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Mapping public support for climate solutions in France

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Abstract
Although successful sustainability transitions depend on public support, we still know little about citizens' opinions on climate solutions. Existing research often focuses on the problem perception of climate change rather than analyzing attitudes toward specific climate solutions. Studies also largely use closed questions to assess public opinion, posing a problem of ecological validity. Here, we address these gaps by leveraging data from a large-scale public consultation process, the "Grand Débat National", launched by the French government in response to the Yellow Vest movement in 2019. Combining structural topic modelling, dictionary-based text analysis and qualitative coding, we map the salience and directionality of public opinion on climate solutions. We find that consultation participants perceive climate change as the most salient environmental problem. Transforming the transport and energy sectors is the most supported solution for addressing climate change. For these two sectors, substitution-based climate solutions - as opposed to sufficiency- or efficiency-based measures - are most salient. For instance, participants stress the need to expand public transport infrastructure and switch to renewable energy technologies for power generation. Our findings demonstrate a strong public consensus on most substitution-based climate solutions, except for the role of cars and nuclear energy. While most participants do not link climate solutions to specific policy instruments, we find preferences for authority-based instruments in the context of phasing out polluting technologies, and treasury-based instruments for supporting innovation and phasing in low carbon technologies.

1. Introduction

Reaching the 1.5 °C target of the Paris Agreement and several sustainable development goals requires fast and deep transitions of key economic sectors, such as the energy, transport, agri-food, and building sectors (IPCC 2018, UN Environment 2018). Policy interventions are necessary to accelerate these transitions and induce climate solutions (Kivimaa and Kern 2016, Geels *et al* 2017, Schmidt and Sewerin 2019). Yet, the political feasibility of such interventions often depends on a combination of interest group politics (Meckling 2011, Meckling *et al* 2015, Schmid *et al* 2020) and mass politics such as voting behavior and public opinion (Bernauer and McGrath 2016, Stokes and Warshaw 2017, Beiser-McGrath and Bernauer 2019a, Fesenfeld 2020, Fesenfeld *et al* 2020, Schmid 2020). Effective climate solutions are unlikely to be implemented and remain sticky without support by citizens because, if successful, they have manifest effects on citizens' lives (Drews and van den Bergh 2016, Ingold *et al* 2019, Sterner *et al* 2019, Wicki *et al* 2019, Cox *et al* 2020, Lamb *et al* 2020). While there is extensive research on citizens' problem perception of climate change (Jenkins-Smith *et al* 2020, Levi 2021a) we know less about public opinion on climate solutions and related policy instruments (Howe *et al* 2013, Capstick *et al* 2016, Rhodes *et al* 2017). More recent research is addressing this gap, for example by studying public opinion on CO_2-pricing (Klenert

et al 2018, Beiser-McGrath and Bernauer 2019b, Levi 2021b), renewable energy policy (Anderson *et al* 2017), coal phase-out (Rinscheid and Wüstenhagen 2019), carbon capture and storage (Pianta *et al* 2021), transport policy (Rinscheid *et al* 2020, Kallbekken and Sælen 2021), or food policy (Fesenfeld *et al* 2020).

These studies, however, mostly use country-level surveys with closed questions to examine public opinion on climate solutions (Tvinnereim and Fløttum 2015). Here, we complement insights from these studies by exploiting a large dataset based on an open question on 'preferred solutions' to climate change. Analyzing open text responses rather than responses to closed-ended survey questions produces more ecologically valid results (Tvinnereim and Fløttum 2015). They allow people to express what is 'on top of their mind', i.e. which policy instrument, argument or frame they activate when formulating an open respone (Tvinnereim *et al* 2017). Closed-ended survey questions, however, demand a specific response (e.g. on a Likert scale) to a predefined question and policy attitude. As such, the question already frames the response space and might thus suffer from lower ecological validity compared to open-end questions (Savin *et al* 2020). To comprehensively understand the political prospects for climate solutions it is helpful to provide more detailed and exhaustive insights on the solutions supported by the public in open questions (Howe *et al* 2015, Tvinnereim and Fløttum 2015, Tvinnereim *et al* 2017, Olson-Hazboun *et al* 2018). Furthermore, existing research on public opinion on climate solutions predominantly covers the US (Kotchen *et al* 2013, Howe *et al* 2015, Jenkins-Smith *et al* 2020) with only few studies on European countries (Capstick *et al* 2016, Cox *et al* 2020) and even less beyond.

To address these gaps, our study exploits a novel and original data source to comparatively examine public support for specific climate solutions across different sectors. To do so, we collected data from one of the largest public consultation processes worldwide, the 'Grand Débat National' in France[4]. This process was launched in response to the Yellow Vest protests and carried out from January to March 2019. Over this period, the French government received almost 600 000 submissions to an online survey with closed and open-ended questions on the issue of sustainability transitions (Fourniau 2019). We analyze this unique dataset with a mixed-methods approach combining structural topic modelling (STM), keyword-based classification (Roberts *et al* 2014) and qualitative coding. We manually coded survey answers to assess the prevalence of substitution-, sufficiency-, and efficiency-based

measures, the patterns of citizens' support or opposition to climate solutions, as well as the salience of related policy instruments. The online survey was not randomly assigned, and participants decided themselves to take it, which makes robust inference difficult. However, the use of more than 100 000 open-ended answers related to climate change enables an original and unprecedented insight into public support for climate solutions of a politically engaged subset of French society.

To meet the ambitious climate targets France has set itself in 2017, emissions need to decrease in all major sectors of the economy, especially the transport (accounting for 31% of national emissions in 2018), building (19%), agricultural (19%), and energy sector (10%) (High Council on Climate of France 2019). Yet, current policies and related emission trajectories are largely insufficient to achieve these targets (High Council on Climate of France 2019). Whether this large gap between required and implemented climate action is supported by public opinion is thus far unclear.

Our findings show that climate change is the most salient sustainability challenge among survey participants, before biodiversity and air pollution. Citizens see transforming the transport and energy sectors as primary levers to tackle climate change, followed by the agricultural and building sectors. In the transport and energy sectors, support for substitution-based climate solutions is higher than for sufficiency- and efficiency-based measures. While most substitution-based climate solutions such as expanding deployment of renewables or use of train are consensual and widely supported, two salient solutions are contested among the French public: electric vehicles and nuclear energy. We also find that most consultation responses remain vague in that they do not link climate solutions to specific policy instruments. Among respondents that specify a policy instrument, we primarily find preferences for authority-based measures in the context of phasing out polluting technologies, and support for treasury-based measures for promoting innovation and phasing in low carbon technologies. Our analysis contributes to ongoing efforts to better understand the mass politics of sustainability transitions (Howe *et al* 2015, Fesenfeld and Rinscheid 2021, Schmid *et al* 2021). Our findings support the hypothesis that there is a gap between widespread support for and effectively supplied climate solutions, suggesting that climate policy lacks responsiveness and deviates from the democratic ideal of a policy shaped by citizens' preferences (Prakash and Bernauer 2020). The identified consensus and support for most (substitution-based) climate solutions among survey participants also aligns with the ambitious propositions put forward by the French Citizens' Convention for Climate, a representative sample of 150 French citizens convened by the French government in 2019 (Giraudet *et al* 2021).

[4] https://granddebat.fr/

2. Leveraging the French Grand Débat National as original data source

To map public support on climate solutions in France, we leverage data from the 'Grand Débat National' taking place from January to March 2019. The unprecedented scale of this public consultation allows for previously unavailable insights into French public opinion on sector-specific climate solutions. We use data collected in the large-scale online survey that received a total of 569 029 individual contributions, and which accompanied more than 10 000 physical town hall meetings across France. The survey was split into the four themes of fiscal policy (186 713 contributions), sustainability transitions (153 812 contributions), democracy and citizenship (116 549 contributions), and organization of the state (111 955 contributions). In our analysis, we examine data from two survey items of the thematic field 'sustainability transitions'.

Respondents were first asked to indicate 'the most important problem related to the environment', choosing between five categories: air pollution, climate change, coastal erosion, biodiversity, and all of the above ($N = 129\,627$). Second, in an open-answer field, survey participants had the opportunity to describe how the most important problem identified earlier should be mitigated ($N = 123\,626$). Although the survey does not contain individual-level data on socio-demographic or other variables, an analysis of the ZIP codes of survey participants has shown that some sub-groups, such as urban, well-educated, and older are likely to be over-represented (Bennani *et al* 2019, Fourniau 2019). This specific subset of French society is arguably politically influential. Indeed, the above-mentioned variables (education, age, etc) have been shown to correlate with the likelihood to vote (Akee *et al* 2020) and the propensity to become otherwise active in the political sphere (Anoll 2018). Hence, considering that political feasibility of ambitious climate policy requires broad political support and mobilization, it is highly relevant to explore the opinion on climate solutions of this subset of the population.

3. Using a mixed methods approach

While open-ended answers constitute a valuable data source (e.g. for reasons of ecological validity), their systematic analysis is a complex and challenging task (Tvinnereim *et al* 2017). Our study's main objective is to measure the salience of individual climate solutions, as well as patterns of support and opposition towards these solutions (and related policy instruments). Due to the large size of our sample, manual coding of all survey answers is not conceivable. Instead, we automatically extract climate solutions by combining topic modeling with a custom dictionary, and use manual coding only for smaller random samples.

The automatic extraction of climate solutions from open-ended survey answers is challenging in two ways. First, there is no exhaustive list of all possible climate solutions readily available. There are different types of policy instruments and the solutions can target different economic sectors (transport, buildings, etc). Some solutions overlap, so that splitting the ensemble of potential climate solutions into well-defined individual instruments is difficult.

Moreover, there are infinite ways to express a preference for a climate solution and related policy instruments. Fortunately, mentioning a given climate solution implies in most cases the use of at least one of a limited set of keywords, easing automatic detection. For instance, a respondent articulating their preference for a reduction of air traffic is extremely likely to use one of the following words: 'to fly', 'airplane', 'airport' or 'kerosene'. These keywords must however be carefully chosen and need to be specific to be able to discriminate between different climate solutions, as some words can simultaneously be associated with several solutions.

To account for these methodological challenges and explore the massive amount of unstructured text data, we proceed in five steps. First, we use a machine learning approach called STM, which, given a corpus of documents, automatically identifies the most salient subjects across all documents (Roberts *et al* 2014). Using STM, we extracted 75 topics, which we manually grouped in 23 general subjects based on qualitative assessment, such as transport, agriculture, or education. The full list of topics and their respective salience is presented in the appendix in figure 2 (available online at stacks.iop.org/ERL/17/044035/mmedia). The validation of the results shows that the topics lack precision and did not offer enough empirical leverage for accurate description of individual climate solutions. For instance, while the model identified transport as one of the most salient topics, it does not allow us to distinguish between more specific solutions related to transport, such as individual vs. public transportation.

Therefore, in a 2nd step, we use the topics identified through STM as a starting point to create a keyword dictionary, able to classify survey responses into more specific climate solutions. In an iterative approach, based on a qualitative assessment of survey responses, and climate solutions identified in the literature (e.g. IPCC 2018), we transform the broad STM categories into more specific themes and add topics that were initially not captured by the STM. To improve the performance of our dictionary, we use regular expressions (regex) (Cui *et al* 2019). Regex are a computational tool that describe and detect patterns of languages and that help us to address typos or minor keyword variations (e.g. singular vs plural of words). As shown in tables 2–8 in the appendix,

Table 1. Dictionary for substitution-based climate solutions in the transport and energy sectors. Categories for climate solutions were developed by the authors in an iterative way based on an initial STM with 75 topics, as well as qualitative hand-coding of data and theoretical expectations. Collectively, these climate solutions represent what survey participants had 'on the top of their mind' when answering the question 'what is the solution to your most important problem' (identified previously as climate change). A more detailed dictionary including the technical search terms (regex) and excluded words for each climate solutions can be found in tables 2–8 in the appendix.

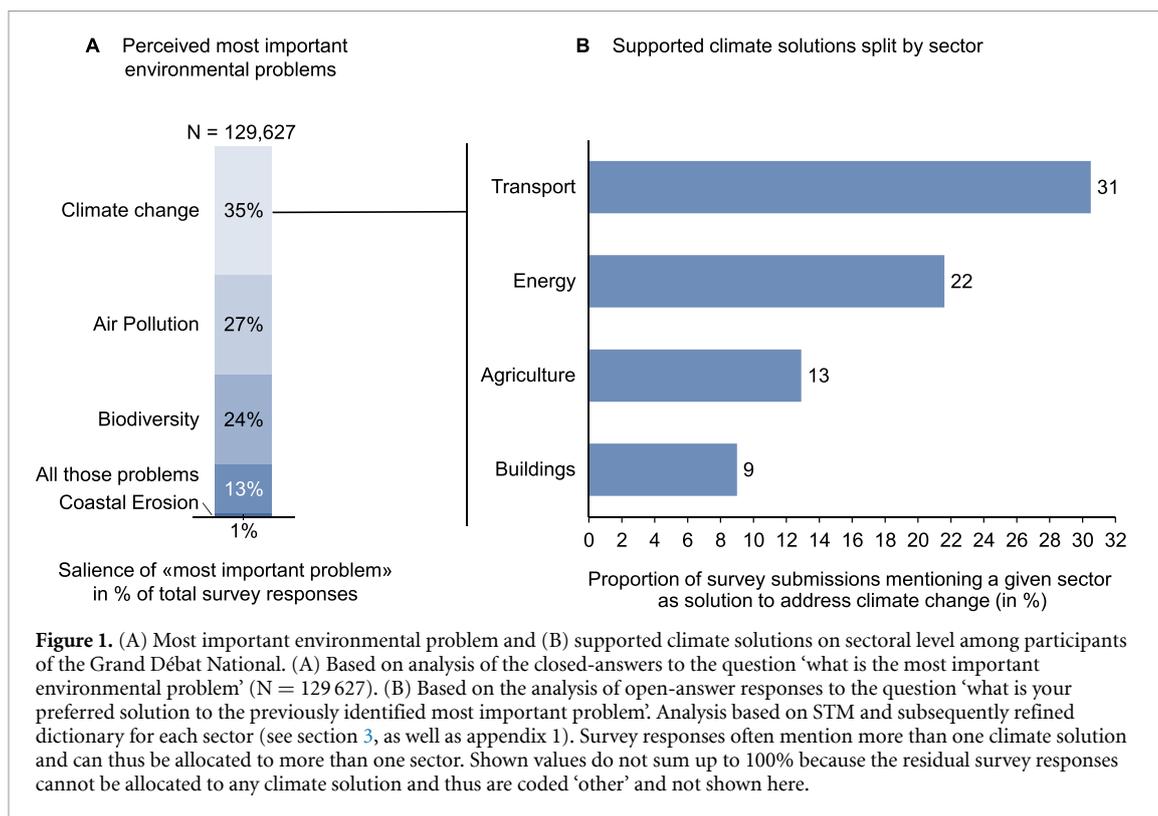| Sector	Climate solution	Search terms in French language (technical regex in appendix)
Transport	Cleaner car fleet	Voiture, moto, automobile, auto, route, véhicule
	Reduce aviation	Vols, voler, aéroport, avion, aviation, kérosène, aérien
	Expand train use	Train, ferroviaire, rail, gare, RER, TGV, TER, métro, tram, ferroutage
	Reduce heavy duty	Poids-lourds, camion, semi-remorque
	Increase shipping	Bateau, fluvial, navire, cargo, paquebot
	Expand bike use	Vélo, cyclable
	Expand bus use	Bus, car, autobus, autocar
	Expand car sharing	Covoiturage
	Walk more	Piéton, à pied
Energy	Deploy renewables	Renouvelable, énergie propre, énergie alternative, énergie décarbonnée, énergie verte, énergie durable, enr
	Keep/expand nuclear	Nucléaire
	Deploy solar	Solaire, photovoltaïque
	Deploy wind	éolien, éolienne
	Reduce coal use	Charbon
	Deploy hydro	Barrage hydroélectrique, hydroélectricité, énergie hydraulique, énergie marémotrice
	Reduce natural gas	Gaz naturel, gaz de schiste
	Deploy biomass	Biomasse, méthanisation, biogaz
	Deploy geothermal	Géothermique, géothermie

our final dictionary includes 34 climate solutions that can be allocated to four broader categories representing the transport, energy, agriculture, and building sectors. The tables also include details about the technical regex linked to the keywords. Table 1 below depicts the non-technical dictionary for the two sectors we zoom into in our subsequent analysis. We iteratively improved the dictionary through a systematic validation protocol, involving the hand-coding of random samples for each climate solution. Our classification scheme performs very well and correctly classifies 98% of the hand-coded documents.

Third, we label a random sample ($N = 200$) for both the transport and energy sectors to establish the relative prevalence of substitution-, sufficiency-, and efficiency-based solutions among survey answers. Substitution-based solutions primarily plans the replacement of polluting activities and/or technologies by a cleaner alternative (e.g. taking the train instead of flying). Sufficiency-based solutions largely rely on reducing the economic activity or use of technology (e.g. reducing electricity consumption by switching lights off). Finally, we coded solutions as efficiency-based if they rely on using less input for the same output (e.g. improving the efficiency of coal-power plants). Collectively, these categories are key principles to achieve sustainability goals (Princen 2005, Anadon *et al* 2016, Creutzig *et al* 2018, Fesenfeld *et al* 2021).

In a 4th step, we manually code a random sample of responses for each climate solution in the transport and energy sectors (total coded statements $N = 2547$, see table 1 in appendix) to assess the directionality of public opinion. We chose to manually code statements due to the absence of clear keywords denoting the directionality of a position (Thelwall *et al* 2010). Hence, for each statement we hand-coded if the respondent was supportive or opposed (or neutral) toward a particular climate solution.

Finally, we qualitatively assess whether and what type of policy instruments citizens associate with individual climate solutions. To do so, we draw on an established policy instrument typology by Hood (1983), see also Capano and Howlett (2020). This typology distinguishes between four governing resources available to policymakers: using the nodality of government to draw in and dispense information (e.g. information campaigns, labelling schemes), using the power to legally determine through authority (e.g. licenses, standards), using the treasury to tax and spend (e.g. subsidies, loans, taxes), and using the ability to directly act on markets via organization (e.g. state-owned enterprises, state investment in infrastructure) (Steffen 2021). To allocate individual statements to these policy instruments, we manually coded a random sample of statements for each climate solution. We excluded an automatized approach due to the lack of clear keywords for most instruments, and the innumerable ways in which support for a policy instrument can be expressed.

Figure 1. (A) Most important environmental problem and (B) supported climate solutions on sectoral level among participants of the Grand Débat National. (A) Based on analysis of the closed-answers to the question 'what is the most important environmental problem' (N = 129 627). (B) Based on the analysis of open-answer responses to the question 'what is your preferred solution to the previously identified most important problem'. Analysis based on STM and subsequently refined dictionary for each sector (see section 3, as well as appendix 1). Survey responses often mention more than one climate solution and can thus be allocated to more than one sector. Shown values do not sum up to 100% because the residual survey responses cannot be allocated to any climate solution and thus are coded 'other' and not shown here.

4. Results

In the following, we first report which sustainability challenges and related solutions are particularly salient in French public opinion. In a 2nd step, we zoom into the two most salient sectors, namely transport and energy.
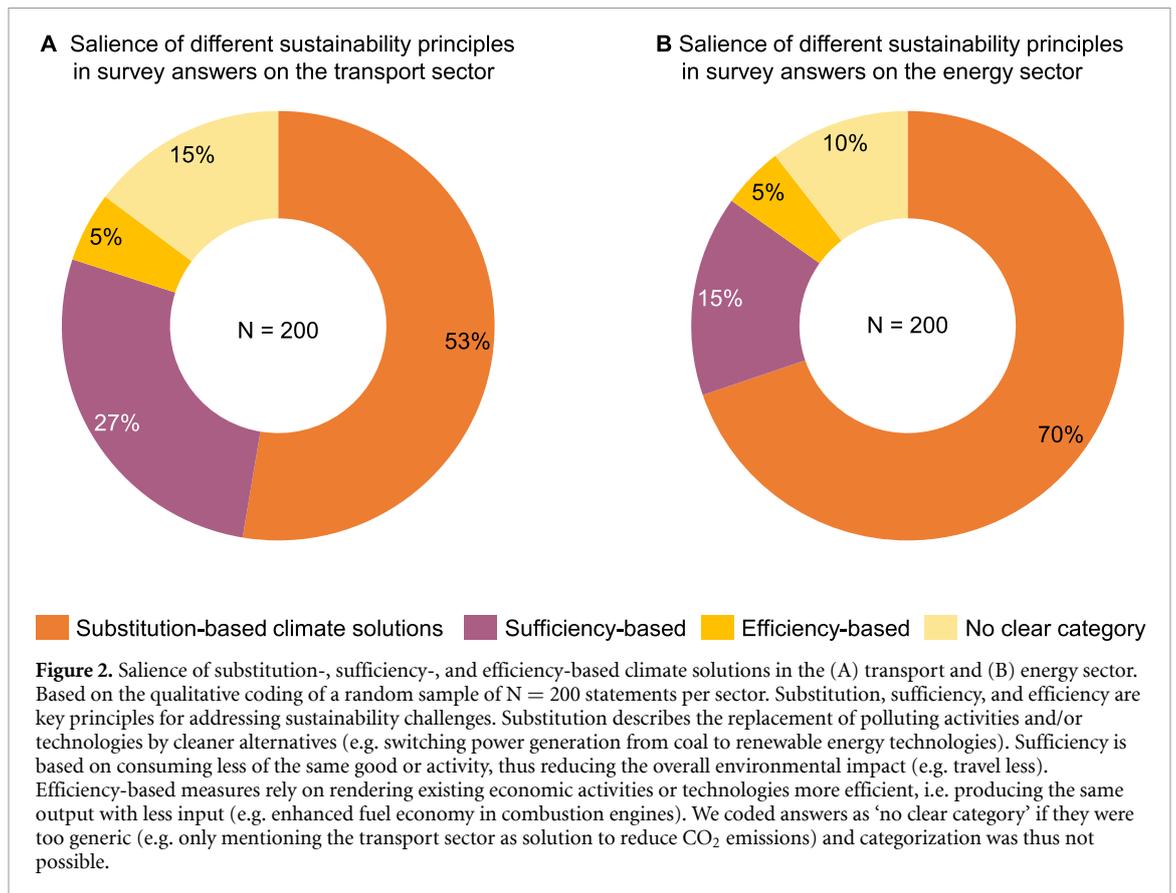
Figure 1(A) illustrates the survey responses to the closed question 'what is the most important environmental problem?' (N = 129 627). Among survey participants, climate change is the most salient environmental problem, accounting for more than one third of all answers (35%), followed by air pollution (27%) and biodiversity (24%). Next, survey participants could answer an open-ended question on supported solutions that tackle the previously identified 'most important problem' (N = 123 626). As discussed in the section 3, we combine quantitative and qualitative methods to analyze this massive and unstructured data. Figure 1(B) zooms into all respondents that identified climate change as the prime environmental problem. The results of our quantitative text analysis shows that participants primarily mention the transport sector as possible solution to climate change (with 31% of all submissions mentioning transport), followed by the energy (22%), agriculture (13%), and building sectors (9%).

In the 2nd step, we zoom into the two most salient sectors put forward by survey participants, namely the transport and energy sectors. Based on qualitative coding of a random sample of 200 statements for transport and energy, figure 2 shows the distribution of supported solutions across the three sustainability principles substitution, sufficiency, and efficiency (more detailed description in section 3). We make two main observations. First, substitution-based climate solutions, e.g. switching from fossil fuels to renewable energy technologies for power generation, are most salient in both sectors (accounting for 53% and 70%, respectively). Sufficiency-based solutions are less salient, followed by efficiency-based measures. Second, sufficiency-based measures appear to play a more important role in the transport than in the energy sector. For instance, a recurring solution mentioned by participants was reducing individual travel by car of plane.

In the following, we zoom into substitution-based climate solutions given their high salience. Figure 3 shows the salience of specific substitution-based climate solutions for transport (A) and energy (B) as identified with the help of quantitative text analysis (see section 3). In addition to the salience, we also report whether these solutions are framed in a positive, negative, or neutral way (see section 3).

Two main findings emerge from figures 3(A) and (B). First, some substitution-based climate solutions are more salient than others. Among the survey answers referring to the transport sector (as identified in figure 1 above), moving to cleaner car fleets is mentioned most often, accounting for 50% of answers, followed by reducing aviation (25%) and expanding train use (22%). Other means of transport such as biking or walking are only rarely mentioned (9% and 1%, respectively). Among survey answers dealing

A Salience of different sustainability principles in survey answers on the transport sector

B Salience of different sustainability principles in survey answers on the energy sector

Substitution-based climate solutions · Sufficiency-based · Efficiency-based · No clear category

Figure 2. Salience of substitution-, sufficiency-, and efficiency-based climate solutions in the (A) transport and (B) energy sector. Based on the qualitative coding of a random sample of N = 200 statements per sector. Substitution, sufficiency, and efficiency are key principles for addressing sustainability challenges. Substitution describes the replacement of polluting activities and/or technologies by cleaner alternatives (e.g. switching power generation from coal to renewable energy technologies). Sufficiency is based on consuming less of the same good or activity, thus reducing the overall environmental impact (e.g. travel less). Efficiency-based measures rely on rendering existing economic activities or technologies more efficient, i.e. producing the same output with less input (e.g. enhanced fuel economy in combustion engines). We coded answers as 'no clear category' if they were too generic (e.g. only mentioning the transport sector as solution to reduce CO_2 emissions) and categorization was thus not possible.

with the energy sector, survey participants primarily emphasize the role of deploying renewable energy technologies (70%), followed by nuclear (30%), and individual renewable energy technologies such as wind (28%) and solar (21%). Phasing out fossil fuel-based electricity generation such as from coal or natural gas is less salient (10% and 4%, respectively).

Second, most substitution-based climate solutions such as the deployment of renewable energy technologies, the expansion of train or bus use, or the limitation of aviation, are consensual and relatively uncontested among survey participants. Yet, our findings suggest that two solutions, e.g. shifting to cleaner car fleets and expanding nuclear, strongly polarize French public opinion. Approximately two third of survey participants believe that car-based climate solutions are not viable and argue for limiting car use or banning cars from certain use cases altogether (e.g. in cities). Participants arguing in favor of car-based climate solutions primarily refer to the possibility of electrification or use of hydrogen. Yet, electrification of cars is not homogenously supported by French citizens. Many respondents highlight the environmental damages related to the manufacturing process of batteries as a key problem. In answers pertaining to energy, the role of nuclear technology is contested. While approximately half of all answers related to nuclear argue in favor of either maintaining or expanding the share of nuclear power, the other half maintains that nuclear does not represent a viable

climate solution, e.g. due to environmental risk or cost concerns.

Besides the target technologies and climate solutions themselves, we also examine the types of policy instruments related to the solutions mentioned by participants. To do so, we build on the typology of policy instruments as established in public policy literature (Hood 1983, Capano and Howlett 2020) (see section 3). Figures 2(C) and (D) show which government resources (and thus instrument types) are mentioned in relation to each of the individual climate solutions identified in A and B. The results rely on the manual coding of a sample of 200 survey submissions for each solution. Again, two main findings emerge from this analysis.

First, most survey participants do not explicitly mention government resources when they put forward substitution-based climate solutions. As figures 3(C) and (D) show, between 51% (use of coal) and 82% (deployment of hydro) of coded survey answers do not contain concrete propositions for policy instruments (see red boxes). Only for the climate solutions 'reduce aviation' and 'deploy renewables' more than half of survey participants mention specific policy instruments (66% and 52%, respectively). These findings show that when not asked specifically in a closed-question survey design, support for climate solutions largely remains on an abstract level, without detailed propositions for policy interventions.
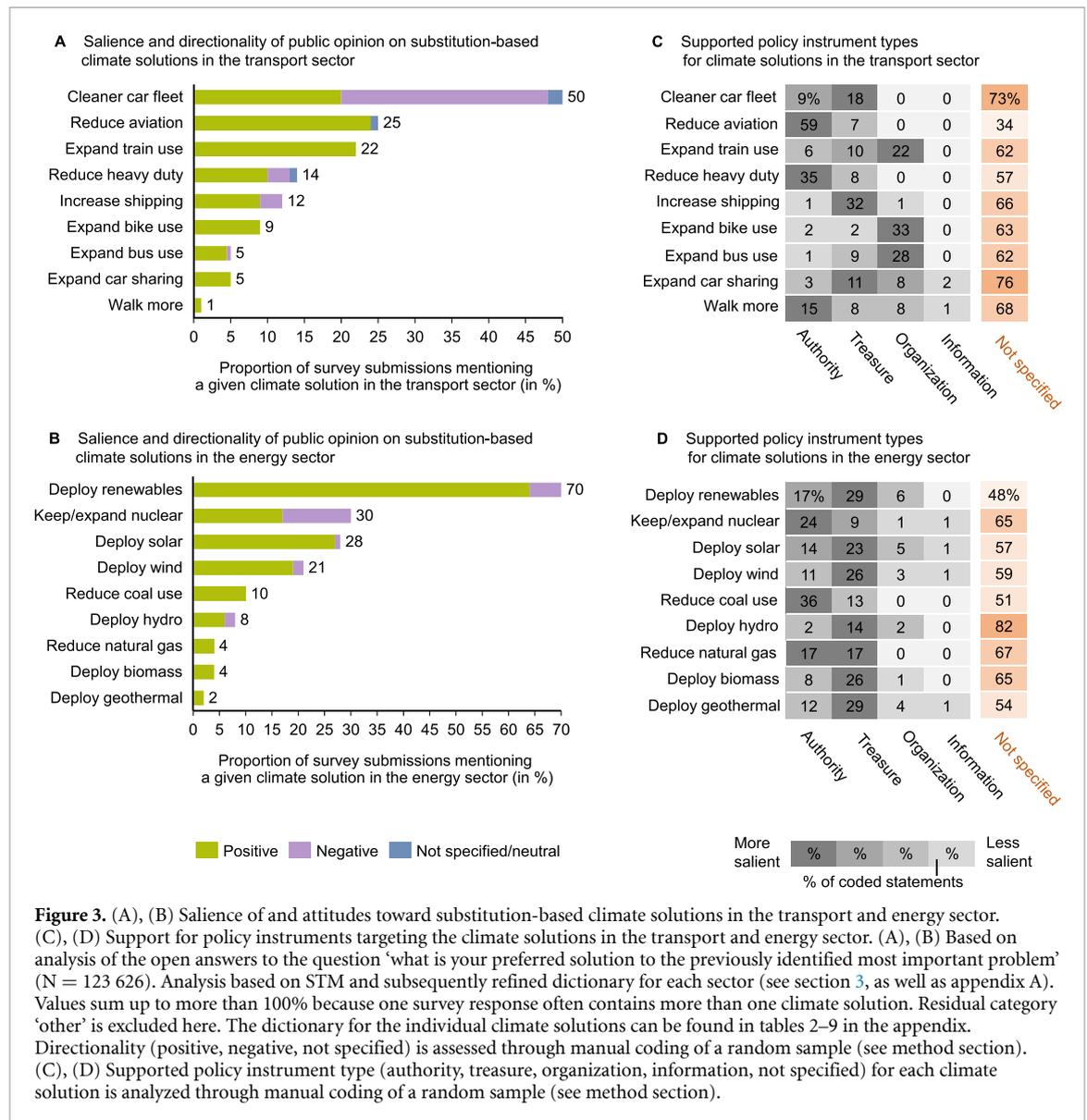
A   Salience and directionality of public opinion on substitution-based climate solutions in the transport sector

Cleaner car fleet	50
Reduce aviation	25
Expand train use	22
Reduce heavy duty	14
Increase shipping	12
Expand bike use	9
Expand bus use	5
Expand car sharing	5
Walk more	1

Proportion of survey submissions mentioning a given climate solution in the transport sector (in %)

C   Supported policy instrument types for climate solutions in the transport sector

	Authority	Treasure	Organization	Information	Not specified
Cleaner car fleet	9%	18	0	0	73%
Reduce aviation	59	7	0	0	34
Expand train use	6	10	22	0	62
Reduce heavy duty	35	8	0	0	57
Increase shipping	1	32	1	0	66
Expand bike use	2	2	33	0	63
Expand bus use	1	9	28	0	62
Expand car sharing	3	11	8	2	76
Walk more	15	8	8	1	68

B   Salience and directionality of public opinion on substitution-based climate solutions in the energy sector

Deploy renewables	70
Keep/expand nuclear	30
Deploy solar	28
Deploy wind	21
Reduce coal use	10
Deploy hydro	8
Reduce natural gas	4
Deploy biomass	4
Deploy geothermal	2

Proportion of survey submissions mentioning a given climate solution in the energy sector (in %)

■ Positive   ■ Negative   ■ Not specified/neutral

D   Supported policy instrument types for climate solutions in the energy sector

	Authority	Treasure	Organization	Information	Not specified
Deploy renewables	17%	29	6	0	48%
Keep/expand nuclear	24	9	1	1	65
Deploy solar	14	23	5	1	57
Deploy wind	11	26	3	1	59
Reduce coal use	36	13	0	0	51
Deploy hydro	2	14	2	0	82
Reduce natural gas	17	17	0	0	67
Deploy biomass	8	26	1	0	65
Deploy geothermal	12	29	4	1	54

More salient   % % % %   Less salient
% of coded statements

Figure 3. (A), (B) Salience of and attitudes toward substitution-based climate solutions in the transport and energy sector. (C), (D) Support for policy instruments targeting the climate solutions in the transport and energy sector. (A), (B) Based on analysis of the open answers to the question 'what is your preferred solution to the previously identified most important problem' (N = 123 626). Analysis based on STM and subsequently refined dictionary for each sector (see section 3, as well as appendix A). Values sum up to more than 100% because one survey response often contains more than one climate solution. Residual category 'other' is excluded here. The dictionary for the individual climate solutions can be found in tables 2–9 in the appendix. Directionality (positive, negative, not specified) is assessed through manual coding of a random sample (see method section). (C), (D) Supported policy instrument type (authority, treasure, organization, information, not specified) for each climate solution is analyzed through manual coding of a random sample (see method section).

Table 2. Illustrative quotes from online survey responses. Own translation.

Instrument type	Exemplary statement
Authority	'Introduce a modest but increasing taxation for all fossil fuels'. 'Close nuclear power plants in the short term and replace them with renewable energy technologies'. 'Increase the share of nuclear power, and simultaneously ban coal'. 'Ban domestic flights where a train line exists. Prohibit car access to city centers'.
Treasure	'Incentivize direct private investments towards renewable energies to the detriment of nuclear power with the help of state subsidies'. 'Invest heavily in research and development for solutions related to maritime and air transport'.
Organization	'Massively develop renewable energies (on- and off-shore wind, solar, biomass, etc) by simplifying the rules to avoid appeals and speed up procedures'. 'Invest massively and as a priority in measures that rapidly reduce the production of CO_2, by tax credit for individual issues and direct state investment for major projects'. 'Create public, local electric bus networks in all areas that are not covered.'
Information	'Better inform, explain and sensitize the population through the media, advertising campaigns, information of the state for the advantages of soft transport'.

Second, depending on the specific climate solution at hand, different governing resources and thus policy instruments are supported (see grey boxes, figures 3(C) and (D)). Table 2 below gives direct quotes from the survey to illustrate support for specific instruments. On the one hand, survey participants typically mention treasury-related instruments in the context of innovation-based

climate solutions such as deploying renewable energy technologies or moving to cleaner car fleets. For example, participants support instruments such as subsidies for solar, wind, and electric vehicles. On the other hand, when talking about phasing-out fossil-fuel based technologies, such as aviation, coal power plants or natural gas, participants predominantly support authority-based measures, such as carbon taxes or regulation that limits or stops the use of the target technology. Organization-based policy instruments, such as infrastructure investment, is predominantly supported in the context of expanding public transport, such as for trains, buses, and bikes. Information-based policy instruments are only rarely supported, for instance on low levels in the case of expanding car sharing.

5. Discussion and conclusion

The goal of this paper is to improve our understanding of public opinion on the problem of climate change and its possible solutions. Better understanding citizens' attitudes toward climate change mitigation is important because, ultimately, effective climate policies require sustained public support to remain sticky. Unlike many existing studies that take a rather aggregated view on climate policy, our study provides insights into the salience of and support for sector-specific climate solutions. Based on a mixed methods approach, we exploit an unstructured text data source from one of the largest consultation processes to date on opinions related to sustainability transitions: the 'Grand Débat National' launched by the French government in 2019. The use of text data from the responses to an open-ended question enabled us to detect which climate solutions French citizens support in absence of framing effects of a closed question.

Our findings show that climate change is the most salient sustainability challenge among survey participants. The transport and energy sectors, in turn, are perceived as the most relevant sectors to tackle climate change. Zooming into these sectors, we find that substitution-based climate solutions are more salient among citizens than sufficiency- and efficiency-based measures. Solutions such as moving to a cleaner car fleet and switching to renewable energy technologies are particularly prominent. While most climate solutions are consensual, car-based transport and nuclear energy polarize French public opinion. These novel insights contribute to ongoing efforts to explore the mass politics of transitions (Stokes 2016, Howe *et al* 2019, Mildenberger and Tingley 2019, Rinscheid and Wüstenhagen 2019, Egli *et al* 2020, Fesenfeld 2020, Schmid *et al* 2021). More specifically, our paper makes four key contributions.

First, we contribute to shed light on the case of public opinion on climate policy in France, which to date has remained under-researched. Amongst

others, our findings underscore the existence of strong political polarization around the question of nuclear energy among French citizens (see also Brouard and Guinaudeau 2015). This polarization in public opinion on nuclear technology correlates with opposed positions among French political parties (Schmid 2021). The conflictual nature of nuclear energy stands in stark contrast to the widespread support for renewable energy technologies both among citizens and political parties in France, but also beyond (see also Schmidt *et al* 2019, Schmid 2021). Note that the examination of this case relied primarily on the analysis of open-ended answers, which—as noted in the introduction—presents various advantages over closed questions such as higher ecological validity (see also Tvinnereim *et al* 2017).

Second, we contribute to the academic debate on public support for specific policy instrument types. Our results show that for most climate solutions put forward by citizens more than half of the responses did not specify any policy instrument, suggesting a lack of salient and concrete ideas on how climate solutions may be achieved through policy interventions. This finding is relevant given that recent research highlights the central role of citizens' knowledge on climate change (and related instruments)—also coined climate literacy—for successful implementation and acceptance of climate policy (Simpson *et al* 2021).

Among those French citizens that link climate solutions to specific policy instruments, we find interesting patterns that partially contradict earlier findings. For instance, treasury-based and organization-based instruments are primarily supported in relation to innovation in low-carbon technologies, while authority-based instruments are mostly supported in the context of phasing out technologies. Earlier research suggests, amongst others, that citizens usually prefer authority-based measures in the context of climate policy (Stadelmann-Steffen 2011, Cherry *et al* 2012). Yet, we show that preferences for instrument types depend on the target technology at hand. Our findings also contrast with previous results that indicated strong support for softer, information-based policy instruments (Drews and van den Bergh 2016, Rhodes *et al* 2017), which we do not find in our data.

Third, our results speak to the academic debates on the relative prevalence of sufficiency-, efficiency-, and/or substitution-based solutions in sustainability transitions (Princen 2005, Anadon *et al* 2016, Creutzig *et al* 2018, Fesenfeld *et al* 2021). The findings show that supported climate solutions in the transport and energy sectors are primarily based on substitution, i.e. the replacement of polluting activities and technologies by cleaner alternatives, rather than sufficiency- or efficiency-based measures. Hence, supported climate solutions primarily depend on (induced) technological change, emphasizing the

centrality of collective action in the form of ambitious innovation and industrial policy (Anadon *et al* 2016, Schmidt and Sewerin 2017). The findings are also in line with earlier research showing that climate solutions which primarily target sufficiency and related behavioral change are less supported by citizens (Fischer *et al* 2011, Bothner *et al* 2019). In our view, the extent to which public opinion supports substitution and thus technology-based measures is a novel and important insight.

Fourth, while our results point to widely homogenous support for substitution-based climate solutions, and also show agreement with strong authority- and treasury-based policy instruments, current climate policy in France has repetitively been criticized as insufficient, e.g. by the High Council on Climate of France (2019), see also Giraudet *et al* (2021). This points to a potential gap between widespread support for and effectively supplied climate solutions. Such a gap would signify that French climate policy is not entirely responsive and accountable, resulting in a divergence between public opinion and public policy (Prakash and Bernauer 2020). There are many reasons for such divergence, but one possibility is that there is a biased view by policymakers on their constituencies' attitudes toward desired policy output (Hertel-Fernandez *et al* 2019). In general, further research is needed to investigate this suggested gap between widespread public support for ambitious climate action on the one hand, and inertia and lack of ambition by elected policymakers on the other hand. The upcoming national elections in France in 2022 may provide an occasion to contrast our findings with campaign promises and subsequent government action over the next legislative periods.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

Conflict of interest

The authors declare no conflict of interest.

Ethical statement

Research was conducted in accordance with the principles embodied in the Declaration of Helsinki and in accordance with local statutory requirements. All participants of the public consultation 'Le Grand Debat National', on which our analysis is based, participated voluntary. The resulting data is anonymized, openly available and compatible with open license standards, such as CC-BY 2.0.

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