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# Eliciting policymakers' preferences for technologies to decarbonise transport: a discrete choice experiment

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**Abstract**

Socio-technical transitions are often hindered by the resilience of existing infrastructures, as policymakers are reluctant to invest in novel products or services. Using the example of carbon capture and utilisation (CCU) based fuels, we set up a discrete choice experiment to assess whether European policymakers have a tendency to avoid investing in novel, and more disruptive technologies, and rather prefer to invest in technologies that resemble the incumbent. Results indicate that policymakers prefer to allocate funding to dominant technologies. The results also revealed an overall positive perception of CCU technologies among policymakers. As the commercialisation of such products and processes continues, acceptance among this group of stakeholders is key.

**Keywords:** discrete choice experiment; innovation; lock-in; public funding.

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## Research Highlights

- We discuss the relevance of lock-in in the context of strategic public funding decisions.
- European policymakers took part in a discrete choice experiment and were given hypothetical choice tasks.
- Policymakers were asked to allocate funding to the transport decarbonisation project of their choice.
- We assess whether policymakers prefer to invest in technologies resembling incumbents, or those that are more disruptive.
- We discuss the implications of policymakers' funding decisions on technological change.

# 1 Introduction

While consumers ultimately determine which technology will be successful, policymakers influence the rate and direction of technological change. By governing innovative activity through subsidies, they also generate support for policies that send powerful signals to investors. Understanding what drives policymakers' preferences in the assessment of decarbonisation projects - referring to projects that reduce the amount of gaseous carbon compounds released in the atmosphere - is therefore crucial. Despite governmental initiatives to decarbonise energy systems, and action taken to steer away from current unsustainable technological systems, transition processes are often hindered by the resilience of existing infrastructures.

This paper addresses one particular system transition: decarbonising transport within the European Union. Decarbonising transport requires substantive system innovation; namely from one socio-technical system to another (Rip and Kemp, 1998; Geels, 2004). The transition literature refers to these systemic changes as 'socio-technical', as they do not *solely* involve technological innovation or substitution, but also require complex and interconnected changes in the overall configuration of transport, energy, and agri-food systems - involving alterations in technology, policy, markets, consumer practices, infrastructure, culture and scientific knowledge (Geels, 2011; Elzen et al., 2004; van den Bergh and Bruinsma, 2008; **?**). Essentially, what matters is not merely the technological innovation itself, but also the social and economic systems in which it is embedded (Upham et al., 2019). This paper seeks to shine a light on actors that play a complex role amid this social-economic-technological-institutional system: policymakers. Specifically, we investigate policymakers' funding preferences in the early iterative innovation stages, which may serve as input to any consequent debate on strategic public funding decisions, that may in turn affect the development of new products and services. The results provide indications as to whether policymakers may indirectly be contributing to technological and cognitive lock-ins that exist within established socio-technical regimes (Kemp et al., 2007; Avelino et al., 2016).

The research question underlying this paper is as follows: are policymakers more likely to fund technologies that resemble the incumbent system? In this regard, the paper assesses whether policymakers may be reinforcing dominant, incumbent systems, and notably whether they have a tendency to invest in technologies and energy systems resembling incumbents, or rather those that are novel, and more disruptive. In order to better understand whether this is the case, 129 European policymakers working at European, national, regional and local level participated in a discrete choice experiment (DCE) in which they were asked to allocate funding to their preferred decarbonisation project. The policymakers that were targeted worked with European funding programmes or advisory bodies related to realising Europe's transport infrastructure policy.

To find out whether decision-makers were more likely to favour more established technologies, and whether they are therefore more likely to invest in the technological systems they know best, the choice task in question involved allocating funding for the R&D of a project that would develop two types of carbon capture and utilisation (CCU) based fuels: liquid-based, and gas-based CCU. Policymakers also had the option to fund neither if they preferred to do so. These technologies were chosen as examples as they can either be compatible with current dominant incumbent engine systems (and these were representative of the conventional transport system), but CCU fuels can also require more of a change in design, products and processes

- depending on the type (and these were representative of a more innovative choice). Before beginning the choice task, the policymakers were primed and told that it was liquid-based fuel that was compatible with current infrastructure (with attention being visually drawn to how fueling would occur). In addition, as these technologies have not reached the market at scale yet, they made for a realistic R&D funding option.

The choice model used in this paper, where policymakers make hypothetical funding decisions, allows us to predict both average and individual tastes and preferences in a hypothetical setting. This means we can in turn predict which alternative will be chosen in a similar scenario. If we assume that political power and choices are influenced by majoritarian principles, we can in this way reveal whether policymakers would be open to funding new technologies or not. While CCU powered passenger vehicles have been chosen as examples, this line of reasoning applies to decision-making on technological transitions where future gains and losses of the technological system are unknown. DCEs are widely used to study how people make choices and to identify the elements that drive them. By analysing the trade-offs that European policymakers face when allocating a limited budget to the decarbonisation of fuels, we can provide indications as to whether decision-makers are prone to sustaining, and therefore - locking-in - the incumbent system. We suggest that DCEs have an important role to play in better understanding and improving policymakers' (deliberative and intuitive) decision-making processes in promoting sustainability systems transitions.

The remainder of the paper is structured as follows. In Section 2 we discuss the conceptual and theoretical frameworks underlying the study. This includes the examples studied, the concept of lock-in applied to this case, and the role of political decision-making in socio-technical transition narratives. Section 3 presents the DCE design and how it is applied to the study in question. The design of the questionnaire is elaborated upon, along with its respective attributes and levels for study and the distribution of the questionnaire. Section 4 discusses the results, and section 5 concludes with a discussion.

# 2 Conceptual framework

## 2.1 Techno-institutional lock-in in public R&D funding

Mitigating climate change, and by extension - decarbonising fuels, requires governments and institutions to boost innovation - through investment in research and development, subsidies, as well as favourable tax or price regimes that can decrease the time-to-market of environmentally friendly technologies (van der Vooren et al., 2012). However, institutional set-ups can inhibit the diffusion of carbon-saving technologies due to systemic relations and interdependencies where transitions result from joint development of technology and society (Van Bree et al., 2010; Foxon, 2002). This is often the case for infrastructure-dependent vehicle technologies, where sunk costs significantly influence their technological development (Klitkou et al., 2015). Investments in technology, to human resources, skills or physical assets, can bias policy towards the preservation of the status quo and the alternatives that are most familiar to decision-makers (Cecere et al., 2014).

Lock-in processes are generally referred to as increasing returns to the adoption of a technology, where incumbent technologies have a distinct advantage over new entrants - not because they are necessarily better, but because they are more "widely used and diffused" (Arthur, 1989; Unruh, 2002; Klitkou et al., 2015). Our discussion of lock-in mechanisms takes a broader view than traditional definitions, such as the textbook QWERTY case (David, 1985). An incumbent regime is the outcome of various lock-in processes, and such a regime favours incremental, as opposed to radical, innovation (Sandén and Azar, 2005). We focus on lock-in at the *system* level, as opposed to the product level. Our broader discussion of lock-in mechanisms in this regard is applied to the role of policymakers in transitioning to a decarbonised transport system, where we argue that the existing socio-technical system has a restrictive influence on innovation dynamics and technological change. We specifically seek to investigate whether policymakers may be likely to avoid investing in a highly innovative idea, not because of any intrinsic flaw in the technology, but because the technology would require too much change from the incumbent system. This may in turn prevent the introduction of radically new technological trajectories, in this case on the road to decarbonising our transport system.

While market forces are the often deemed culprits behind the lock-in of certain technologies, Unruh (2002) argues that institutions could be perpetuating these barriers from the outset. Through positive feedback mechanisms existing between policymakers, suppliers and infrastructure support, dominant technologies can be sustained in the face of potentially superior substitutes: when a technology is dominant it is much more likely to receive support. Governments can influence the rate and direction of technological change through investment in the R&D for developing infrastructure. This occurs before technologies actually compete - both in the market for goods and services, but also to gain influence over institutional frameworks (Jacobsson and Lauber, 2006). This means that decision-makers can affect the success of novel, radical and disruptive innovations, and therefore reinforce the dominance of incumbent systems of energy technologies (Bjørnåvold and Van Passel, 2017). When innovation is mentioned in the remainder of this paper, it is disruptive innovation that is being referred to.

Understanding what drives funding decisions when allocating public funds for clean technologies is critical. While abundant literature exists on ex-post evaluation of R&D projects and programmes (Verbano and Nosella, 2010), research on what exactly determines strategic public funding decisions ex-ante is limited (Hirzel et al., 2018). This is an issue, among others, due to the potential impact funding has on the cognitive development of science (Braun, 1998), and the problem of 'conservatism bias' in R&D evaluation - that highly innovative projects run a higher risk of rejection. Brezis suggests focal randomisation can fix this - that the projects that are unanimously ranked at the top by all reviewers will be adopted (Brezis, 2007). Another study proposes that a decision support system for decision-makers evaluating R&D projects is needed (Ashrafi et al., 2012). While these studies do look into ex-ante public funding decision-making and point to issues, no study - to the best of our knowledge - investigates the preferences that drive these decisions.

If options that resemble the incumbent are consistently chosen to receive the most funding, innovation can become path-dependent from a systemic perspective. If technological change becomes path dependent, superior alternatives can be locked out, and the dominant, inferior solution locked-in which is difficult to change over time (Arthur, 1989; Cowan, 1990). Novel and innovative technologies are rarely strong enough to enforce transitions alone. Incumbent firms, on the other hand, are familiar to decision-makers and have established and fixed routines, constraining them to respond appropriately to changing environments. Policymakers can thus be faced with deeply entrenched, path-dependent systems because of the unwillingness to change (Ettlie et al., 1984; Henderson, 1993). Consequently, systems can experience inertia that can prevent adaptation and innovation.

## 2.2 Reconciling political decision-making processes with transition narratives

This paper contributes to the recent literature seeking to reconcile sustainability transitions studies with considerations of policy and political decision-making processes. Politics and power have been receiving increased attention in recent years, due to criticism raised that they have been neglected within the field (Meadowcroft, 2011; Avelino et al., 2016; Kuzemko et al., 2016). After all, policy represents one of the core dimensions of the socio-technical regime, along with user practices, science, cultural meaning and infrastructure (Geels, 2014). Further, "transitions are inherently political processes in the sense that different individuals and groups will disagree about desirable directions of transitions, about appropriate ways to steer such processes and in the sense that transitions potentially lead to winners and losers" (Köhler et al., 2019).

One criticism directed towards transition studies, has been the skewed focus on green niche-innovations, while less attention has been given to the actions of existing regimes and incumbent actors behind the scenes that contribute to or prevent their deployment (Geels, 2014). In order to engender transitions and structural change to low-carbon systems, many of these regimes and incumbent actors may themselves be restricting these systems through various lock-in mechanisms. For instance, incumbent socio-technical regimes and actors might seek to resist innovation and restrict existing systems for reasons of institutional commitments, shared beliefs, vested interests, power relations, or convenience, making them resistant to change over time. New entrants will in turn seek to oppose this resistance in a power struggle of their own (Köhler et al., 2019; Unruh, 2002).

Against this background, this paper focuses on existing regimes and the actors involved in political decision-making processes. The specific contribution to the transitions literature is to consider regime stability, and in turn dependence on dominant technologies, as being a result of resistance, whether deliberate or not, by incumbent actors, and in this case: policymakers (Geels, 2014). We have in this regard chosen to investigate policymakers' use of power through funding mechanisms to resist transitions to disruptive and innovative low-carbon transport systems. As van Rijnsoever et al. (2013) did to estimate the preferences for alternative fuel vehicles by Dutch local governments, we also make use of a choice model to better understand trade-offs that policymakers face in the socio-technical transition to sustainability.

Technology does not exist in a vacuum - away from society, social behaviours and social institutions – it both shapes and is shaped by society (Bijker et al., 1989). For instance, personal vehicles required infrastructures, supply and service systems, and norms of behaviour to develop alongside them. In fact, socio-technical transitions do not just change the structures of existing systems, such as transportation, but they also affect related societal domains, such as living, housing and working, production, trade and planning. For reasons such as this, infrastructure systems are often regarded as inflexible, difficult to change and vulnerable to path dependence and lock-in and can result in inertia for many transport systems (Markard, 2011).

We investigate the hypothesis that policymakers contribute to this inertia through a wish for consistency by investing in and funding technologies that resemble incumbent systems. Experimental evidence illustrates that individuals tend to prefer to purchase familiar goods and make familiar choices, and this has been particularly well documented in capital markets among investors. Investors have been over-documented to purchase stocks that are in culturally, geographically and linguistically proximate markets, while being reluctant to trade away from their existing ownership positions (Cao et al., 2009; Graham et al., 2009). Further, investors have been shown to be biased in favour of choice options made salient as default choices; and are prone to prefer past choices or investments that they currently hold (Cao et al., 2009). This experimental evidence has largely been applied to investors in capital markets, yet little attention has been leveled at policymakers'in this regard. This is of concern, as the choices decision-makers face when deciding how to allocate and invest public financial resources is complex and can have great significance on society at large (van der Vooren et al., 2012). Any decision-maker – be it in daily life or a policymaking context – interprets their surroundings through a lens of their own past and experiences; learning by combining heuristics and cognitive filters and known processes (Witting, 2017).

Samuelson and Zeckhauser (1988) maintain that various theories such as misperceived sunk costs and a wish for consistency can be reasons for a preference to remain within the current position. Nonetheless, innovation, especially breakthrough innovations, requires steering away from what you already know. Unsurprisingly, regulators as well as consumers generally value stability and predictability (Kiesling, 2008). Nonetheless, innovation generally brings with it change, and will for this reason often cause initial resistance. This can be caused by resistance to the behavioural change that is imposed as opposed to the actual innovation itself (Talke and Heidenreich, 2014). Understanding how decisions are made on a regulatory level is therefore crucial: decision-making depends on individual preferences and interests, which can contradict, most likely change over time, and develop based on experience with the issues at hand. Decision-makers have to consider uncertain outcomes, act in a political system, face novel and interconnected situations and problems, as well as the need to search for new ways to handle them (Goldthau, 2013). As a consequence there will always be uncertainty and risk about the eventual outcome and decisions taken, which therefore raises the importance of better understanding the trade-offs that policymakers face in the regulatory sphere.

## 2.3 Example used: carbon capture and utilisation based fuels

Transport represents close to a quarter of Europe's greenhouse gas emissions and is the foremost cause of urban air pollution. Transport has not shown the same gradual decline in emissions as other sectors, given that demand for transport only continues to rise. Road transport is the largest emitter, and accounts for up to 70 per cent of the sector's greenhouse gas emissions in the European Union (EU) (Commission, 2018b). Decarbonising transport fuels is therefore a priority, and the Renewable Energy Directive II will become the EU's binding policy framework for renewable fuels from 2021 to 2030. Early drafts of the Directive suggest that fuels derived from CCU will be included within the definition of renewable transport fuels. CCU is a process that finds end-use opportunities for captured and recycled carbon dioxide ($CO_2$)– from industrial outlets (i.e. factories and industry point sources) or the atmosphere – in order to produce commercially viable products such as construction materials, chemicals and fuels. It is considered a viable option to not only reduce $CO_2$ emissions, but also to shift some of the costs of decarbonisation onto willing consumers (Perdan et al., 2017). CCU-based fuels are currently not viable without high policy support, given their high cost of production. Brynolf and colleagues (Brynolf et al., 2018) suggest costs for different CCU-based fuels lie in the span of €17.4 – €152 per litre in 2015 and €14.5 – €62 per litre in 2030. However, the costs are still uncertain given that these fuels have not been demonstrated at scale yet, which in turn makes it difficult to attract significant investments.

The rate at which $CO_2$ will establish itself as a feedstock depends largely on the political framework to develop it further (Vreys et al., 2019). It is for this reason that the motivations behind policymakers' decisions to fund specific CCU-based alternatives is of interest. CCU-based fuel (also called power-to gas, power-to-liquids or synthetic fuels) can be used as a 'drop-in' fuel that can be used in existing engine types and infrastructure. This is mainly possible with liquid-based CCU (conversion of $CO_2$ into methanol (MeOH) using $H_2$ produced by electrolysis) – with drop-in meaning that they are compatible with current engines and vehicular systems (Blanco et al., 2018). The major hurdles for liquid-based CCU are more regulatory in nature (SETIS, 2016). The compatibility of gas-based CCU systems - which refers to the conversion of electrical energy into chemical energy in the form of hydrogen gas ($H_2$) or methane ($CH_4$)) - is not impossible, but less so than with liquid-based CCU. The conversion pathways for power-to-gas are limited due to the lack of dedicated storage and distribution infrastructure (Eveloy and Gebreegziabher, 2018; Jarvis and Samsatli, 2018; CarbonNext, 2018).

Given that liquid-based fuels can be compatible with current dominant engine systems, we present these fuels as representative of the conventional transport system, and in turn incumbent systems. Given that gas-based fuels require more of a change in design, products and processes, in this paper, these fuels are representative of fuels that contribute to a transition, and in this sense a more innovative option than the latter fuel. The study in question uses CCU based fuels as an example to provide theoretically driven insights and explanations into why some technologies receive funding for R&D and others don't, and whether it is an advantage for new technologies to display properties that mimic the current state of affairs (or not). If it is the case that policymakers consistently choose to fund technologies that most resemble the incumbent system, we argue that this could reinforce the lock-out of technologies that have yet to benefit from reinforcing mechanisms such as scale economies, network and learning effects, as well as adaptive expectations. In this regard, regimes, incumbent actors, and in this case, policymakers would have a restrictive influence on innovation dynamics and technological change, necessary to engender transitions and structural change to low-carbon systems.

# 3 Method

## 3.1 Discrete Choice Experiment

Discrete choice experiments (DCEs) are extensively used to model people's choices and to identify people's preferences (Louviere and Hensher, 1982; Louviere and Woodworth, 1983). Each respondent is presented with several alternatives, or choice sets, and asked to choose the alternative of their preference. The main goal of a DCE is to estimate the weight and sign of each attribute level coefficient from the repeated choices made (Cuervo et al., 2016). These weights can then be used to calculate ratios describing the trade-offs that respondents are willing to make among the available attributes (Louviere et al., 2000).

Rational choice theory sees that the respondent chooses, based on the attributes that describe the choices available, an alternative that maximises utility. According to Lancaster's characteristics theory of value (Lancaster, 1966), a good or service can be defined by a set of characteristics, which means that the value of a good is the sum of the values of all its characteristics. Apart from the attributes and their levels no other factors should systematically influence peoples' choices. Combining this with McFadden's random utility theory (McFadden, 1973), as the discrete choice experiment modeling framework does, individuals make choices according to a deterministic part, which is visible to the modeller, but there will always be a stochastic element to people's choices. An unobservable component to people's choices should thus be taken into account: the modeller cannot know what is going on in people's minds, and the error term in McFadden's model captures this. In our discrete choice experiment, respondents are asked to choose between two alternatives and an opt-out. Including an opt-out is useful to attain more realistic results. This avoids people being forced to make choices that they do not wish to make (Lancsar and Louviere, 2006).

There have been few DCEs that focus on policymaker preferences in response to the sustainability transition, and none, to the best of our knowledge, on how these choices might create a barrier for innovation through resource allocation of public funds of the European Union. The reason as to why a DCE is used to test this (based on coefficients), and not revealed preference data, is due to the need for a hypothetical market to be presented to the respondent as these technological options do not yet exist on the market. Further, by varying characteristics and policy options presented to the respondent, it is possible to estimate the tipping point that leads the decision-maker to allocate funding to one option over another. How funding is allocated to transport infrastructure technologies is also unclear, which makes a hypothetical discrete choice experiment such as this even more relevant. For instance, it is known that €70 billion is invested by the EU in the 2014 – 2020 timeframe on funding research and development of new transport technologies and services, €800 million on alternative fuels infrastructure, but not more specific than this (Niestadt and Service, 2019). This funding is spread across different projects and programmes for sustainable mobility – from ESIF, JASPERS, Horizon2020, Connecting Europe Facility (CEF)/TEN-T projects, European Energy Efficiency Fund, LIFE programme, to only name a few: these programmes do not explicitly state the amount of funding that goes to each platform, project or technology.

## 3.2 Study design

The participants faced a policy funding decision in the discrete choice experiment. Each respondent faced six choice sets, with each choice set consisting of two hypothetical funding options labelled 'Liquid-based CCU' and 'Gas-based CCU', as well as one opt-out option with which they could choose to fund neither. As mentioned above, these technologies were chosen as examples as they can either be compatible with current dominant incumbent engine systems (and these were representative of the conventional transport system), but CCU fuels can also require more of a change in design, products and processes - depending on the type. Choosing to opt-out of the funding decision would imply that the policymaker preferred to spend the available budget on other decarbonisation projects. Liquid-based fuel was illustrated to policymakers as the conventional fuel system type, given that engine types, service stations and compatibility with conventional gasoline remains the same. Rather than the technology of CCU, this liquid-based CCU seeks to represent a lock-in of a specific type of hybrid system that resembles the incumbent, while Gas-based CCU sought to represent a more innovative fuel system.

The first two options were characterised by five different attributes as shown in Table 1. These five attributes were i) the reduction in $CO_2$ emissions, ii) the required budget spent from 1 billion of EU Mobility Network funding, iii) the time until market commercialisation, iv) the market share and v) fuel cost (in 2040) compared to current (relative) levels. Fuel cost here refers to the amount the consumer will have to pay to purchase fuel for the given type (of either liquid-based or gas-based fuel). Each of these attributes could take on three different levels as summarised in Table 1.

The attributes and levels were chosen based on current literature, and fine-tuned in a pre-test conducted with seven policymakers all working in the European institutions in the field of energy transition (and familiar with CCU) in September 2018. The main goal of the pre-test was to further develop the questionnaire and the choice scenarios that were presented within the questionnaire, mainly to ensure the clarity and credibility of the information presented. Pre-tests are also helpful to develop a good design that can avoid respondent fatigue from the provision of unnecessary details. Specifically, we obtained a better insight into the survey response rate, item non-response rates, the suitability of the experimental design, and a preliminary investigations of hypotheses. When given choice between liquid and gas-based CCU fuel (and the option to opt-out), the overwhelming majority of pre-test participants (6 out of 7) opted for liquid-based CCU fuel, which confirmed the suggested hypothesis that policymakers do prefer the option that resembled the incumbent the most.

The authors thus sought to make the choice task as realistic as possible by testing the design on the target group before the final discrete choice experiment. As clarified above, modifications were made based on comments received from these individuals. Moreover, by associating attributes and levels in the design to actual EU policy targets and expectations, this realism was further embedded into the experiment.

### 3.2.1 Choice of attributes and levels: discrete choice experiment design

The budget to be allocated was chosen to be €1 billion for a 10-year timeframe. The monetary levels for the attribute 'required budget spent from 1 billion of EU Mobility Network funding' are in this case €100 million, €200 million and €500 million. These amounts were set based on EU Connecting Europe Facility (CEF) for Transport funding: the funding instrument used to realise European transport infrastructure policy. While other funding mechanisms exist, CEF Transport concentrates on building and upgrading the trans-European transport and energy networks, and provided a total of €24 billion for transport between 2014 and 2020. Up to €800 million of these EU investments support alternative fuels infrastructure (Commission, 2018a, 2019a). Based on these amounts, and particularly the €800 million spent on alternative fuel infrastructure, a similar amount of €1 billion was chosen (while somewhat higher due to a higher timeframe of 10 years as opposed to 7 years) with a relative comparison of levels were chosen of €100, €200 and €500 million.

Table 1: Listing of levels considered for each of five attributes of the two fuels (liquid-based CCU and gas based CCU)

| **Attribute** | **Attribute Levels** |
|---|---|
| Reduction in $CO_2$ emissions | 20 %; 50 %; 80 % |
| Required budget spent from 1 billion of EU Mobility Network funding | €100M; €200M; €500M |
| Time until market commercialisation | 2 years; 5 years; 10 years |
| Market share | 15 %; 50 %; 80 % |
| Fuel cost compared to current (relative) levels | Lower; Same; Higher |

In this discrete choice experiment we define 'market commercialisation' as manufacturers' attempt to profit from innovation by incorporating new technologies into products, processes, and services and selling them on the marketplace. Specifically, commercialisation implies the scale-up from prototype to volume manufacturing and committing greater resources to marketing and sales activities (Howard, 1993). The attribute 'Time until market commercialisation' implies that longer durations for the technology to reach market commercialisation correspond to higher transition costs. The levels 2, 5 and 10 years are chosen based on expected timeline of technological development of the Strategic Energy Technology Plan (SET-P) - the EU's platform with the aim to accelerate the development and deployment of low-carbon technologies. The SET-P's CCS and CCU implementation plan has been consulted, and years chosen based on their expected timeline for CCU transport fuels between 2018 and 2030 (Technology Readiness Level (TRL) 9 already expected 2020). As the Renewable Energy Directive II is the EU's binding policy framework for renewable fuels from 2021 to 2030, the timeline has been extended to last for 10 years.

The attribute 'Reduction in $CO_2$ emissions' is essential to capture the main motivation behind decarbonising fuel. This attribute has in previous discrete choice experiments been shown to have substantial effects on preferences for fuel technologies (Achtnicht, 2012). In this specific survey, reduction in $CO_2$ emissions is included as an attribute to represent the environmental component, as it is clearly considered in EU policy design on decarbonising fuels (Commission, 2018b). The three levels of 20, 50, and 80 per cent below 1990 levels were chosen. The varied levels were provided to present the respondent with a wide choice. A recent study commissioned by the European Commission stated that decarbonisation scenarios of 80% to 95% emissions reductions relying on a technology mix with CCU fuels are possible (Fleiter et al., 2019). Another study suggests a reduction potential of more than 70% is possible, making a $CO_2$-based fuel car comparable to an electric vehicle (SETIS, 2016). On the other hand, Fernández and colleagues argue that a system including power and $CO_2$-DME production has 2% higher emissions than business-as-usual (electricity plus diesel) (Fernández-Dacosta et al., 2019). Full emissions potential is therefore contested and uncertain, and the study sought to provide a large span to policymakers to encompass this variation.

The attribute 'Fuel cost' seeks to represent the extent to which the policymaker is willing to value the effort and monetary burden for the consumer, given that it is these costs that will be incurred by the end-user. The levels of lower, same, higher, and not quantitative levels, were chosen due to difficulty of predicting realistic levels across the EU as a whole in such a time scale. We could not predict realistic numbers given that the technologies have not been produced at scale yet. Any price we could have provided would have been contested by the policymakers that took part. Overall, however, this attribute sought to represent the amount the consumer will have to pay to purchase a given fuel relative to current levels.

We seek to highlight the trade-offs that are made in policy funding decisions, and thus uncertainty costs need to be taken into account. In this experiment uncertainty costs are represented through the attribute 'Market share', which expresses the perception of risk associated with the new alternative being accepted on the marketplace. This attribute can be used to understand preferences of respondents on consumers' perceived risks and benefits of the respective technologies. While a technology may have reached market commercialisation, and a high TRL (and thus likelihood of positive net benefit), this does not necessarily mean that it is accepted by the public and reaches a high market share. An emerging technology, or any innovation for that matter, brings with it uncertainty when it comes to public acceptance and will take time before it reaches wider public acceptance (Huijts et al., 2007). This attribute seeks to gain some insight into the extent to which a higher uncertainty with respect to market acceptance, and in turn consumer acceptance, can make decision-makers apprehensive or not about funding a switch to a new alternative. Market share is a tangible way to present the degree to which the technology is used by consumers. The levels chosen for this attribute are also relative on a wide range, from 15 per cent, 50 per cent, up to 80 per cent were chosen due to the variation of predictions that have been made to date depending on the type of CCU fuel (Global $CO_2$ initiative, 2016).

### 3.2.2 Experimental design

The SAS-based software JMP was used to create the experimental choice design for both the pre-test and the actual study. A Bayesian D-optimal choice design algorithm has been integrated into the JMP software package (Kessels et al., 2009). Bayesian D-optimal designs – developed by Sandor and Wedel (Sandor and Wedel, 2001) are useful as they integrate available knowledge on the choice model's parameters into the choice design. They do so by introducing prior knowledge (which was attained through the pilot study conducted with policymakers working in the same field as the target group), and associated uncertainty about the parameters into the design - thus reducing the dependence of the design on unknown parameters (Kessels et al., 2011). The design created two alternative profiles, with 12 different choice sets, which were then blocked into two groups of 6 choice sets to which respondents were randomly assigned. Thus, each participant answered six choice scenarios to limit their cognitive burden (Hensher et al., 2015).

### 3.2.3 Questionnaire

The policymakers targeted for the DCE included those involved in financing EU transport infrastructure programmes - at European, national, regional and local levels. Programmes targeted included ESIF, JASPERS, advisory bodies of the Connecting

Europe Facility (CEF)/TEN-T, European Energy Efficiency Fund and the LIFE programme. Policymakers working on these issues in the European Commission (especially Directorate General for Mobility and Transport and Energy) as well as Members of Parliament in the European Parliament in committees related to transport, energy and budget were also contacted. All contact and questionnaire administration procedures were done electronically and participants' anonymity was guaranteed. All respondents received the exact same information on the purposes of the experiment: better understanding decision-makers' preferences in the area of funding decarbonisation projects. Our survey instrument included DCE questions and other questions regarding their work, attitudes, and socio-demographic characteristics of the participants. Survey distribution took place from mid-November 2018 to mid-January 2019.

In the valuation scenarios all subjects are asked to imagine that they are on the board of a fictitious transport infrastructure funding board called the 'European Mobility Network'. This is to avoid any preconceived ideas or opinions about any other funding platform that might already exist. Further, the fictitious nature of the network made it more likely that respondents followed their personal preferences, and not the vision of a body they might have already been affiliated with. The following text was provided to respondents in the online questionnaire developed on the survey platform Qualtrics:

*"Imagine you have been chosen to join the board of the European Mobility Network. The European Mobility Network brings together European policymakers to promote the transition to a decarbonised transport sector. The board is a group of elected representatives, responsible for contributing to the deployment of innovative solutions and projects. To achieve this goal, the board is currently assessing the allocation of €1 billion from the R&D budget for the next 10 years.* ***As a member, you are required to choose your preferred projects for further developing (or improving) personal transportation infrastructure.*** *The set of questions provided to you on the next pages are hypothetical. First, you will receive a description of the 3 alternatives amongst which we ask you to make a choice, before we ask you to make that choice.* ***One of the decisions you will have to make is to choose the alternative fuel types for passenger vehicles you would allocate funding to. Two of the fuel types presented rely on a process called carbon capture and utilisation (CCU).*** *If you would not consider allocating part of the R&D funding to the alternative fuel options based on CCU, you also have the option to not do so. If so, the remainder of the budget would be spent on other options for decarbonising the transportation sector."*

Simplified illustrations and descriptions on the process of producing both liquid-based and gas-based CCU are presented to the respondents. Respondents are then told that liquid-based fuels are compatible with existing infrastructures, such as service stations, while gas-based CCU has a compatibility that is limited to existing infrastructures. It is further clarified that the values presented to them are hypothetical, and only represent possible future technological options. They are asked to take the information presented to them as a given: features not presented cannot be taken into consideration when making a choice, and each choice should be made independently from the previous choice.

Data on background and socio-demographic characteristics of respondents are also gathered at the beginning of the survey, in addition to which level they represent as a policymaker (local; regional; national or European), how they would describe their current role (policy advisor; legal advisor; political (elected)), which topics they dedicate most of their time to, and where they fall on the political spectrum. Once

| | Liquid-based CCU | Gas-based CCU | Neither |
|---|---|---|---|
| **Reduction in $CO_2$ emissions** | 20 % | 50 % | The remaining budget will be spent on other options to decarbonise the transportation sector |
| **Required budget spent from 1 billion of EU Mobility Network funding** | €100 million | €200 million | |
| **Time until market commercialisation** | 2 years | 10 years | |
| **Market share (in 2040)** | 50 % | 15 % | |
| **Fuel cost (in 2040) compared to current (relative) levels** | Same | Same | |
| **I would choose** | ☐ | ☐ | ☐ |

Figure 1: Example of a choice card

the respondents have chosen one option for each of the six choice sets, they are then asked the choice of which alternative – out of the liquid-based or the gas-based option, or neither at all – they would choose if they had to.

Finally, we present several statements to participants with the goal to identify participants' attitudes and beliefs on the contribution of policy to the decarbonisation of fuels. All respondents, irrespective of their preference for the decarbonised fuels in the choice sets, respond to the statements on a five-point scale (from strongly agree to strongly disagree). The different statements address attitudes towards innovation and alternative fuels, the decarbonisation of fuel as well as climate change. These statements are sought to reveal additional information that may not be captured by the discrete choice experiment, and possibly to investigate a link between participants' attitudes and the stated choices.

## 3.3 Statistical analysis

As discussed above, the analysis of respondents' choices is based on random utility theory, which states that a respondent's utility function is comprised of a deterministic, observable component $X_{ij}$ and a random, unobservable component $\varepsilon_{ij}$ (Hanemann, 1994). Thus, the utility U of an individual $i$ choosing alternative $j$ from choice set $C$ is represented by

$$\mathrm{U_{ij}} = \mathrm{ASC} + \beta_{\mathrm{i}}\mathrm{X_{ij}} + \varepsilon_{\mathrm{ij}} \tag{1}$$

where $X_{ij}$ is the M-dimensional column vector of observed variables for alternative $j$ and respondent $i$; $\beta_i$ is the M-dimensional vector of coefficients capturing generic marginal (dis)utilities of attributes; and $\varepsilon_{ij}$ is the error term. The utility also includes the alternative-specific constant $ASC$ that represents the opt-out option.

Eq. 1 can be estimated by different models, depending on assumptions made about the error terms. In the conditional logit model, the error terms are assumed to be independently and identically (Gumbel) distributed. Hence, the probability $P_j$ of choosing alternative $j$ is expressed as a function of a policymaker's expected utility from the choice of $j$ relative to the expected utility of all alternatives $J$ in the choice set:

$$P_{ij} = e^{U_{ij}} / \sum_{k \in J} e^{U_{ik}} \tag{2}$$

In this model the preference parameters are fixed for all participants, assuming preference homogeneity in the sample (Hensher et al., 2015). Further models were then tested in the next stages of analysis, including the random parameters logit model (RPL) and a modeling approach combining both Error Component and Random Parameters Logit model (EC-RPL). The assumption of homogeneity is relaxed in mixed logit models as it enables capturing unobserved preference heterogeneity by allowing the preference parameters to vary across participants. In RPL models one can also relax the traditional assumption of having no correlation between the random parameters (Train and Sonnier, 2003). The probability of participant $i$ choosing alternative $j$ is then computed as follows (McFadden, 1973):

$$P_{ij} = \int \frac{e^{X_{ij}\beta}}{\sum_{k \in J} e^{X_{ik}\beta}} f(\beta) d\beta \tag{3}$$

EC-RPL models also take correlation across alternatives into account and have been shown in the literature to produce higher model fit and robustness in contexts such as these - where choices between the hypothetical alternatives are more similar than those for the opt-out (Hess and Rose, 2009; Van Loo et al., 2014). We have introduced the error component by incorporating a zero-mean normally distributed random parameter, additional to the usual Gumbel-distributed error term in the non-status quo alternatives (Scarpa et al., 2007; Marre et al., 2015).

# 4 Results

## 4.1 Descriptive statistics

129 complete responses were obtained, and with 6 choice sets each, this represents 774 choice observations. With three options per choice set this results in a total of 2322 alternatives for analysis. The response rate was approximately 10%, which is the average response rate for discrete choice experiments (Johnstone et al., 2017). The small sample size is a common limitation for groups that are more difficult to reach as compared to the general public - and in this case policymakers working in a rather niche field. The duration of the survey was on average 10 minutes, and policymakers were incentivised to take part in the discrete choice experiment with the assurance that each completed survey would result in a small donation to the charity of their choice. With regard to choice shares, 40 % of respondents chose gas-based CCU, and 38 % chose liquid-based CCU. The remaining 22% chose to opt-out and fund different projects.

The 70.11 % of respondents were male and the average age of respondents was 46. The gender imbalance corresponds to the reported number of women working in political positions in the European institutions - especially related to political positions in areas of transport (Commission, 2019b). The nationality of respondents varied within the EU but the most represented countries were Belgium, Germany, the Netherlands, Greece, Poland and France. The majority of respondents work in the European Commission, European Parliament, National, Regional and Local Government. Respondents remained anonymous - apart from providing their place of work - but as specified above, policymakers targeted worked on programmes providing funding for sustainable mobility – from advisory bodies of the Connecting Europe Facility (CEF), TEN-T projects, ESIF, JASPERS, Horizon2020, to name a few. Responses show that people working on these topics and responding to the survey were much more likely to be left-leaning (39.67 %) on the political spectrum than right-wing (11.89 %). A large proportion of respondents described themselves as liberal/central (23.80 %), while the rest preferred not to answer this question. Descriptive statistics of the questionnaire can be found in the annex.

Once the respondents had completed the choice task, all respondents were asked to choose, based on a multiple choice task, which of the alternatives from the discrete choice experiment – out of the liquid-based or the gas-based option, or neither at all – they would choose if they had to. In this question, it was specifically stated that the liquid-based fuel was closer to incumbent engine system, while the gas-based fuel was closer to the innovative engine system. Close to 50 % of respondents chose liquid-based fuel, 30 % chose gas-based fuel and the remaining 20 % preferred to fund neither at all.

## 4.2 Random Parameters Logit Model with an error component

The discrete choice experiment was labelled, meaning that all choice sets shown to policymakers included the option to fund liquid-based CCU, gas-based CCU, with the third option being none - where the remaining budget would be spent on other options to decarbonise the transport sector. Even though these three options remained consistent in each of the six choice scenarios presented to respondent, the levels - or characteristics - of the two aforementioned fuels varied in each of the six choice scenarios presented to the respondents (as is the case in all DCEs). The labels are represented as alternative specific constants, of either being liquid-based CCU and gas-based CCU (ConstantL and ConstantG presented in the results, respectively). We thus included alternative specific constants $\gamma_j$ for each fuel alternative $j$ in the random parameters logit model. These constants should reveal the general attitude of participants towards the two fuel types. Both constants were encoded as dummy variables, having a value of 1 if the respective fuel alternative was chosen and 0 otherwise. All attributes were treated as continuous variables, except for the attribute fuel costs which was modelled as a categorical variable (with values lower, same, higher) via a dummy encoding, with the base level being 'same'. All attributes were assumed to be normally distributed.

Given that it was a labelled discrete choice experiment, we sought to determine which preference parameters should be modelled as alternative specific (i.e., depending on the respective alternative $j$) and which as generic (i.e., independent of the respective alternative). In other words, we wanted to find out whether respondents chose fuel options based on the name of the label in the choice sets. We used likelihood ratio (LR) tests to establish this. For each attribute, the log-likelihoods of the model in which the respective parameter is modelled as alternative specific is compared with the generic model (normally used for unlabelled discrete choice experiments), in which all parameters are assumed to be generic. The model fit of the generic random parameters logit model with an error component provided a better model fit than the alternative-specific random parameters logit model with an error component (log-likelihood test; $p < 0.001$). The results of a mainly generic specification estimated by the random parameters logit model with error components (while accounting for correlation between random parameters) are thus reported in Table 2.

The results were obtained using Nlogit, an econometric software specifically designed for the analysis of discrete choice experiments.

The constants for liquid and gas-based fuels were not significant, indicating that participants do not attach utility to the alternative-specific label. This finding appears counter-intuitive in view of the participants' responses to the post-experimental multiple choice question on whether they preferred liquid-based fuel (described to respondents as the "incumbent option") - which turned out to be 50 % of the time, as compared to gas-based fuel (described to respondents as the "innovative option") 30 % of the time. This means that different mechanisms are at play in making a simple choice or a choice in a discrete choice experiment as commonly found in the discrete choice literature (Johnstone et al., 2017).

Nonetheless, the attributes characterising each fuel option were significant - barring budget - which means that attributes selected for the experiment were relevant and important to the policymakers. Further, almost all associated standard deviations are significant, indicating preference heterogeneities within the target population. Policymakers generally had a strong preference for a larger reduction in emissions, a short time to market commercialisation, a high market share and significantly disliked a higher fuel cost. These observations held independent of the fuel type, and are in line with the hypothesised directions. Policymakers showed a tendency to support dominant technologies and those that held a higher technology readiness level: thus potentially supporting and reinforcing techno-institutional lock-in.

Interaction terms show that the preference for budget allocated to the transport system choice varied slightly between three groups – the older segment of the respondent population, policymakers from central Europe, and those that displayed an incumbency bias - compared to the group of respondents as a whole. The groups that had significant differences are presented in the results table. The older the respondent, the less likely they were to devote part of their budget to liquid and gas-based CCU. Further, gender did not have an impact on the results. Five regions were interacted with the results – Northern, Southern, Central, Western and Eastern Europe. Policymakers that stated they were from Central Europe – and in this case either from Germany, Poland, Czech Republic, Austria and Slovenia – preferred to spend less money on the CCU-fuel options, which was not the case for the other regions. Attitudinal responses that were collected from the post-experimental questions (see appendix), including statements on preference for transport systems that are similar to those already in use were also interacted. This showed, that the higher the respondent's bias, and preference for incumbent technologies, the lower they wished the budget be spent on the new systems (presented as "Incumbency Bias" in the results). This was based on respondents' level of agreeing to statements such as "It is more effective to invest and improve existing fuel technologies, than in those that have not yet entered the market", "If the choice of an alternative fuel choice were up to me, it would be compatible with current engines and infrastructure", "People are more likely to prefer vehicle technologies similar to those currently in use." For the remain-

Table 2: RPL model with correlated error component (RPL-EC) estimates (n=129) using 1000 Halton draws. Alternative-specific parameters are marked with subscripts $L$ for liquid-based fuel and $G$ for gas-based fuel.

| | | Coefficients | Standard Errors | $p$-Values |
|---|---|---|---|---|
| **Main effects** | | | | |
| *Non-random parameters* | | | | |
| $\text{Constant}_L$ | | 0.649 | .717 | 0.364 |
| $\text{Constant}_G$ | | -0.027 | .849 | 0.974 |
| Standard deviation of Err. Comp. | | $2.63155^{***}$ | .508 | <0.01 |
| *Random parameters* | | | | |
| Reduction in $CO_2$ emissions | Mean | $1.016^{***}$ | 0.259 | <0.01 |
| | St. dev. | $0.904^{***}$ | 0.227 | <0.01 |
| | Cholesky Diag. Val.[a] | $0.904^{***}$ | 0.227 | <0.01 |
| Market share | Mean | $0.591^{***}$ | 0.161 | <0.01 |
| | St. dev. | $0.646^{***}$ | 0.166 | <0.01 |
| | Cholesky Diag. Val. | $0.504^{***}$ | 0.152 | <0.01 |
| Time to market commercialisation | Mean | $-.399^{***}$ | 0.100 | <0.01 |
| | St. dev. | $0.379^{***}$ | 0.086 | <0.01 |
| | Cholesky Diag. Val. | $0.227^{***}$ | 0.083 | 0.006 |
| Budget | Mean | -0.219 | 0.153 | 0.152 |
| | St. dev. | $0.707^{***}$ | 0.186 | <0.01 |
| | Cholesky Diag. Val. | 0.007 | 0.363 | 0.982 |
| Lower fuel cost | Mean | -0.171 | 0.578 | 0.767 |
| | St. dev. | $2.568^{***}$ | 0.959 | <0.01 |
| | Cholesky Diag. Val. | 0.709 | 1.607 | 0.658 |
| Higher fuel cost | Mean | $-1.766^{**}$ | 0.826 | 0.032 |
| | St. dev. | $2.538^{**}$ | 0.999 | 0.011 |
| | Cholesky Diag. Val. | 1.314 | 1.873 | 0.483 |
| **Subject effects** | | | | |
| Budget*Age | Mean | $-0.00517^{**}$ | 0.00235 | 0.0275 |
| | St. dev. | 0.00439 | 0.00332 | 0.1861 |
| Budget*Incumbency Bias | Mean | $-0.09672^{**}$ | 0.04497 | 0.0315 |
| | St. dev. | 0.00079 | 0.184 | 0.996 |
| Budget*Central Europe | Mean | $-0.392^{*}$ | 0.200 | 0.050 |
| | St. dev. | $0.34968^{*}$ | 0.184 | 0.058 |
| $N$ | | | | 774 |
| Log likelihood | | | | -525.39722 |
| AIC | | | | 1110.8 |
| AIC/N | | | | 1.435 |

Asterisks denote statistical significance at the $^{***}$ $p < 0.01$, $^{**}$ $p < 0.05$, $^{*}$ $p < 0.1$ level. [a] These values are the diagonal elements of the random parameter model's Cholesky matrix.

ing statements, no significant difference in results were found. Results for remaining groups also stayed the same regardless of the group the respondent might have fitted into, which points to the respondents being part of a rather homogeneous group, which is indeed the case and the point of the survey.

Correlation across alternatives was also verified given that the standard deviation of the error component was statistically significant. In addition to this, values of the Cholesky matrix were statistically significant which means that some of the random parameters were correlated (correlation matrix can be found in the appendix). This is evidence for the appropriateness of using a random parameters logit model with correlated parameters (RPL-EC) and the estimates illustrate that respondents perceived the experimentally designed alternatives to be different from that of the opt-out. Upon further analysis of the results, certain policymakers that chose the opt-out verified this by clarifying their choice by anonymously stating comments such as the following: "producing fuels from $CO_2$ is too energy intensive. There are better and more sustainable options to reduce $CO_2$ emissions from transport"; "There is already too much attention to the decarbonization of fuel: budget must be used on research in particular how to manage the demand of transport and to improve the energy efficiency of the whole transport system";"The market share in 2040 was not satisfying in combination with the $CO_2$ savings. I would prefer to allocate budget to alternatives transport modes instead of car fuels"; similarly another respondent stated that "I would not invest 1bn in any "technical fix" but instead in a radical change of (urban) infrastructure (esp. removing car lanes, boosting bike lanes) and supporting the systematic regionalisation of economic relationships".

# 5 Discussion and conclusions

This paper has analysed the trade-offs that European policymakers face when allocating a limited budget to foster the decarbonisation of transport fuels. The respondents represented a homogeneous target group working in the domain of EU funding programmes for transport and energy infrastructure. An example of this homogeneity is illustrated by the fact that a large majority of the respondents described themselves as left-leaning on the political spectrum, with a minority of respondents describing themselves as right-leaning. All respondents claimed to be rather well-informed on the topic in question and further held strong beliefs in the importance of policy in the sustainability transition. With this in mind, our main findings can be summarised as follows.

Firstly, the results illustrate that the participants showed to consistently opt for whichever transport decarbonisation fuel system provided the quickest fix to emissions reductions, regardless of whether the system chosen (as represented by the labels) was closer to the incumbent or not. This was illustrated through the specific attributes investigated in the discrete choice experiment: policymakers preferred to fund technologies with the lowest time to market commercialisation, and the highest emissions reductions potential. In addition, the desire for dominant technologies was shown to prevail when choosing a fuel system for decarbonising transport. Technologies with a higher predicted market share and market penetration were much more likely to receive funding than those that had not; thus potentially showing how the lock-in of more dominant technological systems is reinforced. In a worst case scenario, this can reinforce the lock-out of the development of new technologies that have yet to benefit from feedback mechanisms such as economies of scale, learning effects, and network effects.

Secondly, what can generally be concluded is that policymakers display a healthy scepticism when funding innovative technologies that require significant modifications.

This was especially indicated in respondents' direct responses with regard to stating a preference for incumbent as opposed to innovative fuels, which was further documented in their attitude towards innovate fuel in the post-experimental questions. For the direct question, policymakers were not presented with exact information on the extent to which each fuel would reduce emissions, nor any information on the transition or uncertainty costs expected (as had been the case in the discrete choice experiment). Policymakers were only told that liquid-based fuel most resembled incumbent fuel types, while gas-based fuel was representative of the more innovative option requiring significant modifications. The policymakers were thus unable to make a fully informed choice, and it was in this case that they were instinctively less likely to allocate their budget to a more innovative and unfamiliar option, and thereby more risky option. As discussed above, when they *were* provided with the associated information to each fuel, however, policymakers did not show a preference for the incumbent or innovative option and fully made their choice based on the attributes and characteristics presented to them.

Thirdly, policymakers chose the alternatives based on the characteristics presented to them, while indicating that there was not always one dominant alternative in each choice set. Given that policymakers fully made their choice based on the attributes, it suggests that respondents either disregarded or did not care about the fact that the source of the fuel came from CCU. Nor did it matter whether the fuel came in a gaseous or liquid state. Additionally, the percentage of opt-out choices was fairly low, and only a few respondents chose to opt-out consistently, thereby clearly accepting CCU-based fuels. This illustrates that CCU does not have negative connotations and perception as a fuel source among policymakers. While ample research exists on the development and feasibility of CCU, there has been limited research into the social acceptance of CCU technologies (Jones et al., 2017; Arning et al., 2019). This paper thus contributes to this literature and points to the fact that the acceptance appears to be high among the policymakers that took part in this study.

The interpretation of these results should be done carefully within the boundaries of the study's limitations. As discussed above, the relatively small sample size potentially limits the generalisability of the findings. We selected a rather homogeneous sample and the results cannot necessarily be applied to policymakers in general, but are rather restricted to those working in the area of funding transport infrastructure projects. Further research on policymakers should take this into account, and attempt to reach a wider and more representative group of respondents. Moreover, a common limitation of discrete choice experiments is its hypothetical nature (Johnstone et al., 2017), and we cannot conclude whether the respondents would have chosen the same alternatives in real circumstances. However, hypothetical choices can be meaningful for improving real-world choices. Previous studies show that it is possible to elicit real world choices with fair precision when field or real-world data is unavailable (de Bekker-Grob et al., 2019; Haghani et al., 2016). Therefore, it is reasonable to assume that our conclusions will also ring true in real-world settings and not only hypothetical ones.

Overall, the results provide insights into the trade-offs of policymakers when allocating funding to clean technologies – they seek options that can ensure a quick solution to emissions reductions and stated an initial preference for the familiar and incumbent option. These findings have important implications for policy design and illustrates the importance of taking institutional actors' decisions into account in studies of transition. The experiment itself allows us to gain some evidence as to why incumbent technologies prevail in the market: even when the policymakers were provided with a hypothetical choice to allocate funding, they still chose the option that required the least amount of change and least amount of time to market. Thus, policymakers may be likely to avoid investing in a more innovative idea, not because of any intrinsic flaw in the technological system, but because it would require too much change. These insights should at the very least be made available to and communicated among policymakers overseeing innovation funding programmes.


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# A Appendix

## A.1 Descriptive statistics

| Variable | % | Mean | SD |
|---|---|---|---|
| **Age** | | 46 | 11.226 |
| **Gender (% male)** | 70.11 | | |
| **Place of work** | | | |
| European Commission | 26.98 | | |
| European Parliament | 26.19 | | |
| National Government | 18.25 | | |
| Regional Government | 10.31 | | |
| Local Government | 5.55 | | |
| European Investment Bank | 3.17 | | |
| Other | 9.51 | | |
| **Main topic of focus** | | | |
| Transport | 43.65 | | |
| Energy and environment | 20.62 | | |
| Regional policy | 8.73 | | |
| Research and innovation | 6.34 | | |
| Development and cooperation | 6.34 | | |
| Other | 14.28 | | |
| **Political spectrum** | | | |
| Left-wing | 17.45 | | |
| Centre-left | 22.22 | | |
| Liberal/centre | 23.80 | | |
| Centre-right | 10.31 | | |
| Right-wing | 1.58 | | |
| Prefer not to say/other | 24.6 | | |
| **Overall fuel preference** | | | |
| Liquid-based fuel | 48.46 | | |
| Gas-based fuel | 30.76 | | |
| Prefer not to fund either | 20.78 | | |

## A.2 Post-experimental questions

| **Attitudes statements** |
|---|
| 1) It was easy to compare the different fuel alternatives with each other |
| 2) New fuel technologies cause more problems than they solve |
| 3) It is more effective to invest and improve existing fuel technologies, than in those that have not yet entered the market |
| 4) Compared to other policy measures, decarbonising fuel is not a high priority. |
| 5) If the choice of an alternative fuel choice were up to me, it would be compatible with current engines and infrastructure. |
| 6) Policy plays an important role in ensuring clean technologies enter the market. |
| 7) I consider myself well informed about sustainable technologies. |
| 8) People are more likely to prefer vehicle technologies similar to those currently in use. |
| 9) I would rather buy a car running on an alternative fuel such as CCU (that uses recycled $CO_2$) |

## A.3 Correlation matrix

| | Emissions | Market share | Time to market | Budget | Low fuel cost | High fuel cost |
|---|---|---|---|---|---|---|
| Emissions | 1.00 | 0.625 | -0.401 | 0.543 | 0.253 | -0.571 |
| Market share | 0.625 | 1.00 | 0.288 | -0.043 | -0.450 | -0.727 |
| Time to market | -0.401 | 0.288 | 1.00 | -0.966 | -0.933 | -0.084 |
| Budget | 0.543 | -0.043 | -0.966 | 1.00 | 0.853 | -0.097 |
| Low fuel cost | 0.253 | -0.450 | -0.933 | 0.853 | 1.00 | 0.853 |
| High fuel cost | -0.571 | -0.727 | -0.084 | -0.097 | 0.100 | 1.00 |