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Originally published in:
Climate Policy 23(7), https://doi.org/10.1080/14693062.2023.2211042

Climate Policy

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tcpo20

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To cite this article: Janna Hoppe, Anthony Patt & Tim Tröndle (2023) Public support for phasing out carbon-intensive technologies: the end of the road for conventional cars in Germany?, Climate Policy, 23:7, 813-828, DOI: 10.1080/14693062.2023.2211042

To link to this article: https://doi.org/10.1080/14693062.2023.2211042

CLIMATE POLICY
2023, VOL. 23, NO. 7, 813–828
https://doi.org/10.1080/14693062.2023.2211042

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RESEARCH ARTICLE

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Public support for phasing out carbon-intensive technologies: the end of the road for conventional cars in Germany?

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ABSTRACT

Limiting the global mean temperature increase to 1.5°C requires phasing out fossil fuel combustion almost entirely within the next three decades and replacing carbon-intensive technologies with low-carbon alternatives. Such socio-technical transitions are politically feasible only if public acceptance is sufficiently high. Here we investigate German citizens' views on the phase-out of internal combustion engine vehicles (ICEVs) using a random forest (decision trees) classification and logistic regression model. We surveyed a demographically representative sample (N = 1,663) in 2021, finding that the majority of respondents (67%) approve of an ICEV phase-out by 2040 or hold a neutral stance. Acceptability is best predicted by the degree to which environmental problems are attributed to ICEVs, followed by respondents' willingness to abandon cars altogether or adopt electric vehicles (EVs). Our results further indicate that acceptability can be increased by providing people with information that present EVs in a more favourable, and ICEVs in a less favourable light. When the European Commission proposed to ban the sale of ICEVs by 2035, we conducted a follow-up survey to investigate whether this had influenced acceptability in Germany – with the result that it had not. In terms of concrete policies, pull measures such as public transport or electric vehicle purchase subsidies are preferred by the public over more restrictive policies such as taxes or bans. The findings of this study shed light on different dimensions of public opinion and their important implications for policymaking and the political feasibility of this socio-technical transition. Insights from this research can help policymakers in designing effective yet widely acceptable transport decarbonization policies.

Key policy insights:

- Overall, 45% of respondents approve of an ICEV phase-out by 2040, while 34% disapprove.
- Acceptability is best predicted by the degree to which environmental problems are attributed to ICEVs, as well as respondents' willingness to adopt electric vehicles or give up their cars altogether.
- Emphasizing the advantages of electric vehicles or the adverse effects of ICEVs increases acceptability, while indicating the inevitability of an eventual phase-out does not.
- On average, public transport and electric vehicle purchase subsidies enjoy higher levels of public support than taxes or different permutations of ICEV bans.

ARTICLE HISTORY
Received 15 March 2022
Accepted 30 April 2023

KEYWORDS
Energy transition; climate policy; phase-out; transport; random forest; public opinion

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Supplemental data for this article can be accessed online at https://doi.org/10.1080/14693062.2023.2211042.

1. Introduction

Limiting the global mean temperature increase to 1.5°C requires the near-complete phase-out of fossil fuel combustion by mid-century (Rogelj et al., 2018) and the replacement of carbon-intensive technologies by low-carbon alternatives. While phasing out some technologies, such as coal-fired power plants, is well-underway in many countries (Jewell et al., 2019), in the case of other carbon-intensive technologies decline is imminent even though it may not yet be highly visible. This holds true for internal combustion engine vehicles (ICEVs) which are gradually being replaced by electric vehicles (EVs).

Achieving climate neutrality in the next three decades requires ambitious, transformative policies that induce technological and behavioural change. While the effectiveness of 'pull'-policies has been empirically demonstrated, including subsidies for new low-carbon technologies, (e.g. Coffman et al., 2017; Delmas et al., 2013; Peñasco et al., 2021; Polzin et al., 2015), it is unlikely that these policies are sufficient for achieving full decarbonization. An increasing number of policymakers and scholars are calling for stricter regulatory policies that specifically target incumbent technologies or socio-technical systems (Heyen et al., 2017; Plötz et al., 2019; Rosenbloom & Rinscheid, 2020).

In the case of road transport, full and timely decarbonization requires more than 'carrots' targeted at raising EV adoption rates. Even policy instruments that disincentivise the purchase of ICEVs (e.g. vehicle registration taxes), discourage their use (e.g. fuel taxes), or improve their performance (e.g. emission standards) cannot guarantee an end to conventional car use unless they create prohibitively high costs (Axsen et al., 2020). This is where bans and phase-out pledges come into the picture.

Over the past decade bans and phase-out requirements or pledges have begun to see real-world implementation. While city-level bans are motivated primarily by air quality concerns, national-level bans aim to lower countries' oil import dependence, to reduce CO_2 emissions, or to establish a domestic EV manufacturing industry (Meckling & Nahm, 2019; Plötz et al., 2019). Car manufacturers are expected to innovate and form alliances around the low-carbon alternative, while consumers are assumed to refrain from buying a technology that is being phased out (Fulton et al., 2019).

These real-world developments were increasingly mirrored in scientific research. The socio-technical transitions literature long portrayed an 'innovation bias' by focusing on niche technologies in the early stages of a transition (Markard, 2018; Rosenbloom & Rinscheid, 2020; Turnheim & Geels, 2012). As a result, there exists ample evidence that new energy technologies such as EVs are potent mitigation options (e.g. Knobloch et al., 2020; Sovacool et al., 2020), and that they enjoy rather high levels of public support (e.g. Hamilton et al., 2018; Sütterlin & Siegrist, 2017). After Turnheim and Geels (2012) seminal paper on the 'flipside' of energy transitions, however, the concepts of destabilization, discontinuation, exnovation, creative destruction, divestment, and phase-out gained scholarly attention (Rosenbloom & Rinscheid, 2020).

Phase-outs range from aspirational goals to real-world regulations that differ in their intentionality, speed, scope, and substitutional dynamics (Koretsky & van Lente, 2020). Often, technological decline is associated with the emergence of a new, superior technology that renders the old technology unattractive or obsolete (Stegmaier et al., 2021). But this is not always the case (Adner & Kapoor, 2016). It can also stem from the emergence of new information that questions the efficacy (Finkelstein & Gilbert, 1985) or legitimacy (Greenwood et al., 2017) of the established technology. Several energy-related phase-outs (e.g. coal or nuclear energy) have been attributed, at least in part, to the diffusion of anti-fossil fuel norms and citizen opposition rather than new technologies per se (Green, 2018; Meckling & Nahm, 2019).

Research on phasing out ICEVs specifically is sparse but growing. Hoffmann et al. (2017) conceptualize the deliberate destabilization of the ICEV-dominated automobility regime. Meckling and Nahm (2019) investigate the nature of countries' phase-out pledges. Plötz et al. (2019) evaluate ICEV sales bans as policy options, and Brand et al. (2020) and Fulton et al. (2019) calculate the abatement potential of such policies.

This article investigates public opinion so as to yield insights that are relevant for climate policy design and communication in the individual transport sector, as well as into the feasibility of climate action (Fesenfeld, 2020). Policymakers tend to be risk-averse and refrain from implementing measures that evoke a strong public response (Banister et al., 2007; Weaver, 1986). The feasibility of governmental goals and policies in the climate change arena thus critically depends on citizens' acceptance. On the one hand, public opinion

can pose a substantial transition barrier, such as when affected workers, consumers, or citizens mobilize and protest against mitigation measures; as exemplified by the 'Gilets Jaunes' movement in France (Arning & Ziefle, 2020). On the other hand, public pressure can accelerate sustainability transitions, as was the case in the phase-out of nuclear energy in Germany (Markard et al., 2020).

Overall, public support for technology phase-out policies remains understudied across academic disciplines despite far-reaching environmental, economic, and social consequences. To date, only few scientific studies have investigated citizens' views on an ICEV phase-out. Bennett and Vijaygopal (2018) studied UK drivers' attitudes regarding the (then) forthcoming 2040 ICEV sales ban, finding that 40% of drivers would vote in favour of it, and 60% against it in a hypothetical referendum. Support was positively influenced by high environmental concern, by positive attitudes towards EVs, and by having played an EV driving simulation game. In a study by Rinscheid et al. (2020), US citizens were asked to rank different policy options in the phase-out of conventional cars. Overall, 34% of respondents were in favour of a ban, while 20% opposed it. Support was higher among younger and urban residents, as well as among citizens adopting pro-environmental behaviours and those not owning a car. Dechezlepretre et al. (2022) discover that bans are preferred over monetary penalties in most countries and applications, and that in a comparative ranking of 20 countries, acceptance is second lowest in Germany, following only Australia.

In this study, we seek to solidify previous research findings on public opinion by examining the phase-out of ICEVs in Germany as a case study. This choice of case study is interesting for at least two reasons: firstly, due to the considerable contribution of ICEVs to climate change in Germany (German Environment Agency, 2022) and elsewhere; and secondly, because of Germany's exceptionally high degree of techno-institutional and behavioural lock-in (Seto et al., 2016; Steg, 2005). We also aim to expand our knowledge about the factors that influence support for phasing out carbon-intensive technologies. We address the following research questions:

Q1: Which factors predict the public acceptability of an ICEV phase-out?

Q2: What are the anticipated impacts of an ICEV phase-out?

Q3: Which concrete policy instruments towards the phase-out of ICEVs are preferred by the public?

Q4: What effect does the provision of information have on public acceptability?

Note that we follow Kyselá et al. (2019) in using the term 'acceptability' to describe passive evaluative responses to a policy proposal. Please view Supplementary Material (Appendix B) for a visual representation of the conceptual model.

2. Methodology

2.1. Variable selection

For our variable selection, we incorporated findings from the fields of environmental psychology, public policy, and transportation research if the contributions were seminal and theory-defining, demonstrated outstanding methodological rigour, or were particularly similar to our case. For our final selection of predictors and following Nielsen et al. (2021), we pursued an inductive approach by synthesizing research findings with themes that frequently emerged in the public discourse which we closely monitored over the course of three months.

Socio-demographics and political views: Characteristics of the individual (e.g. age, gender, income, having children) are frequently identified as significant predictors of pro-environmental behaviours (PEB), such as EV adoption (Broadbent et al., 2018; Brückmann et al., 2021; Hackbarth & Madlener, 2012). Compared to other factors, however, their effect tends to be small (Blankenberg & Alhusen, 2019; Dechezlepretre et al., 2022). Political views play a stronger role, whereas left leaning people generally demonstrate higher support for climate policies (Dechezlepretre et al., 2022; McCright & Dunlap, 2011).

Context and habits: The Value-Belief-Norm theory (Stern et al., 1999) highlights the influence of contextual factors, which can be economic, technological, or socio-structural. For our case, this includes car ownership (Carley et al., 2013) and car use (Dechezlepretre et al., 2022; Jensen et al., 2013), which is highly habitualised (Blankenberg & Alhusen, 2019; Orru et al., 2019). Following the Ipsative Theory of Behaviour (Frey, 1988),

people's behaviours are constrained by the lack of real or perceived opportunities, such as the availability of and intention to use alternative modes of transport (Bamberg & Rölle, 2003). This also relates to the Theory of Planned Behaviour (Ajzen, 1991), which developed the notion of 'perceived behavioural control', which describes a combination of an individual's internal conditions and external circumstances.

Values and beliefs: People are more likely to behave in an environmentally-friendly way, if they subscribe to biospheric or altruistic values (Groot et al., 2007; Schuitema et al., 2010; Stern & Dietz, 1994), demonstrate high environmental concern (Blankenberg & Alhusen, 2019; Dunlap & Van Liere, 2008; Vining & Ebreo, 1992), and show high problem awareness or attribution (Bamberg & Möser, 2007; Rienstra & Rietveld, 1996; Steg & Vlek, 1997). However, the influence of these factors diminishes if behavioural costs are high, such as when limiting car use (Bamberg & Schmidt, 2003; Hunecke et al., 2001).

Additionally, affect and positive emotions influence behaviour (Steg, 2005) and policy acceptability (Lu & Schuldt, 2015; Wang et al., 2018) as does the perceived procedural and distributional fairness of any policy (Huber & Wicki, 2021; Jakobsson et al., 2000; Lind & Tyler, 1989). Culture, which encompasses values, beliefs and practices that are shared among a social group, also impacts PEB and can complicate or catalyze transformative change (Filippini & Wekhof, 2021; Sovacool & Griffiths, 2020; Tanner, 1999).

Treatment effect (information): With regards to changing people's opinion [Q4], framing strategies (e.g. small changes in the presentation of an issue) can be successful (Chong & Druckman, 2007), though reasonable doubt has been cast on the magnitude and persistence of effects (Fesenfeld et al., 2021). More significant opinion change can be induced by the provision of additional information on an issue. Yet again, according to the Theory of Cognitive Dissonance (Festinger, 1962), pre-held attitudes mediate the acceptance and interpretation of new information (Egan & Mullin, 2017; Wiest et al., 2015), and effects are short-lived (Abrahamse et al., 2005).

Nonetheless, researchers consistently study and find effects of informational treatments, and continue to suggest using educational measures in public policy (Blankenberg & Alhusen, 2019; Dechezlepretre et al., 2022; Prakash & Bernauer, 2020; Steg & Vlek, 2009; Stokes & Warshaw, 2017). Explaining the mechanisms and rationale behind climate policies ultimately remains a key strategy to foster policy support (Dechezlepretre et al., 2022), and continues to be one of the most frequently used instruments in policymaking.

Other factors: Policy acceptability also depends on personal outcome expectations, the degree of affectedness of oneself and others, as well as costs to the individual (Dechezlepretre et al., 2022; Jakobsson et al., 2000; Lindenberg & Steg, 2007; Schade & Schlag, 2003). We do not include this in our model [Q1], as this would add circularity to our line of argument, but instead ask a related question in [Q2].

Finally, previous literature unambiguously finds that 'soft' measures (e.g. information, subsidies) are preferred over 'hard' measures (e.g. regulation, pricing) (Brückmann & Bernauer, 2020; Drews & Van den Bergh, 2016; Gärling & Schuitema, 2007; Steg & Vlek, 2009) – though conflicting evidence exists on the relative preferability of some restrictive measures over others (e.g. bans vs. pricing). We evaluate preferences for different policy instruments in [Q3].

2.2. Case motivation

The German energy transition (Energiewende) gained global prominence when feed-in-tariffs led to the large-scale deployment of solar PV in Germany and abroad (Hoppmann et al., 2014; Quitzow et al., 2016). Yet, the country did not emerge as a first-mover in the adoption of electric vehicles (Rietmann & Lieven, 2019) nor as a frontrunner in the decarbonization of transport more generally, as evidenced by the fact that transport-sector emissions have not notably declined over the past 30 years (IEA, 2021).

This is partly due to the exceptional role of the automotive industry (Haas, 2021). Germany is home to several global automaker brands such as Volkswagen, Audi, Mercedes-Benz, and BMW. The automotive industry produces over 5.1 million cars annually (ICCT, 2020) and employs 840'000 people directly and another 800'000 people indirectly (Fraunhofer IAO, 2018). After the financial crisis, a car scrappage scheme was the main instrument to revive the economy, and vintage cars ('Oldtimers') continue to enjoy tax reductions for 'preserving technical cultural heritage' (Gössling & Metzler, 2017).

When the U.S. Environmental Protection Agency revealed that Volkswagen used an illegal software in its driving emissions test, public trust in car manufacturers was severely damaged (Gross & Sonnberger, 2020).

More recently, citizen groups such as Fridays for Future or Extinction Rebellion publicly criticized the hegemony and environmental impact of conventional cars. Despite the slow erosion of public support for both automakers and conventional cars in some parts of society, the restriction of ICEVs is still considered a 'political suicide' and a 'topic of outrage' by some (Hoffmann et al., 2017).

2.3. Survey administration

The questionnaire was developed in English, translated into German, and tested on a group of approximately 30 people prior to being launched by the professional panel provider and market research institute respondi/bilendi in the field in May 2021. In contrast to similar studies, we sampled from the entire adult population rather than from only car owners given that all citizens are affected by conventional cars. We applied quotas so that our sample reflected the gender and age distribution of our target population (Appendix B). All respondents who completed the online questionnaire and provided answers to at least 85% of the survey items were included in our final sample (N = 1663).

2.4. Variable operationalization and analysis

The outcome variable, policy acceptability of an ICEV phase-out by 2040, was operationalized via the expressed approval thereof and measured on a 5-point Likert-scale (see Appendix B for question wording and response options). Given that hybrid electric vehicles have a sizable climate impact (Plötz et al., 2018), we specifically included them in our precursory definition of ICEVs.

All data preparation and analysis was conducted in R (version 4.1), using the packages likert (Bryer & Speerschneider, 2016), rstatix (Kassambara, 2021), randomForest (Cutler & Wiener, 2018), lavaan (Rosseel, 2020), MASS (Venables et al., 2002) and marginaleffects (Arel-Bundock, 2023).

Predictors of acceptability [Q1]

Socio-demographic (e.g. age, gender, location, income), contextual and habitual factors (e.g. ICEV ownership, driving frequency) were measured by providing respondents with comprehensive but mutually exclusive response options. Given our theory-driven variable selection, we conducted a Confirmatory Factor Analysis (CFA), which confirmed the validity and reliability of our (latent) value and belief variables (see table A1). The CFA model resulted in a Comparative Fit Index of 0.99 and a Tucker-Lewis Index of 0.99 alongside a Root Mean Square Error of Approximation (RMSEA) of 0.045, which indicates excellent model fit. The factor scores for each respondent were estimated using this model and used as predictor variables for the regression models.

We used random forest (RF), a supervised machine learning technique, to conduct a classification task (Breiman, 2001). Compared to conventional regression analyzes, RF performs well in the case of complex and non-linear relationships, multiple mixed-type variables, non-parametric distributions, collinearity among co-variates, and theory-informed rather than theory-driven research design (Strobl et al., 2009), which makes it an appropriate method of analysis for our case. As a first step, we imputed missing data using a RF algorithm which replaced missing values by considering similar cases to the one with missing data. Then, we drew a bootstrap sample from the entire sample on which we trained the model. Finally, we tested our model on the 'out-of-bag' sample which had not been used for training.

Random forests consist of multiple decision trees (see Kingsford & Salzberg, 2008). The construction of each tree follows a process called 'recursive partitioning' in which the sample is split into groups depending on the values for a randomly restricted set of predictor variables (Strobl et al., 2009). Each node (branching point) is split so that the purity of the daughter (i.e. subsequent) node increases, as a result of which individuals with similar responses are grouped together. Since one classification tree on its own is unstable and dependent on both sample and variable selection, multiple trees are aggregated to increase prediction accuracy (Breiman, 2001; Bühlmann & Yu, 2002). Each observation is run down every tree, which all return a prediction (here: acceptability = 1 or 0). The prediction that receives the most 'votes' is returned as the final prediction of the ensemble of trees, i.e. the forest (Strobl et al., 2009). We fine-tuned our model by limiting the number of randomly selected variables for each split (mtry = 4) and the overall number of trees (ntree = 1'000). Overall, 81% of respondents were correctly classified, which indicates good model fit.

We then assessed variable importance, which describes the independent importance of each explanatory variable in predicting acceptability of an ICEV phase-out. By randomly permuting a given explanatory variable, its initial link to the outcome variable is broken (Strobl et al., 2009). When all variables, including the randomly permuted one, then predict the response, the prediction accuracy decreases if the randomly permuted variable did, in fact, predict the outcome better than random. Even though the absolute values are not immediately interpretable, they show the relative differences in variables' importance, which we rescaled to 0–1 for better readability.

Since this does not provide information on the direction of a relationship, we complemented our RF results by performing an ordered logit model, which acknowledges the ordinality of the response options (Fullerton & Anderson, 2023). This makes it methodologically superior to assuming that the ordered outcome variable is of numerical nature, while also maintaining more granular data than in the case of binary logistic models, where the outcome variable is dichotomized. For easier readability and comparability, we included a binary logistic regression in Appendix A (figure A1). We performed the Brant test (table A2) to test the proportional odds (parallel lines) assumption, which was largely met.

We also investigated whether acceptability was related to the perceived likelihood of an ICEV phase-out, ranging from 'inevitable to unrealistic'. This variable was not included in the above-mentioned models, because it cannot be said to precede the outcome variable, so instead we calculated Spearman's rho.

Outcome expectations [Q2]

The anticipated effects ('outcome expectations') of an ICEV phase-out on different entities (the respective individual, society at large, the average citizen, the German automobile industry, the economy, the environment, and public health) were measured on a 5-point Likert scale ranging from 'very negative' to 'very positive', for which descriptive statistics were produced.

Policy preferences [Q3]

With regards to policy options, we included both pull measures (public transport and EV subsidies), pricing and regulatory measures (purchase tax on ICEVs, EV company car mandate), as well as permutations of ICEV bans (registration ban by 2030, inner-city driving bans by 2025, full driving bans by 2040). We assessed respondents' approval of each instrument on a 5-point Likert scale and produced a visual summary. Additionally, a McNemar test was conducted to test for differences in the distribution of variables (Appendix A, tables A4 and A5).

Information treatment [Q4]

The questionnaire concluded with a repeated measure of acceptability after respondents were subject to an information treatment. Respondents received factually correct information that followed one of three policy-relevant narrative groups as background for the policies, groups to which they were randomly assigned. This included narrative A ('Change is inevitable'), narrative B ('EVs are better than you think') and narrative C ('ICEVs are worse than you think'). Such within-subject pre–post design (Campbell & Stanley, 1963) has been found to yield similar results as between-subject post-treatment only comparisons, while increasing precision (Clifford et al., 2021). We used the non-parametric Wilcoxon signed-rank test (Rey & Neuhäuser, 2011) to calculate treatment effect sizes and significance. When in July 2021, the European Commission (EC) proposed to ban the sale of new ICEVs by 2035, we also conducted a follow-up survey to investigate whether this announcement had an effect on acceptability, using the same statistical tests as for the information treatment.

3. Results

Compared to previous studies (Bennett & Vijaygopal, 2018; Rinscheid et al., 2020), rates of explicit approval are slightly higher (18.3% strongly and 27.2% rather approve), while at the same time disapproval remains sizable (15.8% strongly and 17.6% rather disapprove), and 21.1% of respondents hold a neutral stance. Approval is closely related to whether respondents believe an ICEV phase-out is likely (Spearman's rank correlation rho: 0.74, $p < 0.01$). While 43% think an ICEV phase-out is ultimately inevitable or rather likely, 40% think it is rather unlikely or completely unrealistic.

Predictors of acceptability [Q1]

Overall, variables that relate to respondents' values, beliefs and political views play a larger role in contributing to the RF model's predictive accuracy than socio-economic or contextual variables (Figure 1). One variable

in particular, namely the degree to which respondents attribute air pollution and climate change to the use of ICEVs (problem attribution), is highly predictive of acceptability. This is followed by the degree to which respondents favour market liberalism and reject regulation, and the degree to which respondents feel emotionally attached to conventional cars. The perceived cultural and economic significance of ICEVs also plays an important role, albeit smaller than two factors related to respondents' context and perceived behavioural control: their willingness to abandon cars altogether as well as their willingness to adopt EVs.

The ordered logit model results paint a very similar picture (Figure 2): There is a positive and strong relationship between problem attribution and acceptability. Liberalism, emotional attachment, and cultural/economic significance are all negatively associated with acceptability, in decreasing order of effect size. All value and belief items except liberalism are characterized by comparatively low variability.

Respondents' willingness to give up their car has a positive effect on acceptability. The probability of strong approval increases by about 13% if respondents are unconditionally open to the idea compared to respondents who reject it. Willingness to adopt EVs also has a statistically significant and positive effect that is most pronounced in the case of unconditionality with average marginal effects (AMEs) of up to 13%. Owning an ICEV decreases the probability of strong approval by up to 2%, while possessing a driving license increases it by up to 1%. The direct effect of weekly car use on acceptability is positive but not statistically significant.

With regards to socio-demographic variables, younger respondents are more likely to demonstrate at least moderate rates of approval, while at the same time acceptability and income are generally positively associated, but there are exceptions. People who support the Left, Green, and Conservative Party are up to 8% more likely to strongly approve than people who support the Social-Democratic Party (SPD). The variables location, having children, and gender are not statistically significant.

Outcome expectations [Q2]

The majority of respondents believe an ICEV phase-out would affect the environment and public health positively (66 and 56% respectively; see Figure 3a). Interestingly, while 45% think the effect on society would be positive, only 31% think so in the case of themselves or the average citizen. Almost an equal number of respondents think that the effects on the economy would be positive, neutral, or negative respectively.

Policy preferences [Q3]

Even though 45% of respondents approve of an ICEV phase-out by 2040, only 29% approve of the specific policy instrument of a 2040 ICEV driving ban (Figure 3b), despite the equivalence in implications. Unsurprisingly, pull measures like subsidies enjoy high levels of support, wherein approval of public transport subsidies is higher (69%) than of EV purchase subsidies (53%). The third most popular (and net approved of) policy instrument is an EV-only mandate for company cars by 2028. All remaining policies, including pricing policies and permutations of ICEV bans, are equally unpopular, with disapproval rates of 48-57%.

Information treatment [Q4]

Providing respondents with information that makes EVs appear more and ICEVs less favourable had a statistically significant effect on acceptability ($p < 0.01$), with effect sizes of 0.114 and 0.143 respectively. The provision of information following narrative A ('Change is inevitable') had no statistically significant effect. While across narratives, the treatment effect was positive, a surprisingly large number of respondents (~16%)

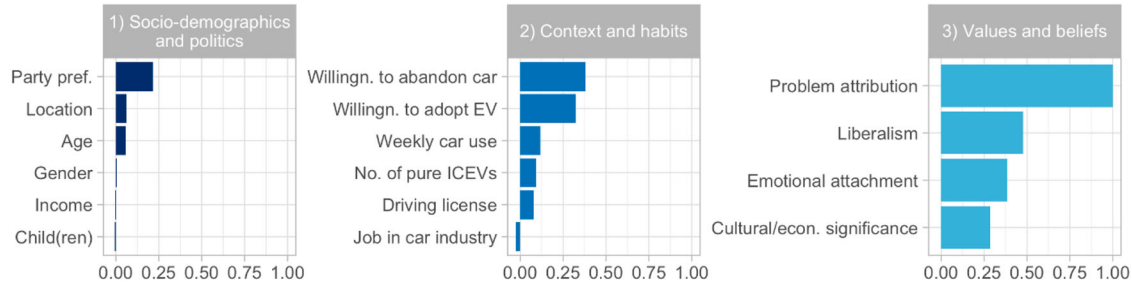

Figure 1. Variable Importance in predicting acceptability of an ICEV phase-out (random forest model)

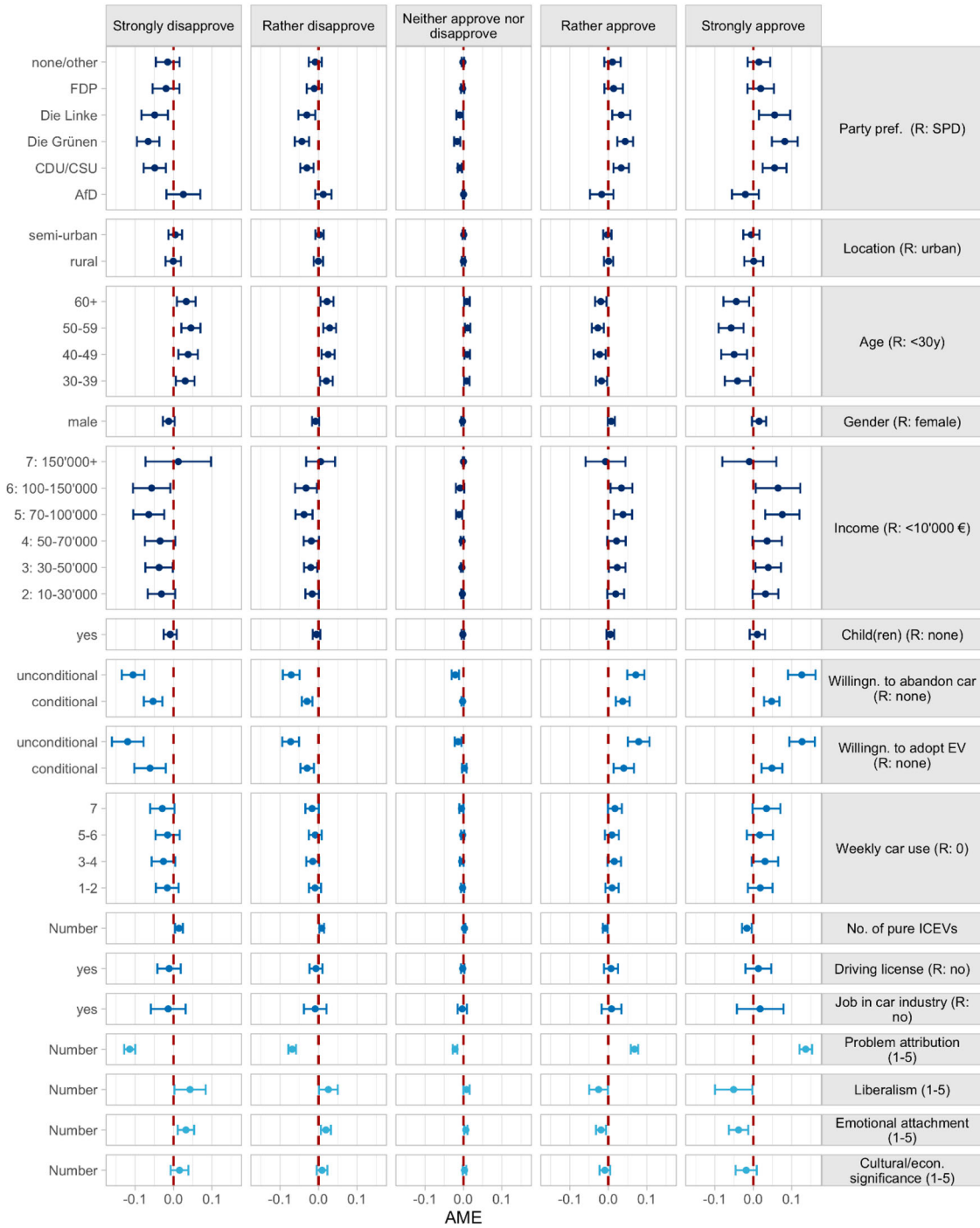

Figure 2. Average Marginal Effects (AME) of the ordered logit model. Note: Shown are the effects of each explanatory variable on the probability of each level of the outcome variable. The red dashed line marks the reference for each variable (see reference (R:) in right panel). Confidence intervals (95%) are displayed as whiskers. Explanation on political parties: SPD (social-democratic), CDU/CSU (conservative), Die Grünen (green), FDP (liberal), Die Linke (left), AfD (right-wing populist). The results are also printed in tabular form in Appendix A (table A3).

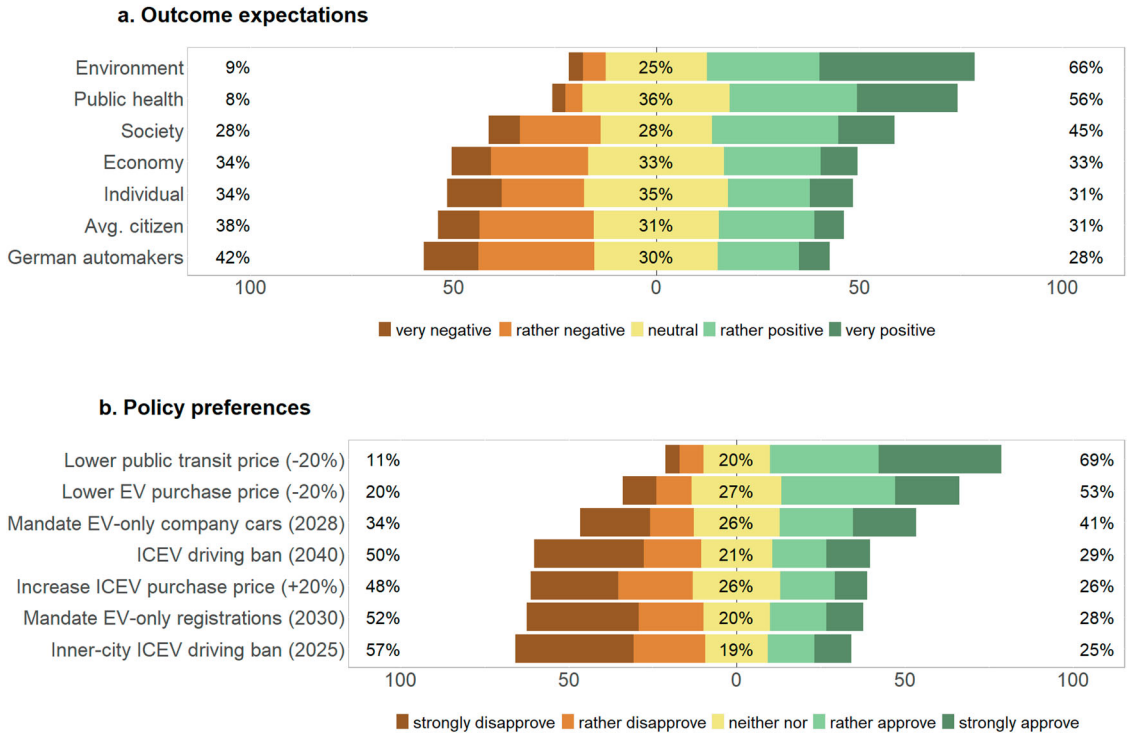

Figure 3. Outcome expectations (a.) and policy preferences (b.). Plot a. displays the percentage of respondents that anticipate negative, neutral, or positive effects of an ICEV phase-out on different entities. Plot b. shows respondents' approval rates of several policies towards phasing out ICEVs. The difference of the four least approved policies are not statistically significant (tables A4 and A5).

demonstrated a decrease in acceptability, while the majority did not change their opinion in response to new information (Figure 4a).

The EC's proposal to ban the sale of new ICEVs by 2035 can be thought of as a real-world manifestation of narrative A, indicating that the phase-out of ICEVs is ultimately inevitable. Of all respondents that took part in the follow-up study (N = 1,327), the majority (66%) had heard about the legislative proposal, but it did not have a statistically significant effect on acceptability, neither did acceptability differ significantly from the group that did not hear about it (Figure 4b). While these results could indicate that some information is ineffective in influencing acceptability, they could also stem from a methodological design that allows for 'regression to the mean' (Bonate, 2000).

4. Discussion

Our results have important implications for policy and notably for the political feasibility of technology phase-outs. Overall, the majority of the surveyed public has a positive or neutral attitude towards a complete ICEV phase-out by 2040, which is a goal that can be said to be more ambitious than the EU-level sales ban from 2035 onwards. This suggests that public opinion may not act as a significant barrier to policy implementation, though it shall be noted that other political economy constraints such as high costs or industry interests remain. Additionally, there is reason for caution. Firstly, the 'Gilet Jaunes' movement in France has demonstrated that opponents may not be in the majority, but that they may be highly motivated to mobilize (Arning & Ziefle, 2020), which in turn can lead to delay and ultimately jeopardize decarbonization efforts. Second, our results show a considerable gap in the acceptability of an ICEV phase-out and a driving ban for the same year. Also, impacts are believed to be more favourable for society than for the respective individual. These findings suggest that respondents may be in favour of phasing out ICEVs on an abstract level, but that their support

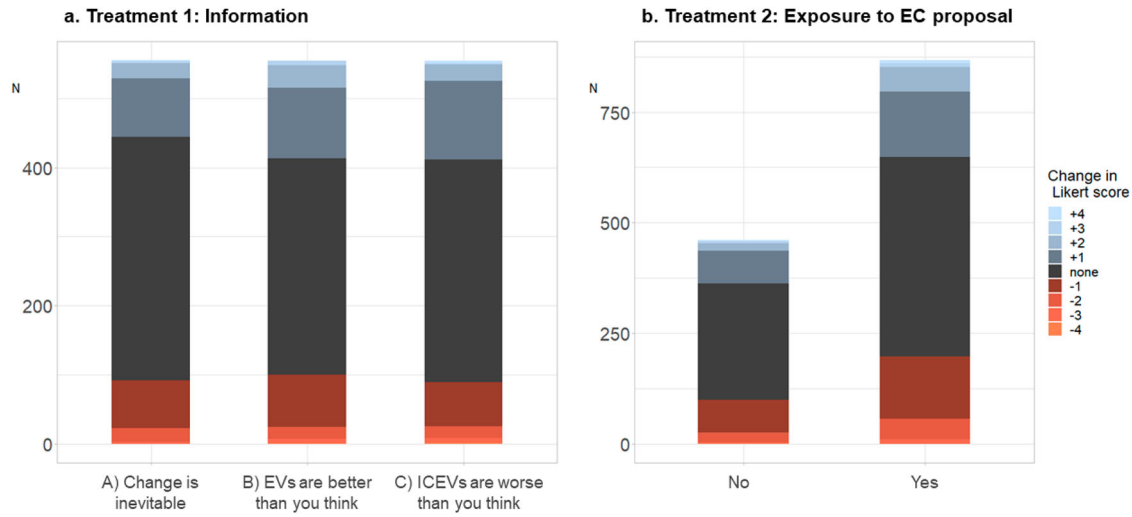

Figure 4. Information treatment effects. Plot a. displays changes in acceptability in response to new information, which followed one of three narratives (A-C). Plot b. shows changes in acceptability in response to the EC's legislative proposal.

diminishes when concrete policy measures threaten to affect them personally. This points to a social dilemma (Lange et al., 2013), i.e. a conflict between long-term societal benefits and short-term negative affectedness. It also supports previous research findings on diminishing motivation to behave in an environmentally-friendly way when high behavioural costs are involved (Steg & Schuitema, 2007).

It should also be noted that respondents' *willingness* to abandon cars altogether or adopt EVs may in fact describe respondents' *ability* to do so. This is supported by the finding that wealthier respondents show higher rates of approval, as they likely have more opportunities for adapting to any policies. Low levels of approval among voters for the social-democratic party further suggest a working-class effect. Lastly, owning ICEVs is associated with lower levels of acceptance, which points to an endowment effect and a status quo bias, as outlined (Kahneman et al., 1991) and detected in previous analyzes (Rinscheid et al., 2020).

This calls for policy design that mitigates adverse effects, especially for economically vulnerable groups within society. It could entail measures in the spirit of a 'just transition' (Galgóczi, 2020), such as financial compensation or 'universal basic transportation' financial transfers (Bloomberg CityLab, 2021). Introducing an EV mandate for company cars is relatively popular and could grow the second-hand market for EVs, making them affordable for more people. Additionally, since policy packages can increase support for climate policies (Fesenfeld, 2020), less popular policies could be coupled with more popular ones. In line with previous research (Rinscheid et al., 2020), we find that pull measures, such as EV adoption subsidies, are preferred over more restrictive policies (such as taxes or bans) and thus contribute to a balanced policy mix.

In addition to policy design or policy packages, policymakers can also increase acceptability through targeted policy communication. Our results indicate that communicating the inevitability of an ICEV phase-out does not lead to increased acceptability. However, it may still be worthwhile to address misinformation and facilitate citizens' mobility and purchase decisions. More importantly, policy advocates should highlight the advantages of EVs, such as improvements in range or falling costs, or emphasize the negative impacts of ICEVs, such as their contribution to air pollution, human health risks and climate change. Problem attribution is the most important predictor of acceptability, and the problem-frame was the most effective of all treatments. While the magnitude and persistence of information effects has been challenged (Fesenfeld et al., 2021), our results similarly show that values and beliefs have a greater influence than structural barriers originating from respondents' socio-economic circumstances – suggesting that it is insufficient to change people's external environment. Previous research has also shown that policy acceptance rises after implementation (Murray & Rivers, 2015), and that people tend to adapt well to new policies even if their circumstances do not change (Diener & Fujita, 1996).

When relating our findings to the technology transitions and phase-out literature, we provide supporting evidence for the notion that incumbent technologies not only decline in response to the emergence of new, superior technologies, but also due to information that delegitimizes the old technology. Given the urgency of timely and ambitious climate action, it is crucial to pursue the two technology strategies simultaneously: supporting the rapid scale-up of low-carbon technologies (e.g. via EV purchase subsidies or improved public transport) while accelerating the destabilization and decline of carbon-intensive ones (e.g. via banning the sale of ICEVs or restricting their use).

Our results have implications for other countries and technologies. First, if phasing-out ICEVs appears sufficiently acceptable in Germany, where conventional cars are particularly locked-in, it is likely acceptable elsewhere. Second, most predictors of public opinion, such as underlying values and beliefs, relate to a shared human experience that is not constrained by country borders. Third, phase-out pledges and associated policies will accelerate domestic automakers' transition from producing ICEVs to producing EVs. In Germany, this will lead to international spillover effects and cost declines, as Germany is the largest car exporter (by value) globally. Finally, our findings add to the growing body of literature on the increasing delegitimization of fossil fuels and related carbon-intensive technologies for environmental reasons (Green, 2018).

Our study has important limitations. First, we may have introduced bias by quota-sampling from an existing panel rather than randomly sampling from our target population, as well as through self-selection, i.e. respondents holding a stronger view and thus being more motivated to participate than non-respondents. Second, unknown confounders not included in our models may have influenced respondents' attitudes towards an ICEV phase-out. While we took measures to mitigate these effects, we cannot rule out demand side effects (e.g. repeated measure enables respondents to infer researchers' hypotheses) or consistency pressures (respondents feel motivated to provide consistent answers) in our information treatments.

5. Conclusions

In surveying 1663 citizens of Germany, we find that the majority (67%) approve of, or are indifferent towards a complete ICEV phase-out by 2040, though disapproval remains sizable (33%). Acceptability is most strongly influenced by respondents' values and beliefs, especially the degree to which air pollution and climate change are attributed to ICEV use (problem attribution). Acceptability is also positively influenced by people's willingness to adopt EVs or abandon cars altogether, as well as preferences for certain political parties (especially for the green, left, and conservative party). At the same time, our findings also show that acceptability of specific policy instruments varies greatly. Subsidies for EVs and public transport enjoy higher levels of support, with 53 and 69% of respondents respectively in favour, compared to 25–29% in the case of taxes and bans. We also find that respondents fear adverse effects of an ICEV phase out, especially on German automakers, the average citizen, and themselves. In fact, over a third of respondents anticipate being negatively affected personally.

This calls for careful policy design that is sufficiently ambitious while also mitigating adverse effects. Policy packaging, e.g. combining more and less favourable policies, promises to combine ambition and acceptability. Another strategy to increase acceptability concerns the communication of policies. We find that presenting EVs in a more favourable light, and ICEVs in a less favourable one, has a statistically significant and positive, albeit small, effect on acceptability. When the European Commission announced a ban on the sale of ICEVs from 2035, we conducted a follow-up survey to test whether this had influenced acceptability, given that we had found a strong correlation between the acceptance of an ICEV phase-out and the perceived inevitability thereof. However, the proposed legislative manifestation of the policy had no effect on respondents' views.

We have entered the next phase of the energy transition (Markard, 2018), where low-carbon technologies are on the rise while several carbon-intensive technologies have entered a phase of decline. Policy researchers face two key tasks: understanding which mitigation policies are effective in bringing down emissions and understanding how to make these policies politically feasible by increasing their acceptability. This requires a thorough investigation of public opinions about existing mitigation measures, as well as the identification of political economy constraints. Policymakers should be encouraged to implement more ambitious measures, while taking into account scientific evidence on policy design and policy communication to simultaneously increase political feasibility.

Data availability statement

The workflow code to reproduce our findings is publicly available on Zenodo (DOI:10.5281/zenodo.7915863).

Disclosure statement

No potential conflict of interest was reported by the author(s).

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