of functional commodities and appliances, even if they are not necessarily the most efficient. This preference contrasts with experts' recommendations [99,100], as the marginal gains from switching to greener appliances are far greater than those from reducing the use of electric lights. In particular, the risk is that, by making small gestures with relatively little impact but considerable symbolic meaning, consumers fall prey to performative, virtue-signaling behaviors. The perception of having already contributed may reduce willingness to adopt more consequential forms of environmental action. Evidence of this crowding-out effect can be found, for instance, in Nauges and Wheeler [101]. More recently, Sherif and Simon [102] show that social image concerns strongly predict the adoption of certain mitigation behaviors over others, though Ganguli and Mengel [103] suggest that the possibility of influencing others' behavior is more central than mere visibility. Other unintended negative consequences may relate specifically to increased energy efficiency. By lowering the effective cost of energy services, efficiency improvements may induce additional consumption, thereby partially offsetting the expected gains [104]. Critically, the literature finds that the same factors explaining mitigation behaviors may produce asymmetric effects on these two types of energy-saving approaches [105]. For instance, while social influences are consistently positively associated with mitigation behaviors [106,107], income is negatively associated with energy curtailment and positively associated with the purchase of energy-efficient appliances [108].

Likewise, it is essential to note that the framing of these issues plays a key role [109,110], such that support for green technologies does not always translate into greater willingness to pay for them [111]. For instance, consistent evidence indicates that a monetary framing is effective in increasing engagement [110,112], as evidenced by the finding that energy prices predict mitigation behaviors [113]. This is particularly true for low-income individuals from rural areas [114]. Monetary incentives appear to outweigh prosocial incentives [115] and are perceived by households as more effective than informational interventions [116], suggesting that policy tools traditionally associated with economics may be particularly effective means of curbing demand.

In promoting these virtuous behaviors, climate change education may yield long-term benefits [117], although this result does not hold in all contexts [67]. Gains appear more robust when information highlights the mechanisms underlying specific policy actions [79], although the effects of such information tend to be stronger on attitudes than on actual behavior [118–120].

4. Making sense of current research: individual predictors of energy mitigation strategies

Amid an exceptionally fragmented literature spanning sociology, psychology, economics, and other social sciences, this paper seeks to systematize the most important results of prior research, paying attention to the methodological choices made by the authors. Specifically, the following discussion will focus on the predictors most clearly associated with environmental attitudes and energy curtailment behaviors. As discussed previously, the goal of the paper is to characterize the profile of individuals who engage in energy mitigation activities. Three major categories of relevant factors are identified.

4.1. Demographic characteristics

This term refers to the predictors that capture individuals' persistent characteristics. These traits are only partially subject to individual choice, as they are instead the result of their upbringing and other path-dependent, largely immutable circumstances. Precisely because of their persistence, such drivers might be especially informative as markers of green engagement. Among these, the most notable appear to be.

- **Gender** has received widespread attention in the literature, being almost ubiquitous in studies investigating the role of individual predictors. Women have been found to hold stronger pro-environmental stances than men and engage more frequently in mitigation behaviors [121–123]. They also perceive the environmental risks of climate change as more threatening than the economic risks [124] and prioritize sustainability [125]. This gender gap appears to be correlated with a country's level of economic development, with men in wealthier countries tending to perceive mitigation costs as relatively higher [126].
- Although its effects are nonlinear [127], and partly reflect housing choices [128], **age** has been found to influence environmental attitudes [129] and energy consumption [130]. While some studies indicate that older demographics may exhibit more cautious attitudes toward certain mitigation policies—potentially reflecting different generational priorities or specific survey contexts that fail to fully capture experiential wisdom—this dynamic is complex. General awareness of environmental problems has increased over time across all age groups, although some generational differences in policy preferences persist [131].
- The maximum level of **education** achieved is a key predictor of higher levels of energy action [45,132,133]. The effect is both direct, through a greater ability to access, understand, and process information regarding climate issues, and indirect, insofar as more educated people might hold different opinions from the rest of the population. Evidence suggests that more educated individuals display greater concern about the environment [134]. Education also matters with respect to party affiliation, as polarization in beliefs increases with schooling [135,136].
- Individual **socioeconomic status** has also been found to explain attitudes: richer individuals tend to be more willing to adopt energy-related mitigation behaviors to address climate change [98,137,138]. This association is likely linked to the existing correlation between income and other key variables, such as education and political affiliation. It also increases willingness to pay to mitigate climate change, owing to greater financial capacity. High-SES individuals are often considered the group most responsible for greenhouse gas emissions [139,140], so their greater engagement in curtailment behaviors is beneficial for achieving environmental goals.
- Though relatively underexplored, the choice of **residential setting** matters both for environmental attitudes [141] and for energy-reduction behaviors [96,113,114]. People who reside in urban areas appear to express greater concern and be more willing to

engage in curtailment behaviors than their rural counterparts. The dwelling type also predicts mitigation behaviors [142].

4.2. Ideological factors

- **Political affiliation** is among the most popular predictors of climate concern and engagement in energy reduction behaviors [143–145]. More conservative individuals place less value on energy reduction [23] and react more negatively to environmental framings. Gromet and colleagues [146] find that conservatives are less likely to purchase energy-efficient appliances when explicitly reminded that they are protecting the environment than when they are not. Moreover, because political ideologies correlate with other relevant psychosocial traits, this relationship may reinforce identity-protective mechanisms and further reduce the likelihood of climate action.
- Much attention has also been directed toward **personal values** and **worldviews** [147]. An environmental identity, feelings of worry, and personal responsibility are all associated with more decisive energy mitigation actions [72,110]. More generally, human values (such as self-transcendence and openness) are found to matter more than personal responsibility in explaining attitudes toward energy reduction [127], whereas trust in science, institutions, and environmental groups has a positive impact on climate-friendly behaviors [148]. The link between individual attitudes and energy-conscious behaviors holds both in private households and in business settings [149]. Moreover, there appears to be significant heterogeneity between decisions to engage in "extra" mitigation behaviors and decisions to engage in "common" ones. The underlying motivation may reflect both altruistic and egoistic factors, depending on the respondent's psychosocial traits [150].
- As argued in De Sario et al. [151] and González-Rostani et al. [152], occupation has also been found to play a role: workers who have more to lose because green policies threaten their jobs are less likely to support mitigation actions. Similarly, geographic location matters: for instance, those living closer to the equator, who are structurally more exposed to the risks of global warming, appear to be more worried about it, while people living in highly polluted cities are more supportive of mitigation measures [153,154]. Geographic heterogeneity is also documented across the US [155], Europe [156], and the Global South [157]. This evidence aligns with the idea that motivated reasoning is a significant factor in explaining why certain individuals may be more supportive of climate mitigation action than others.

4.3. Cultural factors

- The broader national context appears to play a significant role in explaining engagement: support for mitigation actions seems to depend on the country's level of wealth, as well as on social norms and cultural determinants [153,158–160]. Cultures characterized by a greater long-term orientation seem systematically more willing to bear the costs of climate change mitigation. At the same time, developing countries are less willing to bear the costs of these policies, even though they do not necessarily display lower concern for the issue.
- Cross-country heterogeneity, even when not associated with the previously mentioned mechanisms, has been highlighted in many studies [137,157,161,162]. Beyond the European context, it is crucial to recognize the rapid behavioral and structural transformations occurring in emerging economies. According to the IEA World Energy Outlook [163] and the Energy Technology Perspectives [164], transition pathways in Asia and Africa are increasingly defined by a synergy between energy security and the adoption of clean technologies. The Renewables 2024 report [165] highlights that these regions are not merely adopting Western models but are leading the deployment of decentralized renewable solutions, which fundamentally reshape public engagement with energy. Furthermore, the IEA Electricity Report [166] emphasizes that managing growing demand through behavioral shifts is becoming a cornerstone of sustainable development in these markets. These global trends suggest that, while the core attitudinal drivers remain universal, their practical application is heavily influenced by the rapid technological "leapfrogging" observed in the Global South. The broader context in which people operate influences their perception of the scope and effectiveness of green action. As such, developing countries might struggle to promote and coordinate individual action. Furthermore, affordability concerns, informational asymmetries, and infrastructural limitations, which directly shape energy access, are discussed as key reasons why energy mitigation is difficult to achieve in underdeveloped contexts ([167,168]; [169]). Interestingly, a recent article shows that, despite lower adoption rates, respondents from the Global South exhibited greater support for climate action than in developed countries [170]. For transition economies, estimates suggest that Latin American countries exhibit high levels of concern about climate change, though their willingness to pay for mitigation measures remains relatively low [171]. Therefore, to avoid overgeneralizing existing findings to contexts in which frictions play a key role in shaping individual incentives, country differences should be explicitly considered in climate research.

An established result is that ideological traits have substantially greater predictive power than demographic characteristics. However, we would argue that one potential limitation in the interpretation of their relative importance lies in attributing greater predictive power to specific psychosocial constructs. The latter are inherently more sophisticated concepts, which are themselves byproducts of more fundamental, often unobservable processes that jointly determine both proximate attitudes and actual behaviors. Therefore, attempting to use simple regression models to determine the relative importance of predictors by "horse-racing" covariates is fundamentally flawed, as omitted variables introduce simultaneity that invalidates the analysis. For instance, the fact that political affiliation explains participation in mitigation activities better than respondents' demographics is likely explained by the fact that the former is itself a product (albeit indirect) of these fundamental traits. Therefore, to the extent that opinions are a product of one's upbringing and socioeconomic conditions, statistical modelling will not be able to meaningfully separate the direct effect of, say, income from its indirect effect through political or ideological preference. As a result, the latter concepts will mechanically appear to hold greater explanatory power. While some attempts have been made in this direction using mediation analysis [66,72,143], these studies still rely heavily on researchers' a priori assumptions about the direction of causality, which is often challenging to establish robustly.

4.4. Characteristics of the studies

Among the wealth of studies examining personal engagement in energy curtailment behaviors, diverse perspectives have been brought to the scientific debate, particularly regarding the scope of the analysis and the methodologies employed.

- **Single-vs. cross-country studies:** based on a review of the literature, single-country analyses appear to predominate. For convenience, many seminal studies have used national or even subnational samples [49,77,97,172]. This is also the case for several smaller studies, which apply established frameworks to previously unexplored contexts. Some of these focus on Southern and Eastern European countries, such as Greece [173], Hungary [174], and Lithuania [175]. Others examine developing and underdeveloped areas, such as Pakistan and Bangladesh [176], South Africa [177], and China [178,179]. While they do not yield significant

methodological contributions, they still provide valuable insights, given that some speculate that the greatest potential for cost-effective mitigation actions lies in middle- and low-income countries [180]. Aside from these, even innovative approaches to studying environmental attitudes are restricted to a single country [181,182], thereby limiting the generalizability of the results. At the other end of the spectrum, an increasing number of papers address these problems on a larger scale, for example, through cross-country studies. The main benefit of this setting is that it accounts for potential differences in cultural and institutional settings and for how these differences may affect the results, while also highlighting existing spatial and cultural clusters [79,127,161,183,184]. Cross-European analyses are especially common, primarily relying on the European Social Survey [133,137,138,185]. Other popular databases used at the international level are the Pew Center's Global Attitudes Survey [50,186], the International Social Survey Programme [187], the World Values Survey [188], the Eurobarometer [105,189,190], and the Afrobarometer [191]. Finally, comparisons between geographically distant and culturally distinct countries have been used to support specific arguments [145,192,193]. While the robustness of results generally improves when cross-country samples are used, limitations in the ability to personalize these institutionalized surveys hinder the pursuit of more specific research objectives.

- **Static vs. longitudinal and repeated cross-sectional studies**: while most studies tend to take a cross-sectional approach, gathering responses at a single point in time, this design makes it difficult to disentangle the role of time-invariant characteristics of individuals and countries. For this reason, an increasing number of studies are starting to use repeated cross-sectional and even panel designs to measure individual attitudes and their changes over time [20,21,76,98,111,194]. Nevertheless, the number of papers that effectively study longitudinal variations remains limited. This is due to the costs and complexity of following a population over extended periods, and even more so when researchers aim to construct datasets that track respondents over time. The problem is further complicated by the fact that, even when multiple survey waves are present, the questions may vary considerably. This is the case with the European Social Survey. Although the project has recently reached its eleventh wave, climate and energy items were introduced only relatively recently and have varied in detail across rounds. For that reason, the vast majority of studies still rely on Round 8, which includes a dedicated module on these attitudes and behaviors. In contrast, subsequent waves retain only a handful of these questions, limiting longitudinal comparability.
- **Small vs. large sample studies:** a final dichotomy concerns the number of participants in the study. This distinction often reflects the informal standards of the researcher's discipline. Typically, while psychological research tends to use samples of hundreds of individuals [84,98], sociology and economics rely on much larger pools of respondents, on the order of tens or hundreds of thousands [50,138]. This naturally depends on the type of analysis conducted. In particular, small-sample studies are usually constructed and administered directly by researchers, which would be infeasible at comparable sample sizes. On the other hand, large-scale, general-purpose research is often better equipped to limit biases arising from confounding patterns of non-response and to more accurately approximate the actual distribution of preferences across the population, particularly in a cross-country setting. However, this comes at the cost of relying on third-party surveys, which are less flexible for examining all outcomes.

5. Feature importance ranking using random forests

At the end of the previous discussion, a question remained: what is the best way to measure attitudes toward climate change, and which category of environmental beliefs is more conducive to mitigation-related beliefs and actions? In this section, a solution to this conundrum is proposed through the use of a state-of-the-art machine-learning method to distinguish the most important determinants of mitigation behaviors from those that are only marginally predictive of greater engagement. This research effort closely resembles that of Beiser-McGrath and Huber [195], but with a few substantial differences. This paper extends their analysis by considering not only climate attitudes but also attitudes toward potential solutions, specifically those related to energy use and energy efficiency. Moreover, as discussed in more detail below, the present analysis improves on their methodology by employing debiased impurity-based importance to quantify each predictor's contribution.

The data used have been briefly introduced in the first part of the paper. To train the model, data from Round 8 of the European Social Survey [196] (ESS ERIC, 2023) are used.[1] This is an academically driven, multi-country survey that monitors public attitudes and values across Europe using a cross-sectional design. It is one of the best-known and longest-running attempts to gauge attitudinal changes in Europe and has been repeatedly used to study climate-relevant topics. The analysis considers the "Climate change and energy" rotating module of the survey, which includes several questions concerning climate and energy-mitigation attitudes, beliefs, and policy preferences from respondents. The remaining information on demographics and other control variables is drawn from the core section of the survey. Overall, the key variables are presented in Table 1 and include six measures of energy-related mitigation beliefs and behaviors, as well as five measures of climate change beliefs. In this analysis, all observations with missing values were excluded to account for the differential frequency of demographic variables relative to energy- and climate-related variables. The final sample comprises 37,255 respondents from 23 countries.[2] Other covariates include gender, age, citizenship status, whether the respondent was born in the country, maximum level of education, employment status, marital status, religious faith, political ideology, type of dwelling, and country of origin, as showed in Fig. 2.

To estimate the relative importance of each predictor, a random forest approach is employed [197,198]. This is a supervised machine-learning algorithm that constructs multiple alternative models by random subsets of the data and the available covariates. By aggregating their results and isolating the variables that most consistently improve predictive performance, it is possible to identify the most important drivers of support for energy-related mitigation strategies. The advantage of the approach is that it is less prone to overfitting, which is a major concern in regression-based approaches. The aim is to rank the available covariates by assigning them a variable-importance score. Specifically, rather than using permutation- and impurity-based importance measures, which are inherently biased toward continuous and high-dimensional categorical variables (e.g., country of origin in the sample), the analysis follows the bias-correction approach of Nembrini et al. [199]. Using R's *ranger* package [200], the debiased impurity-based importance index (AIR) is computed. The goal is to reduce the bias typical of standard impurity-based importance measures toward predictors with many categories. Using 500 response permutations and applying the Altmann et al. [26] method to compute p-values, the algorithm effectively ranks variables by their predictive power for the various outcomes.

The results suggest that among the main environmental attitudes, personal responsibility regarding climate change is by far the most

[1] For more information, consult the ESS official webpage at: https://www.europeansocialsurvey.org/.

[2] The included countries are Austria, Belgium, Czech Republic, Estonia, Finland, France, Germany, Hungary, Ireland, Israel, Iceland, Italy, Lithuania, the Netherlands, Norway, Poland, Portugal, Russia, Serbia, Slovenia, Spain, Switzerland, and the United Kingdom.

Table 1
Main energy-related outcome variables and climate-related explanatory variables.

Dimension	Variable	Full text	# of valid responses	Dimension	Variable	Full text	# of valid responses
Attitudes toward energy-mitigation behaviors	Effectiveness of people in reducing energy use	"Now imagine that large numbers of people limited their energy use. How likely do you think it is that this would reduce climate change?"	41,132	Attitudes toward climate change	Belief in CC	"Do you think the world's climate is changing?"	43,289
	Likelihood people reduce energy use	"How likely do you think it is that large numbers of people will actually limit their energy use to try to reduce climate change?"	41,410		CC is caused by humans	"Do you think that climate change is caused by natural processes, human activity, or both?"	42,234
	Effectiveness personally reduces energy use	"How likely do you think it is that limiting your own energy use would help reduce climate change?"	41,654		Worry about CC	"How worried are you about climate change?"	42,654
	Choosing energy efficient appliances	"If you were to buy a large electrical appliance for your home, how likely is it that you would buy one of the most energy-efficient ones?"	43,276		Damage of CC	"How good or bad do you think the impact of climate change will be on people across the world?"	41,232
	Engage in energy use reduction	"In your daily life, how often do you do things to reduce your energy use?"	44,069		Responsibility for CC	"To what extent do you feel a personal responsibility to try to reduce climate change?"	41,927
	Confident reduce energy consumption	"Overall, how confident are you that you could use less energy than you do now?"	43,429				

important indicator of support for energy-related mitigation measures. The predictive power of this construct is so substantial that, conditional on its inclusion, most other predictors add little additional predictive power. Some even receive negative importance scores, indicating that within the model they add noise or an unstable predictive signal rather than consistently improving prediction.

There appears to be little difference between energy curtailment and energy efficiency measures with respect to their relevant predictors, and none between declared attitudes and reported behaviors. Other predictors that play a minor role are age and perceived damage from climate change. The former result is likely due to the way different generations and life stages correlate with distinct worldviews, a relationship not otherwise captured in the models. That said, the explanatory power of personal responsibility is unequivocally superior to that of any other predictor and is a clear candidate for inclusion in any model seeking to predict engagement in mitigation actions. When the goodness of fit of a specification with personal responsibility as the sole explanatory variable is estimated, the model performs comparably to a richer model that includes all available covariates. This is especially true when considering behavioral markers of mitigation action, such as engagement in energy-reduction behaviors and a preference for energy-efficient appliances.

As a robustness check, Table 2 reports the predictive performance of models containing both climate-related and demographic variables, providing further evidence that personal responsibility toward climate change is the most valuable attitudinal marker of support for energy-related mitigation action. Finally, Fig. 3 provides support for the adequacy of the sample size used in the analysis: the learning curves of the random forest algorithm show the sample employed is more than sufficient, as there appears to be little improvement in predictive power when the training sample is increased.

One limitation of this analysis is that, unlike other studies on the topic, it does not examine other psychological constructs, such as values and worldviews. This decision reflects a focus on climate-friendly attitudes and on translating them into mitigation actions. Demographic predictors are included solely for comparison and do not account for the potential confounding effects of deeply rooted determinants of individuals' identities and social positions. Introducing other, more proximate drivers of mitigation attitudes would have required specific operational choices that could have resulted in a less agnostic approach, contrary to the explicit objective of the machine-learning framework.

Table 2
Predictive performance of models containing climate-related and demographic variables.

Outcome	Model	# variables	Accuracy	Mean Absolute Error (MAE)	Quadratic Weighted Kappa (QWK)
Effectiveness of people in reducing energy use	All	16	0.223505	1.772965	0.327943
	Top5	5	0.229402	1.79074	0.343976
	Top1	1	0.234167	1.804064	0.359359
Likelihood people reduce energy use	All	16	0.211332	1.726714	0.239764
	Top5	5	0.210719	1.754753	0.178115
	Top1	1	0.203567	1.784515	0.153457
Effectiveness personally reduces energy use	All	16	0.199996	2.132388	0.35045
	Top5	5	0.212046	2.137876	0.355844
	Top1	1	0.214975	2.192894	0.362874
Choosing energy efficient appliances	All	16	0.314753	1.663269	0.176063
	Top5	5	0.295214	1.77824	0.116164
	Top1	1	0.293346	1.81833	0.035573
Engage in energy use reduction	All	16	0.336752	0.922873	0.233932
	Top5	5	0.331027	0.907966	0.203433
	Top1	1	0.333027	0.886723	0.172529
Confident reduce energy consumption	All	16	0.21778	2.013837	0.247934
	Top5	5	0.223851	2.01402	0.245703
	Top1	1	0.226994	2.016386	0.270655

Notes: This table reports cross-validated predictive performance metrics for six energy-related ordinal outcomes. Estimates are derived from a repeated 5-fold cross-validation procedure with three repetitions using a random forest classification framework. The predictor set includes 16 climate-attitude and socio-demographic variables. "Top-5″ and "Top-1″ specifications include subsets of these variables, selected based on impurity-corrected variable importance [26]. Accuracy measures the empirical frequency of exact matches between predicted and observed categorical outcomes. Mean Absolute Error (MAE) quantifies the average categorical distance between predicted and observed values. Quadratic Weighted Kappa (QWK) evaluates the proportion of agreement beyond what is statistically expected by random chance while penalizing discrepancies according to the square of their categorical distance.

A second limitation is that these results are based exclusively on data from developed countries, particularly European ones. Previous

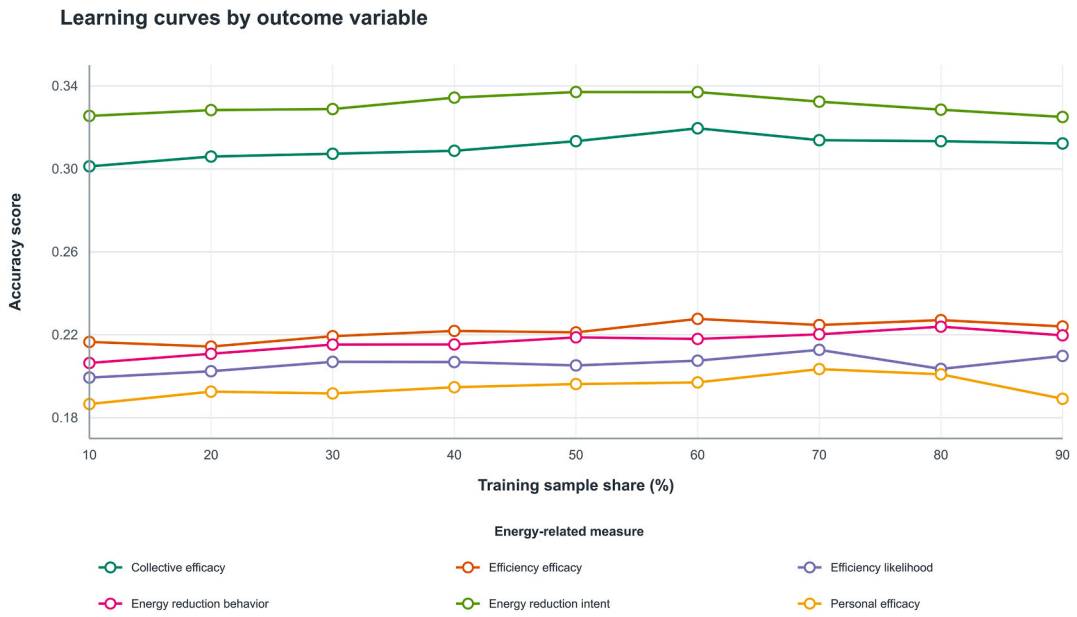

Fig. 3. Learning curves by outcome variable. Colored lines plot the model's predictive performance for each energy outcome as the training sample size varies.

research has highlighted differences in predictor strength between the Global North and the Global South [201]. Therefore, the relevance of the selection exercise may differ across radically different institutional and cultural contexts. Finally, the study's review section relies almost exclusively on published sources. While grey literature is used to support some discussion points, the analysis primarily draws on peer-reviewed papers. Given the breadth of the existing research, this choice represents a necessary compromise that makes the review tractable. Consequently, certain granular dimensions—such as localized urban versus rural dynamics, specific economic and housing sector policies, the cost of clean technologies, and the long-standing environmental initiatives driven by major developing countries in Asia and Africa—are not fully reflected. Addressing these neglected aspects by drawing on a broader literature, including regional reports and non-academic studies, represents a highly valuable avenue for a follow-up study.

6. Conclusion

Our results provide an in-depth understanding of the attitudinal barriers to the energy transition, which is particularly timely following the commitments made at COP30 (2025). As the latest IEA [10] and UNEP [7] reports suggest, closing the emissions gap by 2035 will depend less on further technological breakthroughs than on social acceptance. Indeed, interest in demand-side interventions has grown substantially [95,202–204]. Scenario evidence from the IEA's net-zero pathway suggests that around 55% of the associated cumulative emissions reductions are linked to consumer choices, including decisions such as purchasing electric vehicles, retrofitting homes, or installing heat pumps (IEA, 2021). By identifying perceived personal responsibility as a key driver, this study offers a clear roadmap for policymakers to design more effective, targeted engagement strategies. Such a focus is essential to address the 'insufficient progress' noted in recent global assessments (UNEP, 2024, [7]) and to operationalize the demand-side priorities recently stressed at COP30 (High-Level Champions for Climate Action, 2025). To promote effective behavioral change and widespread engagement in civil society, understanding the primary drivers of environmental action is crucial. However, conceptual vagueness appears to be pervasive in the study of climate change beliefs [205], leading to somewhat discordant results and a general difficulty in establishing the most effective approach for combating environmental skepticism and promoting mitigation actions. To address this problem, the paper provides a conceptual systematization of the key steps necessary to translate beliefs into personal actions to mitigate climate change. Although it does not cover all contributions, which span several fields and include hundreds of original papers, this first attempt to synthesize the literature can serve as a useful foundation for future causal investigations.

In the first part of this paper, the paper takes a closer look at the main obstacles to engagement in mitigation behaviors. Beginning with a discussion of the reasons for climate skepticism and the central role of motivated reasoning, the paper outlines the key drivers of effective action. As discussed earlier, engagement in demand-reduction behaviors is not consistently observed among individuals holding pro-environmental beliefs [206]. Instead, concerns about the urgency, efficacy, and personal responsibility associated with climate change mediate much of this relationship. While the two main approaches to mitigating energy externalities, namely curtailment and increased efficiency, seem to be broadly connected concepts, not everyone who is willing to accept one solution also supports the other. Subsequently, some of the most robust evidence on the main predictors of mitigation behaviors is presented, spanning demographic, ideological, and cultural factors. Overall, heterogeneity among respondents appears to be the most important factor driving behavioral divergence.

In the second part of the paper, a novel contribution to the debate is presented. Through a machine-learning approach applied to a 23-country European sample, personal responsibility toward climate change has been identified as the most valuable attitudinal marker of support for energy-related mitigation action within this context. This result appears to be robust across the various forms of behavior studied and holds for both stated preferences and reported behaviors. In several alternative specifications, the construct accounts for most of the variation in energy-related attitudes. For this reason, the results suggest that future studies should include this measure of pro-environmental orientation, as it can, on its own, effectively predict mitigation actions in a representative sample of the European population. However, it should be emphasized that these specific conclusions cannot be generalized universally. As the analysis does not consider major Asian countries, such as India and China, or African nations with ongoing structural initiatives, future research is needed to determine whether these attitudinal markers hold across regions with distinct socioeconomic dynamics and energy policies. The prominence of personal responsibility over other climate-related attitudes might be explained by the fact that, to feel personally

compelled to act to mitigate climate change, one must believe in its existence, be concerned about the threat it poses, and believe that it is attributable to human activity. If these preconditions do not hold, it is unlikely that one would be willing to sacrifice one's own comfort and resources for something that is perceived to be "natural".

As previously discussed, it is problematic to treat all predictors equally. Because all of them are likely related, with some being more fundamentally rooted in individuals' identities and background and others being a direct or indirect result of the former, the fact that more proximate concepts exhibit greater predictive power may not tell us much about the mechanism underlying these relationships. This is a critical issue for the literature to address, as there has so far been an apparent lack of engagement with the issue of strong correlations among predictors, which may explain the contrasting evidence regarding the "silver bullet" for predicting mitigation actions. In this paper, the first step in this direction is to consider only fundamental, mostly time-invariant determinants of green behavior, along with climate attitudes, to avoid issues of reverse causality and simultaneity in estimating the model. However, future studies should address this complexity by accurately modeling the causal chain and employing experimental and quasi-experimental designs to assess the constructs of interest in a methodologically robust manner.

Overall, there appears to be a discrepancy between the most effective approach to addressing climate change and the approach preferred by most individuals [99]. This misalignment, along with the difficulties in promoting effective action among the public, certainly calls for timely interventions to communicate with and nudge consumers in the right direction. This paper aims to guide researchers and policymakers in addressing the climate issue most effectively.

He published several papers in international journals with high Impact factors such that Corporate Social Responsibility and Environmental Management (with a top 5% cited paper), *Small Business Economics*, *Socio-Economic Planning Sciences* and *Economics of Innovation and New Technology*.

CRediT authorship contribution statement

Giacomo A. Campagnola: Writing – original draft, Validation, Software, Methodology, Investigation, Formal analysis. **Bruno S. Sergi:** Supervision, Funding acquisition, Conceptualization. **Emiliano Sironi:** Writing – original draft, Supervision, Investigation.

Declaration of competing interests

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.

Data availability

Data will be made available on request.

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