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National context is a key determinant of energy security concerns across Europe

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Abstract

Energy security is an important policy goal for most countries. Here, we show that cross-country differences in concern about energy security across Israel and 22 countries in Europe are explained by energy-specific and general national contextual indicators, over-and-above individual-level factors that reflect population demographics. Specifically, public concerns about import dependency and affordability reflect the specific energy context within countries, such as dependency on energy imports and electricity costs, while higher concerns about the affordability, vulnerability and reliability of energy are associated with higher fossil fuel consumption. More general national context beyond energy also appears to matter; energy security concerns are higher in countries that are doing less well in terms of economic and human well-being. These findings indicate that wider energy, social and economic context influence people's feelings of vulnerability and sense of security, which may inform the development of effective energy security strategies that assuage public concerns.

Climate change and energy security are key drivers of current and future energy policy across the world. New low-carbon systems should not only help to achieve emission targets as set out in international agreements, but also ensure reliable access to clean and affordable energy for all ([1–3]). In Europe, the internationalisation of energy markets has increased dependency on foreign energy imports, making the region more vulnerable to interruptions of supply ([4]); and rising energy prices and a prolonged economic crisis have led to widespread fuel poverty ([5]). These concerns, along with uncertainty arising from energy transitions processes, have placed energy security firmly on political agendas across the European region.

Understanding how and in what way people are concerned about energy security is an important aspect of delivering successful energy transitions ([6–9]). There is a growing recognition of the need to account for multiple perspectives in decision-making, as the public are able to shape the planning and construction of low-carbon energy systems through support or opposition of infrastructure, policies and technologies ([10,11,12]). There have been explicit calls for energy security policy to directly incorporate public acceptability ([13]). We suggest that one critical first step in developing policy to enhance energy security is understanding how secure people actually feel in relation to energy provision in their country, especially given the importance of energy services in ensuring people's health and well-being ([14]).

More importantly, it is key to understand the determinants of people's concerns to gain insights into what factors heighten or attenuate these. In this regard, it has been shown that levels of concern vary across individual-level socio-demographic factors ([6,8,15]). However, little is known about how they differ cross-nationally, unlike for climate change perceptions where national-level differences have gained significant attention in recent years ([16–21]). An analysis involving both individual and country-level factors would show the extent to which energy security concerns vary across countries over-and-above the socio-demographic make-up of the populations. This would provide a more robust understanding energy security concerns at the national level.

There are good reasons to expect that the national context matters for public energy concerns. Countries rely on different energy supply systems and face different energy challenges, which may powerfully shape how their residents engage with energy security, for example through experiences of current systems, as well as a country's prevailing social and economic conditions. Aggregate-descriptive analyses suggest that energy policy priorities differ according to levels of energy exports and economic development in a given country ([15,22,23]), which may have important implications for public concerns about these issues. Examining cross-national differences provides an opportunity to assess to what extent, and how, the wider energy, social and economic context has relevance for people's feelings of vulnerability and sense of security. This, in turn, would provide insight into the types of policies that can address public concerns.

Here we present a first exploratory but systematic analysis of energy security concerns across countries. We use the theoretically-grounded, nationally-representative European Social Survey (ESS) Round 8 dataset, in which a total of 44,387 respondents from 23 countries took part (Table 1). This provides a unique opportunity to examine to what extent cross-national differences in perceived energy security exist, and whether these can be explained by individual-level (e.g. socio-demographic) and/or country-level factors. Focusing on the latter, we examine whether public concerns (e.g. import dependency, affordability) reflect the actual energy context within countries (e.g. net energy imports, electricity costs). We also examine the importance of the wider climate, and social and economic context in explaining differences across countries.

Conceptualising and measuring public energy security concerns

Energy security is a complex, multi-faceted concept that is sometimes defined in narrow terms, for example exclusively around demand and supply of energy, and sometimes in broad terms, encompassing large areas of energy and environmental policies ([24,25]). Understanding public perceptions towards energy security requires careful attention to the ways people engage with it ([7,26]). For example, it is unlikely that many non-energy experts, that is large parts of the general public, would be familiar with, or have extensive technical knowledge of, the risks and operation of various energy systems ([6,7]). We therefore focus specifically on energy supplied for domestic purposes, including power and heating, as the most relevant aspect of energy security for the public. These aspects of energy use are also most strongly affected by the transition towards low-carbon energy systems. Furthermore, people engage with energy issues in a multitude of ways, using different sets of values and concerns. We therefore might expect concerns about energy and environmental issues to be differently determined ([27]). For these reasons, we use a more focused conceptualisation of energy security, building on the International Energy Agency (IEA) definition of energy security as the *uninterrupted availability of energy sources at an affordable price* ([1]). Five specific dimensions covering both outcomes of, and threats to, energy supply systems , are studied:

- ***Reliability*****:** Concerns about the reliability of domestic energy supplies, that is, that energy is produced consistently and can meet demand.
- ***Affordability***: Concerns about the affordability of energy as a result of expected price increases.
- ***Vulnerability***: Concerns about the domestic energy supply system being vulnerable to external events, such as natural disasters or terrorist attacks, as well as disruptive internal events, such as technical failures and accidents, causing interruptions to the supply of energy.
- ***Import dependency***: Concerns about the domestic energy supply being too dependent on energy imports.
- ***Fossil fuel dependency***: Concerns about dependencies on fossil fuels, and the lack of long-term investments in the development of new energy sources to prevent future loss of supply.

Drawing on these dimensions, we elicit *concern* about energy security, measuring people's personal feelings of worry about the different aspects (on a scale from 1 to 5). This is based on established research, which has consistently shown that people's risk perceptions are based on affective responses to a threat, and not necessarily statistical calculations of risks ([28,29]).

National differences in energy security concerns

Table 1 presents average concern for the five energy security dimensions for each of the 23 countries included in the survey. It is evident that respondents across Europe are differentially concerned about the five aspects of energy security. The highest levels of concern can be observed for affordability

(*M*=3.24 *SD*=1.03), which is in line with the findings on concern about energy prices elsewhere ([11,30]). This is followed by concerns about fossil fuel dependency (*M*=3.03 *SD*=1.02), import dependency (*M*=2.91 *SD*=1.07) and vulnerability (*M*=2.70 *SD*=0.87). The lowest concern ratings are observed for energy reliability (*M*=2.35 *SD*=1.08), with most countries being not very worried about this aspect of energy security. This mirrors a similar finding in a recent US study, and is likely related to people's current experiences with reliable energy supply systems ([6]). There is, however, variability across countries with more or less worry across the different dimensions. Countries that show relatively high levels of concern include Portugal, Spain, Russia, France and Belgium. Countries with generally lower energy security concerns include Iceland, Sweden, Austria and Switzerland.

In order to understand how much of the variation in the concern for energy security can be attributed to the country-level as opposed to the individual-level, we constructed a series of multilevel models of individuals (level 1) nested within countries (level 2). We started with a series of 'null' models without any individual or country-level predictors (Models A, Table 2). These null models show that around 10-16% of the variance in energy security concern is at the country-level, as indicated by the intraclass correlations (ICC) for these models: 0.101 for reliability, 0.157 for affordability, 0.112 for vulnerability, 0.132 for import dependency, and 0.102 for fossil fuel dependency. This represents the extent to which the observations within countries are more similar than observations across countries, meaning the proportion of the variance that is common to individuals within the different countries.

As cross-national variation may arise from compositional differences in individual-level factors, we subsequently constructed a series of multilevel models that included a number of key socio-demographic variables as predictors for the five energy security dimensions (Models B). The results of these models show that gender, age, level of education, and income are all associated with multiple energy security concern dimensions (Supplementary Table 1). However, these individual-level factors did not explain the differences in energy security concern between the 23 countries. The proportion of the variance that could be found at the country level remained largely the same after controlling for individual-level differences (0.101 for reliability, 0.155 for affordability, 0.111 for vulnerability, 0.133 for import dependency, and 0.105 for fossil fuel dependency).

National indicators of energy, climate change, and wellbeing

Having established that there are substantial differences in energy security concerns between countries that cannot be attributed to differences in population composition, we then set out to determine whether the differences can be explained by eight country-level contextual factors (Table 4). Specifically, we attempt to link energy security concerns to a number of national indicators of energy, climate change, and wellbeing. The relevant indicators are described in detail in the Methods section, and included in Supplementary Table 2. These factors were subsequently added to the random intercept models (Models C), so that we can determine to what extent they can explain national differences in energy security concerns.

Energy prices, imports, and fossil fuel consumption

We first examined a number of indicators associated with the energy context of our included countries, focusing specifically on the role of energy prices, imports and fossil fuel consumption. We hypothesized that *national electricity prices* would be reflected in worry about *affordability*, whereby higher prices are linked to higher levels of concern about affordability of energy; net *energy imports* would be reflected in worry about energy imports; and *fossil fuel energy consumption* in worry about *fossil fuel dependency*. The statistical models confirm these hypothesised relationships for electricity prices and energy imports (Table 3): household electricity prices were positively related to concern about affordability, and countries with higher imports exhibit higher concern about import dependence. In addition, both indicators also exhibit positive relationships with a number of the other energy security dimensions suggesting that these contextual factors matter for wider energy security concerns. In particular, higher electricity prices appear to heighten concerns around energy vulnerability, reliability and import dependency. Higher energy imports also appear to heighten concerns around fossil fuel dependency and affordability.

We did not find a significant relationship between national fossil fuel consumption and concerns about fossil fuel dependency, unlike previous speculations ([15]). However, fossil fuel consumption was positively related to the other dimensions of energy security. Possibly, high dependency on fossil fuels implies significant future changes to the energy system and increased import dependence, which heightens concerns about the future affordability, vulnerability and reliability of energy. Indeed, moving away from fossil fuels is an important policy objective across European countries ([31]).

We further examined *per capita electric power consumption* as an energy context indicator. Here we expected that higher electric power consumption would lead to higher levels of concern, especially regarding the *reliability*, *vulnerability* and *affordability* aspects of energy security. Countries with higher levels of consumption are more dependent on a well-functioning energy supply system, and thus more vulnerable to disruptions and price rises. However, we actually found the opposite association, whereby higher electric power consumption was linked to *lower* levels of concern across *all* dimensions of energy security. It is possible that high power consumption may reflect a country doing well economically and socially, and indicates that people can easily access and afford energy, which in turn reduces concern about energy security (also see section on economic and human wellbeing).

CO_2 emissions and Climate and Energy Wellbeing Index

We subsequently examined two indicators that focus more broadly on the issue of climate change. This is relevant because of the wide-reaching changes to energy systems that are needed to substantially reduce carbon emissions. Uncertainty arising from such energy transitions might lead to higher concern about energy security. Such a transition may be expected to threaten the reliability and affordability of energy due to the anticipated costs and disruptions caused by energy system changes.

We hypothesized that higher *per capita CO_2 emissions* would be positively associated with energy security concerns. This relationship was confirmed by our statistical models but only for the *reliability* of energy, whereby countries with higher emissions also had higher reliability concerns. As a further test, we also used the *Climate and Energy Wellbeing index* as a predictor of cross-country variation in energy security concerns. This index is a weighted aggregation of scores from energy use, energy savings, greenhouse gases, and renewable energy use in a given country. It provides an indication of how well a given country is already addressing climate and energy risks. We might therefore expect that countries with a higher Climate and Energy Wellbeing index see lower levels of concern about energy security across all dimensions. However, no such relationships were found.

Therefore, we do not find convincing evidence that the national climate context is relevant to concerns about energy security. It is likely that indicators of climate change, such as aggregate CO_2 emissions, are not particularly salient in people's everyday lives, unlike for example energy prices. Fossil fuel consumption, a large contributor towards a country's emissions, may however be a more relevant indicator for the general public, as the previous analysis showed. This suggests that transitioning away from fossil fuels and towards low-carbon energy systems, thereby lowering CO_2 emissions, may still be important for attenuating concerns.

Economic and human wellbeing

Having examined the role of energy and climate-related indicators in explaining cross-national variation in energy security concerns, we move towards the role of more general economic and human wellbeing. Conceptually, the socio-economic context of a country is likely to be important for people's concern about energy security for a number of reasons. More affluent countries may be able to provide a wider range of high quality and reliable services and public goods to its population ([17]). In addition, people in more affluent countries may feel that there are more resources available to insulate and protect against potential energy supply threats. As such, people in these countries may feel more secure and less vulnerable around energy provision. This is also an argument forwarded by some scholars examining the affluence hypothesis in relation to climate change perceptions, where it has been found that risk perceptions of climate change are actually lower in affluent compared to less affluent countries due to more immediate economic concerns in the latter ([32]). Here we do not only examine how affluent a country is, as indicated by per capita GDP, but also their overall level of quality of life, as reflected in the Human Wellbeing index. This index is comprised of several measures including basic human needs (food, water, sanitation), personal development and health (education, life expectancy, gender equality), and a well-balanced society (income distribution, population growth, good governance). It therefore provides an indication of the wider social and economic wellbeing of a country, not just national wealth. This is important because a country could be wealthy, but this wealth may be unevenly distributed and/or public services and goods are not fully accessible to the entire population. This in turn would likely produce higher energy security concerns among certain sections of the public.

Our statistical models confirm the hypothesised negative relationship between national wealth (*per capita GDP*) and concerns over energy security, whereby higher GDP relates to lower concern on the *reliability*, *affordability*, and *vulnerability* dimensions. We find the same negative relationships for the Human Wellbeing Index. Together, these findings provide strong evidence that the economic and human wellbeing of a country are particularly important in understanding energy security concerns across Europe, also evidenced by the relative larger effect sizes compared to the other indicators. The results also appear to be in line with the earlier finding that power consumption is negatively linked to energy security concerns. This suggests that electricity consumption reflects economic prosperity, which is associated with lower levels of energy security concerns. Indeed, we find a strong positive correlation between power consumption and per capita GDP (0.70, $p<0.01$) and the Human Wellbeing index (0.65, $p<0.01$) (Supplementary Table 3).

Conclusions

In this paper, we examined public energy security concerns across 23 European countries, arguing that decision-makers should consider public perspectives in addition to traditional indicators of energy security. We find that national contextual indicators of energy, and economic and human wellbeing are important in addition to individual socio-demographic factors (see Table 4). The findings have implications especially for national and European policy and decision-making that seeks to increase energy security. In particular, energy policy can help to assuage public concerns about energy security, by addressing the conditions underlying them. The presented cross-country analysis provides useful starting points for the kind of policies that would heighten or attenuate public concerns.

We conclude that people's energy security concerns reflects the national energy context of the country they reside in, in particular regarding electricity prices, net energy imports and fossil fuel consumption. This suggests that effectively managing energy prices, imports and fossil fuel use will go some way towards addressing public concerns. Given that many countries are currently undergoing substantial energy system changes in part to reduce fossil fuel use, this is a positive move for energy security concerns, as long as they do not also exacerbate other issues in the process (e.g. increase in imports or energy prices, or reductions in energy reliability). Addressing energy affordability as a key concern of the European public constitutes a significant challenge, given that energy transitions are likely to carry substantial costs. How these costs are distributed, and whether they lead to higher energy prices is something that will have to be carefully considered.

We further find that people in countries with higher economic and human wellbeing, also perhaps reflected in higher power consumption, have lower levels of concerns regarding the reliability, vulnerability and affordability of energy supplies. These results suggest that people's energy concerns are not solely shaped by energy-specific factors, but also by the wider socio-economic context of the country in which they reside. This may reflect that more affluent countries are better able to provide secure and affordable energy, but could also suggest that how secure people feel about energy availability is an important part of a country's overall wellbeing. Policy therefore needs to provide better connections between different areas of decision-making. While strategies that seek to improve energy security should consider issues beyond traditional energy policy areas, e.g. how economic and social circumstances influence people's energy use patterns and their access to quality energy services ([14]), the reverse is also important. Non-energy policies, such as on social security and health, are likely to have important implications for energy use ([33]) and thus people's energy security concerns. Policies that are able to take account of these interconnections would more accurately reflect how people experience energy security.

Methods

Data Availability

Data for Round 8 of the European Social Survey is available for download from http://www.europeansocialsurvey.org.

The European Social Survey

The European Social Survey (ESS) is a cross-European comparative survey to examine interactions between Europe’s changing institutions, and the attitudes, beliefs, and behaviour patterns of its diverse population. The survey is academically driven and has been conducted every two years from 2002 onwards. The core section includes a number of substantive issues alongside a comprehensive set of socio-demographic variables. The rotating section comprises two modules designed by specialised questionnaire design teams on an issue of interest to the social sciences. Round 8 of the European Social Survey (ESS8), conducted in 2016, included a module on public perceptions of climate change and energy.

The climate and energy module was designed in English over a two-year period, which included the development of model concepts and associated items, extensive testing, piloting, and translation of the items. Each country had to achieve a minimum random probability sample of 1,500 respondents (countries with fewer than 2 million inhabitants had to achieve a minimum sample of 800), representative of the population aged 15 years or over. In total, 44,387 respondents from 23 European countries took part in the survey. This included 21 European countries from the EU (European Union) and EFTA (European Free Trade Association) area (Austria, Belgium, the Czech Republic, Estonia, Finland, France, Germany, Hungary, Iceland, Ireland, Italy, Lithuania, Netherlands, Norway, Poland, Portugal, Slovenia, Spain, Sweden, Switzerland, and the United Kingdom), the Russian Federation, and Israel (see Table 1). Interviews were conducted face-to-face in people’s own homes. All research was carried out according to guidelines from the EES Research Ethics committee. The sample was weighted to adjust for differences in the likelihood of selection. The total average concern for each energy security dimension across countries, as reported in the text, was calculate using an additional weight to account for the different population sizes of countries. The detailed survey and sampling specifications can be found on the ESS website (http://www.europeansocialsurvey.org).

Measurements

Dependent variables

Concern about energy security. The study included five dependent variables covering concerns about diverse aspects of energy security. All items had 5-point response scales with the following options: 1 not at all worried, 2 not very worried, 3 somewhat worried, 4 very worried, and 5 extremely worried. Concern about *energy reliability* was measured by asking respondents "How worried are you that there may be power cuts in [country]?"; Concern about *energy affordability* by "How worried are you that energy may be too expensive for many people in [country]?"; concern about *Energy import dependency* by "How worried are you about [country] being too dependent on energy imports from other countries?"; and concern about *fossil fuel dependency* by "How worried are you about [country] being too dependent on energy generated by fossil fuels, such as oil, gas and coal?". Concern about *energy vulnerability* was measured by four separate items (Cronbach's α=0.84), covering concerns about the domestic energy supply system having internal and external (e.g. natural disasters) vulnerabilities. The four items were: "How worried are you that energy supplies could be interrupted…" (a) "…by natural disasters or extreme weather?", (b) "….by insufficient power being generated? ", (c) "…by technical failures?", and (d) "…by terrorist attacks?".

Independent variables

Socio-demographics. In this study we considered the socio-demographic variables of gender, age, level of education, and net household income. *Gender* was indicated as 0 (female) and 1 (male). *Age* was centred on its grand mean of 47.04 years, and expressed in 10 years deviations from that mean. *Level of education* was indicated by the ESS version of the International Standard Classification of Education (ISCED), and centred on its grand mean of 4.01. Dummies were used to indicate the national quintiles of net *household income*. A separate dummy variable indicated refusal to provide income information.

National indicators. Eight country-level indicators were considered for this paper, reflective of the energy, climate change and wellbeing context, respectively: Energy - *Household electricity prices*, *Net energy imports*, *Percentage of fossil fuel energy consumption, and Per capita electric power consumption;* Climate change - *Per capita CO_2 emissions, and Climate and Energy wellbeing index;* Economic and human wellbeing - *Per capita GDP,* and *Human Wellbeing index*. Household electricity prices for 2016 were sourced from the International Energy Agency (IEA) and expressed in USD/MWh Agency (https://www.iea.org/statistics/statisticssearch). The figures were calculated using purchasing power parities. Net energy imports for 2014 were estimated by calculating primary energy use minus production. Energy use refers here to use of primary energy before transformation to other end-use fuels, which is equal to indigenous production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transport. The percentage of fossil fuel energy consumption in 2014 was also calculated from data obtained from the IEA, and represents the percentage of consumed energy generated by coal, oil, petroleum, and natural gas. Data regarding the per capita electric power consumption for 2014 were obtained from the IEA, and expressed in KwH. Per capita CO_2 emissions figures for 2014 were similarly obtained from the Carbon Dioxide Information Analysis Center, Environmental Sciences Division, Oak Ridge National Laboratory, Tennessee, United States. Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring. Per capita GDP is the gross domestic product divided by midyear population. GDP figures for 2016 were obtained from World Bank and OECD national accounts data, and calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in current U.S. dollars. Human wellbeing index was sourced from the Sustainable Society Foundation (SSF). The energy and climate change sub-index is a weighted aggregation of scores from energy use, energy savings, greenhouse gas emission per capita per year, and renewable energy. More information regarding the calculation of the 2016 indices can be obtained from the SSF website (http://www.ssfindex.com/ssi/calculation-methodology).

Data analysis

The data were analysed from a multilevel perspective, with 44,387 individuals (level 1) nested within 23 countries (level 2). Analyses were conducted using the MLwiN 2.36 software package. Linear regression models were constructed with the five energy security concern items as the dependent variables. Three sets of analyses were conducted. First, a series of 'null' models were constructed without any predictors (Models A). These null models show what proportion of the variance in concern about energy security can be found at the individual or country level, as indicated by the intraclass correlation (ICC). The ICC was calculated as the ratio of the country-level variance to the total variance (the sum of the country and individual level variance): ICC = $\sigma^2_{country}/(\sigma^2_{country} + \sigma^2_{individual})$. Second, a series of *random intercept models* were constructed with the five energy security concern items as the dependent variables, and the individual-level socio-demographic factors as the independent variables (Models B). This means that the intercepts were allowed to vary across the 23 countries, but not the slopes of the regression coefficients. These analyses were conducted to identify important individual-level predictors of concern about energy security. Third, the set of models was subsequently extended to include the country-level factors of: *Household electricity prices*, *Net energy imports*, *Percentage of fossil fuel energy consumption, Per capita electric power consumption, Per capita CO_2 emissions, Climate and Energy wellbeing index, Per capita GDP*, and *Human Wellbeing index* (Models C). Only one national level indicator was considered in each regression model. That means that eight regression analyses were conducted for each outcome variable. Again, the intercepts were allowed to vary across the 23 countries, but not the slopes of the regression coefficients. Markov Chains Monte Carlo (MCMC) with 15,000 iterations was used to estimate the coefficients.

Methodological justifications, reflections and limitations

Here we reflect on a number of methodological decisions we made as part of conducting the survey and analysis, and the limitations that arise from them. There are a number of caveats that need to be borne in mind when interpreting the findings. These caveats relate to the elicitation of public concerns in surveys, the number of included countries, the scale of analysis, and the use of national level indicators.

Eliciting public concerns in surveys. The study focused on public energy security concerns and their national-level determinants. One important methodological issue to consider is how to elicit public concerns in quantitative surveys, in particularly because energy and energy systems are complex topics on which the public may not necessarily have a lot of information. Eliciting publics perceptions and concerns on complex social issues requires careful attention to what is being asked and why (theory), and to how to ask about it (operationalisation). This ensures respondents are able to understand the question and are motivated to answer it, therefore reducing the risk of satisficing, i.e. respondents giving the same answer in a series of questions. This is often the case in surveys that ask a lot of questions, which sound similar and that include unfamiliar terminology ([34]).

A number of precautions were taken to ensure the survey elicits high-quality answers. We took a concept-based approach to design the questions, and considered what aspect of public 'perception' would be most relevant to examine. It was decided to focus specifically on 'concern' about different aspects of energy security, which could be said to specifically focus on people's own sense of a situation reflected in a personal feelings of worry about the issue. The phrasing was carefully considered so that the questions would be understandable to the general public. The term 'energy security' was not used in any of the questions. The focus was on a number of sub-concepts reflecting different aspects of energy security (e.g., reliability, affordability, etc.), based on previous conceptual work by the lead author ([7]). The developed questions were extensively tested, through pilot surveys and cognitive interviewing in multiple countries, to ensure that participants correctly understand them. An analysis shows that 'straight lining', an indicator of satisficing or 'box ticking', was extremely rare within the data.

Number of included countries. The estimates of the cross-national effects are based on a relatively small number of countries (n=23). This means that the models have the statistical power to detect only large national-level differences, and are not able to show country specific interactions of the studied variables ([35]). One criticism of the current perception literature is that the vast majority of empirical studies has been on countries with largely similar historical and economic backgrounds ([36]). A strength of our study is that it covered many European countries with different energy systems and socio-economic circumstances, including a number of Central and Eastern European countries that have seen a fast economic transition over the past two decades while still having a largely fossil-fuel based energy system ([37]).

Scale of analysis (national). Our analysis focuses specifically on national-level differences in energy security concerns across a number of European countries. This is however not the only relevant scale of analysis. One could argue that energy provision is increasingly international and polycentric, involving actors and organisations beyond nation states ([4]). Similarly, regions within countries often vary in their energy provision and systems. We have however focused on national differences for multiple reasons. Following Brown et al.'s reasoning ([38]), we find data availability and quality is much better at the national level, which allows us to include indicators for multiple types of national context (e.g. climate, economic). Perhaps more importantly, much of energy policy and decision-making is still done at national level, even within the European Union. Similarly, the wider economic and social context that shapes people's lives is still predominantly determined by country specific policies and histories. In order for our analysis to be most useful, the nation level therefore appears to be the most appropriate scale of analysis.

National indicators. We chose to include a range of national level indicators to examine the role of the energy, economic and social context as determinants of energy security concerns. We chose a limited number indicators from a list that was collated as part of the PAWCER (Public Attitudes to Welfare, Climate Change and Energy in the EU and Russia) project. Considerations were that indicators had to be available in all or a majority of the included countries, and reflect a condition that is theoretically important for energy security concerns. Two authors (CD and WP) independently selected indicators that they considered relevant for energy security concerns. After a discussion, the number of indicators was limited to eight to reflect different national conditions regarding energy, climate change and economic and social wellbeing.

The data for the national level indicators was drawn from a range of sources as described in the previous section. Effort was made to select the most recent data aligning with data collection for Round 8 of the European Social Survey in 2016. The most complete and recent data were used as indicators. In a few number of cases more recent data were available, but these were not always complete. For some indicators this means somewhat older data (from 2014) were used instead. We note that there is very little temporal variability within this contextual data, with cross-year correlations being very high (r=0.98-0.99).

There are other indicators that may be relevant and interesting to examine in relation to people's concerns about energy security, however we limited our selection to the most theoretically relevant in order to avoid Type I errors in our statistical analysis. In addition, some aspects of energy context may be useful to examine in the future given the multi-faceted nature of energy security, but for which we did not have reliable data across all countries. Examples that may be of interest for future research include aspects of energy governance, including to what extent energy provision is decentralised or energy markets have been liberalised.

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Data Availability Statement

The European Social Survey Round 8 data that support the findings of this study are available from http://www.europeansocialsurvey.org/data/

Author contributions

CD led the writing of the paper. WP conducted the data analyses. The first version was drafted by CD and WP. All authors contributed to the design of the Climate and Energy module of the ESS Round 8 and to the writing and revisions of this paper.

Competing financial interests

The authors declare no competing financial interests.

Table 1: Mean (M) levels of energy security concern in 23 European countries (standard deviations, SD, in parentheses).

Country	Sample size *n*	Reliability *M (SD)*	Affordability *M (SD)*	Vulnerability *M (SD)*	Import Dependency *M (SD)*	Fossil Fuel Dependency *M (SD)*
Austria	2,010	1.94 (0.82)	2.63 (0.95)	2.19 (0.66)	2.58 (0.99)	2.58 (0.97)
Belgium	1,766	2.40 (0.95)	3.52 (0.88)	2.85 (0.80)	3.21 (0.93)	3.15 (0.92)
Czech Republic	2,269	2.12 (0.90)	3.20 (1.17)	2.58 (0.83)	2.66 (1.05)	2.70 (1.02)
Estonia	2,019	2.38 (0.95)	3.05 (0.98)	2.50 (0.83)	2.84 (0.97)	2.77 (0.93)
Finland	1,925	2.32 (0.88)	3.07 (0.89)	2.54 (0.81)	3.20 (0.85)	3.25 (0.84)
France	2,070	2.28 (1.05)	3.33 (0.92)	2.96 (0.89)	3.07 (0.97)	3.31 (0.98)
Germany	2,852	1.98 (0.86)	3.10 (0.88)	2.51 (0.70)	3.09 (0.92)	3.20 (0.89)
Great Britain	1,959	2.13 (0.89)	3.19 (0.90)	2.56 (0.78)	3.20 (0.96)	3.11 (0.95)
Hungary	1,614	2.25 (0.89)	2.99 (0.93)	2.54 (0.76)	3.05 (0.89)	3.01 (0.91)
Iceland	880	1.53 (0.62)	2.37 (0.91)	1.98 (0.56)	1.83 (0.77)	2.09 (0.93)
Ireland	2,757	2.03 (0.91)	2.90 (0.94)	2.24 (0.79)	2.73 (0.98)	2.78 (1.03)
Israel	2,557	2.60 (1.21)	3.32 (1.22)	2.80 (1.05)	2.76 (1.27)	2.76 (1.25)
Italy	2,626	2.34 (0.93)	3.19 (0.93)	2.66 (0.81)	3.09 (0.95)	3.05 (0.95)
Lithuania	2,122	2.58 (1.08)	3.35 (1.22)	2.76 (0.83)	2.80 (1.04)	2.69 (1.02)
Netherlands	1,681	1.94 (0.83)	2.73 (0.83)	2.36 (0.67)	2.88 (0.83)	3.05 (0.88)
Norway	1,545	2.00 (0.82)	2.59 (0.88)	2.34 (0.70)	2.55 (0.90)	2.91 (0.94)
Poland	1,694	2.32 (0.93)	3.08 (0.98)	2.67 (0.78)	2.95 (0.99)	2.71 (0.93)
Portugal	1,270	2.63 (1.08)	3.81 (0.80)	3.08 (0.83)	3.44 (0.94)	3.50 (0.95)
Russian Federation	2,430	2.84 (1.26)	3.36 (1.19)	2.93 (0.97)	2.38 (1.23)	2.79 (1.13)
Slovenia	1,307	2.23 (0.99)	3.17 (0.93)	2.69 (0.87)	2.90 (0.97)	3.14 (0.96)
Spain	1,958	2.52 (1.12)	3.80 (0.91)	2.75 (0.95)	3.32 (1.00)	3.35 (1.01)
Sweden	1,551	1.73 (0.75)	2.31 (0.84)	2.15 (0.65)	2.52 (0.89)	2.74 (0.94)
Switzerland	1,525	1.85 (0.81)	2.49 (0.89)	2.29 (0.66)	2.71 (0.89)	2.83 (0.92)

Note: The scales ranged from 1 (not at all worried) to 5 (extremely worried). The scale midpoint was 3 (somewhat worried). The data were weighted to account for differences in inclusion probabilities and sampling error and non-response bias (post-stratification weight).

Table 2: Fixed and random effects of the energy security concern multilevel models (Model A); these 'null' models are without any individual and country-level factors as predictors (multilevel regression analyses – 'null' models; n = 44,387 individuals at level 1, n = 23 countries at level 2).

	Reliability	Affordability	Vulnerability	Import Dependency	Fossil Fuel Dependency
Fixed effects	*B (95%CI)*	*B (95%CI)*	*B (95%CI)*	*B (95%CI)*	*B (95%CI)*
Constant	2.210 (2.083 to 2.337)***	3.053 (2.886 to 3.220)***	2.550 (2.436 to 2.664)***	2.840 (2.689 to 2.991)***	2.904 (2.775 to 3.033)***

Random effects	σ² (95% CI)	σ² (95% CI)	σ² (95% CI)	σ² (95% CI)	σ² (95% CI)
Level 2 (country)	0.103 (0.034 to 0.172)**	0.179 (0.061 to 0.297)**	0.083 (0.028 to 0.138)**	0.147 (0.049 to 0.245)**	0.108 (0.037 to 0.179)**
Level 1 (individual)	0.920 (0.908 to 0.932)***	0.958 (0.946 to 0.970)***	0.657 (0.649 to 0.665)***	0.967 (0.953 to 0.981)***	0.956 (0.942 to 0.970)***

Note: the intraclass correlation can be calculated as the ratio of the between cluster (i.e. country level) variance to the total (i.e. country and individual level) variance: $\sigma^2_{country} / (\sigma^2_{country} + \sigma^2_{individual})$. * = $p<0.05$, ** = $p<0.01$, *** = $p<0.001$.

Table 3: Fixed effects of the energy security concern multilevel models (Models C); the models include country-level factors as predictors for worry about energy security dimensions (n = 44,387 individuals at level 1, n = 23 countries at level 2).

	Reliability	**Affordability**	**Vulnerability**	**Import Dependency**	**Fossil Fuel Dependency**
	B (95%CI)	*B (95%CI)*	*B (95%CI)*	*B (95%CI)*	*B (95%CI)*
Household electricity prices	0.120 (0.034 to 0.206)**	0.265 (0.140 to 0.390)***	0.120 (0.028 to 0.212)*	0.154 (0.050 to 0.258)**	0.087 (-0.027 to 0.201) n.s.
Net energy imports	0.077 (-0.052 to 0.206) n.s.	0.177 (0.024 to 0.330)*	0.068 (-0.046 to 0.182) n.s.	0.203 (0.070 to 0.336)**	0.130 (0.003 to 0.257)*
Percentage of fossil fuel energy consumption (proportion)	0.126 (0.018 to 0.234)*	0.175 (0.034 to 0.316)*	0.109 (0.013 to 0.205)*	0.126 (-0.009 to 0.261) n.s.	0.087 (-0.035 to 0.209) n.s.
Per capita electric power consumption	-0.122 (-0.204 to -0.040)**	-0.147 (-0.257 to -0.037)**	-0.107 (-0.180 to -0.034)**	-0.178 (-0.266 to -0.090)***	-0.128 (-0.214 to -0.042)**
CO_2 emissions	0.133 (0.015 to 0.251)*	-0.032 (-0.210 to 0.146) n.s.	-0.018 (-0.140 to 0.104) n.s.	-0.099 (-0.262 to 0.064) n.s.	-0.083 (-0.226 to 0.060) n.s.
Climate and energy wellbeing Index	-0.010 (-0.143 to 0.123) n.s.	0.029 (-0.140 to 0.198) n.s.	0.009 (-0.109 to 0.127) n.s.	0.100 (-0.053 to 0.253) n.s.	0.083 (-0.054 to 0.220) n.s.
GDP per capita	-0.204 (-0.294 to -0.114)***	-0.243 (-0.365 to -0.121)***	-0.172 (-0.254 to -0.090)***	-0.107 (-0.248 to 0.034) n.s.	-0.059 (-0.186 to 0.068) n.s.
Human wellbeing index	-0.224 (-0.338 to -0.110)***	-0.200 (-0.376 to -0.024)*	-0.150 (-0.268 to -0.032)*	0.001 (-0.185 to 0.187) n.s.	0.004 (-0.159 to 0.167) n.s.

*Note: For individual-level predictors also entered into the model, consult Supplementary Table 1. The country-level variables have been standardised so that the effects can be compared. n.s. = non-significant, * = $p<0.05$, ** = $p<0.01$, *** = $p<0.001$.*

Table 4. Summary of hypothesised relationships (and related findings) between national level indicators and energy security concerns.

National indicator	Hypothesized relationship with energy security concern	Finding
Energy (prices, imports, and consumption)		
Household electricity prices	Affordability (+)	Confirmed: Higher electricity prices associated with higher concern about energy *affordability*. Also associated with higher concern for *reliability*, *vulnerability* and *import dependency*.
Net energy imports	Import dependency (+)	Confirmed: Higher energy imports associated with higher concerns about *import dependency*. Also associated with higher concern for *affordability* and *fossil fuel dependency*.
Percentage of fossil fuel energy consumption	Fossil fuel dependency (+)	Not confirmed. However higher fossil fuel energy consumption associated with higher concern about the *reliability, vulnerability* and *affordability* of energy.
Per capita electric power consumption	Reliability (+) Vulnerability (+) Affordability (+)	Not confirmed. Electric power consumption *negatively* associated with all energy security dimensions (higher power consumption associated with lower energy security concerns).
Climate change		
Per capita CO_2 emissions	Reliability (-) Vulnerability (-) Affordability (-) Import Dependency (-) Fossil Fuel Dependency (-)	Confirmed for energy *reliability*: Higher CO_2 emissions associated with higher concern about reliability of energy.
Climate and Energy Wellbeing index	Reliability (-) Vulnerability (-) Affordability (-) Import Dependency (-) Fossil Fuel Dependency (-)	Not confirmed.
Economic and human wellbeing		
Per capita GDP	Reliability (-) Vulnerability (-) Affordability (-) Import Dependency (-) Fossil Fuel Dependency (-)	Confirmed for *reliability*, *affordability* and *vulnerability:* Higher GDP associated with lower concerns about reliability, affordability and vulnerability of energy.
Human Wellbeing index	Reliability (-) Vulnerability (-) Affordability (-) Import Dependency (-) Fossil Fuel Dependency (-)	Confirmed for *reliability*, *affordability* and *vulnerability*: Higher Human Wellbeing index associated with lower concerns about reliability, affordability and vulnerability of energy.

Supplementary Table 1: Fixed and random effects of the energy security concern multilevel models (Models B); the models include individual-level factors as predictors for worry about energy security dimensions (*n* = 44,387 individuals at level 1, *n* = 23 countries at level 2).

	Reliability	**Affordability**	**Vulnerability**	**Import Dependency**	**Fossil Fuel Dependency**
Fixed effects	*B (95%CI)*	*B (95%CI)*	*B (95%CI)*	*B (95%CI)*	*B (95%CI)*
Constant	2.292 (2.170 to 2.414)***	3.216 (3.065 to 3.367)***	2.676 (2.570 to 2.782)***	2.864 (2.723 to 3.005)***	2.917 (2.792 to 3.042)***
Gender (male)	-0.115 (-0.133 to -0.097)***	-0.108 (-0.126 to -0.090)***	-0.168 (-0.184 to -0.152)***	-0.066 (-0.086 to -0.046)***	-0.047 (-0.067 to -0.027)***
Age	0.051 (0.045 to 0.057)***	0.046 (0.040 to 0.052)***	0.039 (0.035 to 0.043)***	0.032 (0.026 to 0.038)***	-0.008 (-0.014 to -0.002)**
Education	-0.017 (-0.023 to -0.011)***	-0.021 (-0.027 to -0.015)***	-0.035 (-0.039 to -0.031)***	0.015 (0.009 to 0.021)***	0.035 (0.029 to 0.041)***
Income (Quartile 2)	0.000 (-0.029 to 0.029)n.s.	-0.025 (-0.056 to 0.006)n.s.	0.000 (-0.025 to 0.025)n.s.	0.045 (0.014 to 0.076)**	0.028 (-0.003 to 0.059)n.s.
Income (Quartile 3)	0.018 (-0.013 to 0.049)n.s.	-0.060 (-0.091 to -0.029)***	0.005 (-0.020 to 0.030)n.s.	0.045 (0.012 to 0.078)**	0.052 (0.019 to 0.085)**
Income (Quartile 4)	-0.045 (-0.076 to -0.014)**	-0.130 (-0.163 to -0.097)***	-0.060 (-0.087 to -0.033)***	0.040 (0.007 to 0.073)*	0.038 (0.005 to 0.071)*
Income (Quartile 5)	-0.080 (-0.115 to -0.045)***	-0.240 (-0.277 to -0.203)***	-0.123 (-0.154 to -0.092)***	0.001 (-0.036 to 0.038)n.s.	0.025 (-0.012 to 0.062)n.s.
Income missing	-0.046 (-0.077 to -0.015)**	-0.208 (-0.239 to -0.177)***	-0.096 (-0.123 to -0.069)***	-0.049 (-0.082 to -0.016)**	-0.045 (-0.078 to -0.012)**
Random effects	*σ² (95% CI)*	*σ² (95% CI)*	*σ² (95% CI)*	*σ² (95% CI)*	*σ² (95% CI)*
Level 2 (country)	0.102 (0.035 to 0.169)**	0.171 (0.059 to 0.283)**	0.079 (0.028 to 0.130)**	0.147 (0.051 to 0.243)**	0.111 (0.038 to 0.184)**
Level 1 (individual)	0.903 (0.891 to 0.915)***	0.933 (0.921 to 0.945)***	0.634 (0.626 to 0.642)***	0.96 (0.946 to 0.974)***	0.949 (0.935 to 0.963)***

*Note: n.s. = non-significant, * = p<0.05, ** = p<0.01, *** = p<0.001. The intraclass correlation can be calculated as the ratio of the between cluster (i.e. country level) variance to the total (i.e. country and individual level) variance: σ²country/ (σ²country + σ²individual).*

Supplementary Table 2: National energy, climate change and social and economic wellbeing indicators. Source: see Methods.

	Energy				Climate Change		Economic and human wellbeing	
Country	**Household electricity prices (2016), in USD/MWh**	**Net energy imports (2014), in % of energy use**	**Percentage of fossil fuel energy consumption (2014), in %**	**Per capita electric power consumption (2014), in KwH**	**CO_2 emissions (2014), in metric tonnes per capita**	**Climate and energy wellbeing index (2016)**	**Per capita GDP (2016), in USD**	**Human wellbeing index (2016)**
Austria	245.5	62	65	8361	6.874	3.48	44676	8.48
Belgium	315.6	76	72	7709	8.328	2.08	41236	8.66
Czech Republic	292	29	75	6259	9.166	1.96	18492	8.56
Estonia	212.3	4	14	6732	14.849	1.41	17727	8.39
Finland	164.9	46	42	15250	8.661	2.47	43403	9.00
France	200	44	46	6938	4.572	3.23	36855	8.41
Germany	376.3	61	80	7035	8.889	2.13	42070	8.84
Great Britain	222.3	40	83	5130	6.497	3.44	40341	8.49
Hungary	266	55	68	3966	4.266	3.93	12815	8.23
Iceland	/	11	11	53832	6.060	3.33	59977	8.84
Ireland	257.2	85	85	5722	7.378	3.13	63862	8.56
Israel	/	68	96	6601	7.863	2.88	37176	6.96
Italy	333	75	79	5002	5.271	4.50	30675	7.69
Lithuania	/	76	68	3821	4.378	3.90	14880	8.12
Netherlands	193	19	91	6713	9.920	1.93	45670	8.84
Norway	91.3	0	58	23000	9.271	3.44	70912	8.76
Poland	340	27	90	3972	7.517	3.10	12421	8.42
Portugal	395	73	73	4663	4.332	5.05	19840	8.20
Russian Federation	/	0	90	6603	11.858	1.44	8748	6.89
Slovenia	266.5	44	60	6728	6.214	3.67	21652	8.75
Spain	360	70	72	5356	5.034	4.15	26640	7.91
Sweden	164.6	29	30	13480	4.478	3.54	51949	8.75
Switzerland	158.1	47	49	7520	4.312	4.20	79891	8.47

Supplementary Table 3: Correlations (Spearman's rho) between country-level variables.

Country	Household electricity prices (2016), in USD/MWh	Net energy imports (2014), in % of energy use	Fossil fuel energy consumption (2014), in %	Per capita electric power consumption (2014), in KwH	CO_2 emissions (2014), in metric tonnes per capita	Climate and energy wellbeing index (2016)	Per capita GDP (2016), in USD	Human wellbeing index (2016)
Household electricity prices (2016), in USD/MWh	1.00 *n* =19	0.53* (n=19)	0.53* (n=19)	-0.62*** (n=19)	-0.11 (n=19)	0.15 (n=19)	-0.62** (n=19)	-0.41 (n=19)
Net energy imports (2014), in % of energy use		1.00 *n* =23	0.21 (n=23)	-0.37 (n=23)	-0.47* (n=23)	0.44* (n=23)	0.02 (n=23)	-0.28 (n=23)
Fossil fuel energy consumption (2014), in %			1.00 *n* =23	-0.58** (n=23)	0.28 (n=23)	-0.23 (n=23)	-0.26/ (n=23)	-0.31 (n=23)
Per capita electric power consumption (20134), in KwH				1.00 *n* =23	0.30 (n=23)	-0.28 (n=23)	0.70** (n=23)	0.65** (n=23)
CO_2 emissions (2014), in metric tonnes per capita					1.00 *n* =23	-0.87*** (n=23)	0.00 (n=23)	0.28 (n=23)
Climate and energy wellbeing index (2016)						1.00 *n* =23	0.07 (n=23)	-0.28 (n=23)
Per capita GDP (2016), in USD							1.00 *n* =23	0.63* (n=23)
Human wellbeing index (2016)								1.00 *n* =23

*Note: * = p<0.05, ** = p<0.01, *** = p<0.001*