Net Zero Societal Change Analysis:

Summary Report

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Authors:

Stuart McKinnon (Energy Systems Catapult) - stuart.mckinnon@es.catapult.org.uk

Scott Milne (Energy Systems Catapult)

Adam Thirkill (Energy Systems Catapult)

With thanks to Richard Carmichael (Imperial College London), David Shipworth (UCL Energy Institute) and Steve Pye (UCL Energy Institute) for input.

About the Energy Systems Catapult

Part of a world-leading network of innovation centres, Energy Systems Catapult (ESC) was set up to accelerate the transformation of the UK's energy system and ensure UK businesses and consumers capture the opportunities of clean growth.

ESC is an independent, not-for-profit centre of excellence that bridges the gap between industry, government, academia and research – with around 200 staff based in Birmingham and Derby with a variety of technical, commercial and policy backgrounds.

ESC takes a whole system view of the energy sector – from power, heat and transport to industry, infrastructure and consumers – helping us to identify and address innovation priorities and market barriers to decarbonise the energy system at the lowest cost.

To overcome the systemic barriers of the current energy market, ESC work to unleash the potential of innovative companies of all sizes. Helping them to develop, test and scale the products, services and value chains required to achieve the UK's clean growth ambitions as set out in the Industrial Strategy.

Disclaimer

This study was commissioned by the Department for Business, Energy and Industrial Strategy (BEIS) and the Department for Environment, Food and Rural Affairs (Defra). The conclusions and recommendations should not be taken to represent the views of BEIS or Defra.

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Executive Summary

In June 2019, the UK set a net zero greenhouse gas emissions target for 2050. The target will have implications for the whole energy system and has increased the urgency and importance of societal change, compared to the preceding 80% emissions reduction target that the UK was committed to under the Climate Change Act (2008). Indeed, it has been estimated that the majority of changes needed to achieve net zero will involve some form of behaviour change (including the adoption and usage of low carbon technologies)[1].

The 'Net Zero Societal Change Analysis' project was commissioned by BEIS and Defra to better understand the possible impact of different societal and behavioural changes in achieving the 2050 emissions target. Energy Systems Catapult delivered the project in four parts:

- **Behavioural mapping:** identified a long list of behaviours affecting energy and carbon emissions, before prioritising these according to greatest potential impact. The priority behaviours were also assessed in terms of their potential distributional impacts, relevant policy barriers/enablers, and the near-term impact of COVID-19.
- **Modelling and analysis:** tested these priority behaviours using a whole energy system model, to assess their contribution to reducing (or increasing) energy system costs on the transition to net zero. For each behaviour modelled, system cost was assessed against a Reference Case net zero pathway.
- **Alternative modelling methodologies**: a scoping study to identify potential improvements in the representation of behaviour in energy models going forward.
- **International review:** assessed cross cutting interventions around public engagement and participation to understand whether lessons could be drawn for the UK.

The detailed annexes alongside this report provide detail on the approaches and insights for each of these, with this report providing a high-level overview of the work.

Key Insights

Key insights from each work package are drawn out in the appropriate sections of this summary report, including:

- The **behaviour mapping** identified 130 individual behaviours across four sectors (heat, transport, electricity and consumption) along with 11 societal changes (such as working from home). The prioritisation of these behaviours resulted in just under 40 behaviours, including the adoption and usage of low carbon technologies as well as consumption/demand behaviours that were used for further analysis in this study. It is

[1] Climate Change Committee, 2020, Sixth Carbon Budget

important to note that this study is not suggesting that all of these behaviours are necessary to reach the target.

- This project identified the importance of considering the challenges different groups may face in adopting a range of low carbon behaviours. For example, our high level assessment has identified that those living in rural locations, low income, living in privately rented properties, living with disabilities, of pensionable age, the digitally excluded, and those who have been disproportionally affected by COVID-19 can all face unique barriers to reducing demand and adopting low carbon technologies. These issues were not looked at in depth and warrant further analysis.
- The **modelling and analysis** of discrete behaviours reveals that the impact on the costs of transition depends on the wider system context. For some activities like flying, where no low carbon technology alternatives were considered, any demand will always result in emissions. At the system level, this determines the level of investment required in offsetting measures in other parts of the system to meet net zero. As the loss of enjoyment from foreign travel or increase in stress or boredom of switching to longer journeys by car or ferry has no cost attributed to it, any modelled shift away from flying will always result in a reduction in modelled transition costs (as many wider benefits or disbenefits are not captured within the costs that are modelled). It should also be noted that there are other areas where societal change could influence the costs of reaching net zero that are not captured here (e.g. by influencing the costs and types of policies that may be required).
- For other activities, where low carbon technology options do exist, the relationship between behaviour and technology is more complex. Often, technology adoption and usage *is* the behaviour, such as for electric vehicles or low carbon heating. At other times, the behaviour might be demand reduction, like opting for lower indoor temperatures. In this case, low carbon technologies are still deployed, but alternative behaviours can affect the optimal choice of technologies, their sizing and operation, and therefore cost.
- Overall, the modelling reveals how much more (or less) effort and cost would be required elsewhere in the system as these behaviours vary. Highlights include:
    - In transport, international aviation demand reduction has the biggest impact on system cost, since there are currently very few options to decarbonise this sector.
    - For reductions in car travel demand, direct emissions savings are highest in the near term, as this reduces miles travelled by petrol/diesel cars. Once the car fleet has been fully decarbonised, no direct emissions savings occur by reducing demand further (though there are wider system benefits, discussed in the report).
    - In heating, similarly, reducing demand delivers most direct emissions savings in the near- to mid-term as a result of less gas being used. By 2045, when the heating sector is almost entirely decarbonised the emissions impact is less significant.

- Considering **alternative modelling methodologies**, there was general agreement amongst the experts interviewed that the role of societal change has been under-represented in prominent scenario studies, in part because of the technical challenge of incorporating endogenous behaviour within the more prominent models. Energy Service Demand (ESD) and maximum rate of take up assumptions are often deeply embedded within scenarios and are not transparent to the reader. Energy Service Demands in particular are usually assumed to be exogenous, reflecting an implicit assumption that social norms are persistent and difficult to change. The COVID-19 pandemic has shown that social norms can change relatively quickly under some circumstances though, suggesting that the potential for such changes should be considered in modelling.
- However, this study has identified that adding increasing sophistication into models (e.g. endogenous behaviour) is not always the solution e.g. because of the difficulty in applying a cost to shift in behavioural norms. Evolution of modelling practice by using different tools at the right time and in the right way may be more appropriate – a number of suggestions for approaches that could be considered to improve representation of societal change in or alongside modelling are set out in Annex C.
- From the **international review**, despite a wealth of evidence on behaviour change initiatives taking place and their aims and objectives, there is relatively little information evaluating their impact. It is therefore hard to draw lessons from these for replication in the UK. What is clear is that in most countries, the changes needed to people's lives span multiple policy areas / government departments. Therefore, collaboration and coherent policy making is required to ensure a consistency in approach. A number of interesting, specific public engagement and participation initiatives from countries such as New Zealand and The Netherlands are set out in this study.
- Many of the public engagement initiatives in other countries have shown that effective engagement requires more than just information provision, and while many approaches to public participation in decision making have been employed in the past, there has been an increased interest in particular methods (e.g. citizens' assemblies) over recent years.

Introduction

In 2019 the UK Government implemented a legally binding target of net zero for UK greenhouse gas emissions by 2050. The net zero target will have implications for the whole energy system and has increased the urgency and importance of societal change (including the adoption of low carbon technologies), compared to the preceding 80% emissions reduction target that the UK was committed to under the Climate Change Act (2008).

In recent decades, there have been societal trends which have been detrimental to decarbonisation efforts. These include more people flying further and more often, increasing private car use, and increasing indoor temperatures in homes. Measures will be needed to counter the emissions resulting from these trends.

It has been estimated that around 60% of changes needed to achieve net zero will involve either behaviour change or a combination of behaviour change and technology solutions[2]. Some changes will result in the same outcomes being delivered in a slightly different way (e.g. when homes switch to a low carbon heating system).

Other potentially beneficial changes could result in different experiences than before, like flying less, taking public transport rather than private car, or changing diet (it should be noted that these changes are not necessarily essential for achieving net zero under some scenarios). People have different values, behave in different ways and live in different situations. This makes it easier for some people to change their behaviour and reduce their emissions than others.

It is also important to consider the influence of wider system factors on the effectiveness of any behaviour changes. For example, the impact on emissions of switching from a natural gas boiler to an air-source heat pump will depend on the carbon intensity of the electricity supply. This project has sought to identify and assess the impact of the key behaviour changes in that wider system context.

[2] CCC. (2019). Net Zero – The UK's contribution to stopping global warming. https://www.theccc.org.uk/publication/net-zero-the-uks-contribution-to-stopping-global-warming/ (Accessed: Aug 2020)

Project Aims and Objectives

The 'Net Zero Societal Change Analysis' project was commissioned by BEIS and Defra (referred to as HMG) to better understand the role of societal change in achieving the 2050 emissions target. The overall objectives of the project were to:

1. Identify the societal changes that are most relevant to net zero.
2. Identify and assess how different levels of societal and behavioural change can (positively and negatively) affect the feasibility and cost of transitioning to net zero.
3. Identify how and where cross-cutting interventions could be implemented to support the societal and behavioural changes necessary for net zero.

Project Approach

The project consisted of four work packages, each of which is reported separately in the supporting annex reports. The two major work packages consisted of a behavioural mapping exercise, and subsequent modelling and analysis of some priority behaviours.

The behavioural mapping (work package 1) identified a long list of behaviours affecting energy and emissions, before prioritising these according to greatest impact. The priority behaviours were also assessed in terms of their potential distributional impacts, relevant policy barriers/enablers, and the near-term impact of Covid-19.

The modelling and analysis (work package 4) tested a selection of these priority behaviours using a whole energy system model, to assess their contribution to reducing (or increasing) energy system costs on the transition to net zero.

Two smaller work packages included an international review (work package 2) of cross-cutting interventions to understand whether lessons could be drawn for the UK, and a modelling methodology scoping study (work package 3) to identify potential improvements in the representation of behaviour in energy models going forward.

Behaviour Mapping

This part of the project (work package 1) addressed the following research questions:

- *Research Question 1.1: What are the large and small behaviour/societal changes that could contribute towards (or hinder) reaching net zero?*
- *Research Question 1.2: For the most significant/important behaviours identified in RQ1.1, what government policies exist which may influence these behaviours?*
- *Research Question 1.3: For the most significant/important behaviours identified in RQ1.1, what evidence exists regarding the distributional impacts and considerations of changing these?*
- *Research Question 1.4: For the behaviours identified in RQ1.1, which have been potentially affected by COVID-19?*

These questions were addressed by subject matter experts from across ESC in a series of discrete tasks: behavioural mapping, policy mapping, distributional impacts, COVID-19. For full details see the supporting work package 1 annex report.

Summary of Findings

In total, over 130 individual behaviours were identified across four sectors, along with 11 wider societal trends. These behaviours were then prioritised based on their emission reduction potential, consumer acceptability and proportion of households able to adopt. This process resulted in 39 priority behaviours which were categorised and are shown in Figure 1.

As can be seen, there are a number of key themes which run throughout the sectors – a general reduction in demand, where possible, as well as changes in the way we buy things and what we buy.

It is also clear that the behaviour changes that affect the choices and costs of meeting net zero and our chances of a successful transition, are wide ranging and relate to many areas of people's lives.

It is important to note that this work is not suggesting or advocating that all of these behaviours will be required to reach net zero – instead it has mapped out behaviours that could positively or negatively affect carbon emissions and progress towards reaching the target.

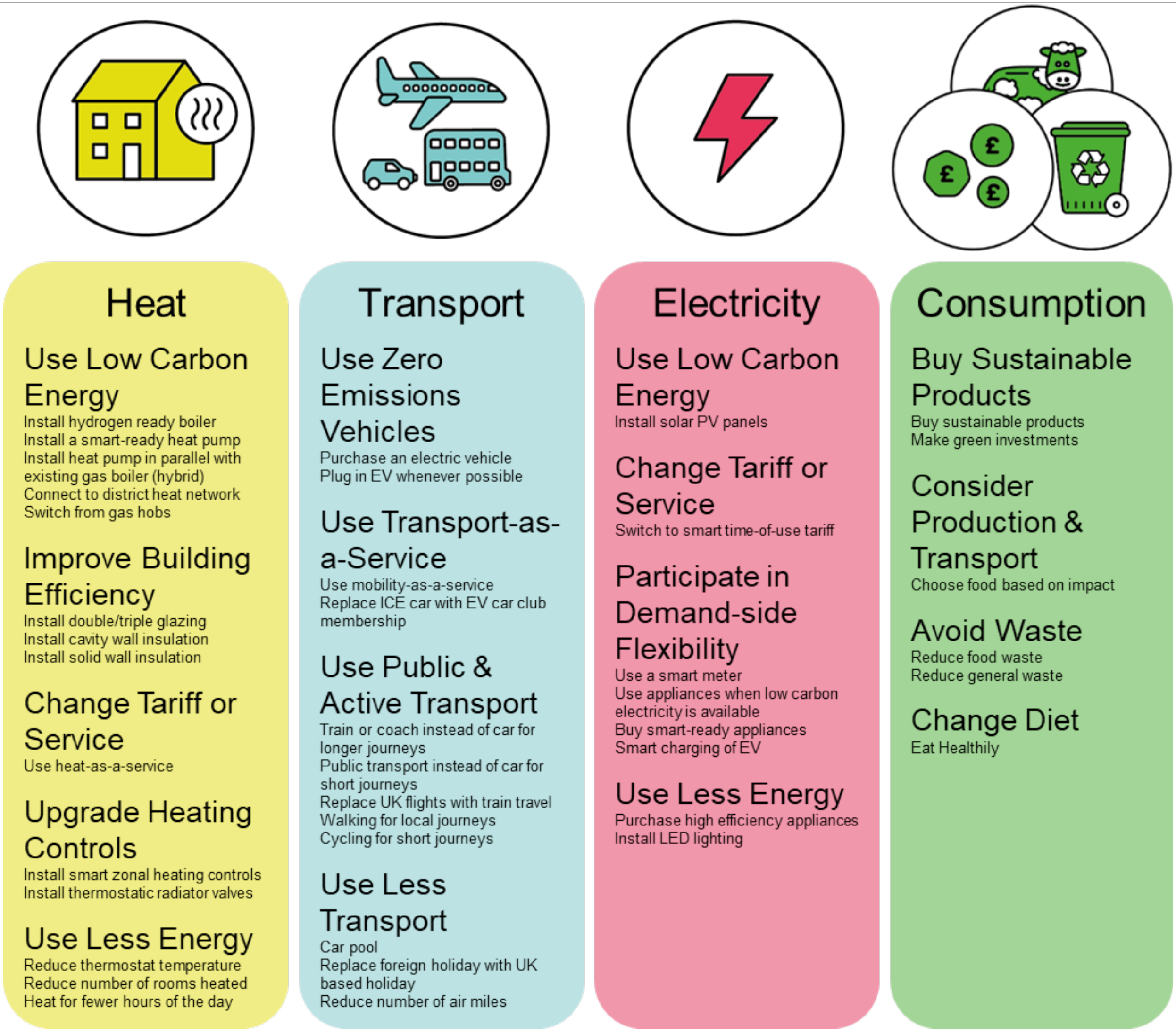

Figure 1: Prioritised behavioural changes and categories[3]

Distributional Impacts

A framework was developed and used to assess how the prioritised behaviour changes might affect key groups of the population (see corresponding annex for further details of the method). This framework was informed through previous research with people in vulnerable situations and consumer-centred energy systems[4] [5] [6] [7]. A range of groups who might struggle to engage

[3] A small number of behaviours were added to this diagram after WP1 had completed due to e.g. findings from the other work packages. Consequently, the distributional impacts, policy mapping and COVID-19 analysis was not carried out for general waste reduction, smart meters and switching from gas hobs.
[4] ESC (2020). Fuel poverty in a smart energy world. https://es.catapult.org.uk/reports/fuel-poverty-in-a-smart-energy-world/ (Accessed: Aug 2020)
[5] ESC (2020). Understanding Net Zero: A Consumer Perspective. https://es.catapult.org.uk/reports/net-zero-a-consumer-perspective/ (Accessed: Aug 2020)
[6] ESC (2018). SSH1: How Can People Get The Heat They Want At Home, Without The Carbon? https://es.catapult.org.uk/reports/how-can-people-get-the-heat-they-want-at-home-without-the-carbon/ (Accessed: Aug 2020)
[7] B. Sovacool et. al. (2019). Temporality, vulnerability, and energy justice in household low carbon innovations. https://www.sciencedirect.com/science/article/pii/S0301421519300102 (Accessed: Aug 2020)

in net zero behaviours were considered: those living in rural locations, low income, living in privately rented properties, living with disabilities, of pensionable age, the digitally excluded, and those who have been disproportionally affected by COVID-19.

People in all of the vulnerable circumstances considered are at an increased risk of experiencing barriers to adopting the behavioural changes identified as being key to achieving net zero. Table 1 highlights this broad impact.

Type of Household Vulnerability	Prioritised Behaviour																
	Heat					Transport					Electricity				Consumption		
	Source	Fabric	Service	Control	Reduction	Electrification	Service	Modal shift	Active travel	Reduction	Source	Service	Flexibility	Reduction	Healthy diet / more fruit and veg	Less food waste	Sustainable products
Rural			●		●			●	●	●	●	●	●				
Low income	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●
Privately renting		●	●	●	●					●	●	●	●	●			●
Residents with disabilities	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●
Pensionable age residents	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●
Digitally excluded	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●
Those disproportionally affected by Covid-19	●	●	●	●	●	●	●	●		●	●	●	●	●	●		●

Table 1: Summary of Distributional Impacts ('dots' indicate that the vulnerable household type face challenges in participating with the prioritised behaviour)

People living on a low income may face the challenge of access to financial capital (including through borrowing). Without access to capital it will be difficult to take up a number of the behaviours needed to achieve net zero. How much money is needed to participate and the nature and size of the risk varies across the different net zero behaviours. To help alleviate these risks, policy can be put in place to overcome these financial barriers (which has been the case through several current policies across government).

People living in rural areas face particular challenges in adopting some of the transport and heat-related behaviours (for example, modal shift to public transport and access to certain energy vectors/networks). Some of these challenges cannot be tackled through policy, e.g. shifting to walking and cycling for some people with physical disabilities, although alternative methods of accounting for that impact can be considered.

Some people have less freedom to participate in some of the behaviour changes (e.g. tenants cannot change their property). Again, some of these challenges cannot be tackled through policy, therefore, alternative methods of accounting for that impact can be considered.

Significant, complex change will be required to the way we heat our homes, the way we move around, how/when we power our appliances and what we consume, if we are to achieve net zero. Access to information and support for decision-making is a challenge for many of the household types. Therefore, initiatives can be put in place that provide information and support in ways, and through channels, which are accessible to all.

Overall, this work has shown that there are many types of distributional impacts that need to be considered as part of the aggregate societal change that is required for net zero. More detailed explanation of these can be found in the relevant annex. These impacts go far beyond simply where the allocation of financial costs fall.

Policy Mapping

The achievement of the net zero target by 2050 will require bold and well-integrated policies to allow a higher speed and larger scale of transition. Policy information was gathered and mapped against the prioritised behaviours to identify current policy coverage of these.

Having a clear, long-term policy framework has been highlighted as key for managing costs and maximising opportunities from the transition[8]. To date, policy focus overall has been more on supply-side measures, but demand-side policies to encourage a shift to alternative behaviours are increasingly recognised as critical factors for the transition and to enable behaviour change. A portfolio of policy instruments working together, including in areas outside of the traditional remit of energy/climate policy, is likely needed to address behavioural barriers and drive change at scale.

In transport, switch to electric vehicle use and active travel provide useful examples of integrated use of policy levers to target specific behavioural change. This includes a combination of economic and fiscal incentives, information and education campaigns, direct investment and regulatory approaches alongside a range of other measures. For other behaviours, such as modal shift (switching from private car travel to public transport), the landscape is more fragmented.

In heat, a significant number of economic measures (e.g. grants, loans) are in place to support building improvements and potential change of heating source with regulatory standards playing an important role. Other solutions (e.g. heat networks) benefit from direct investment but are not supported via end-user policies.

[8] Ekins, P. (2019). Report to the Committee on Climate Change of the Advisory Group on Costs and Benefits of Net Zero. https://www.theccc.org.uk/wp-content/uploads/2019/05/Advisory-Group-on-Costs-and-Benefits-of-Net-Zero.pdf (Accessed: Aug 2020)

In electricity, policies extensively focusing on supply-side measures have been successful in reducing carbon intensity of electricity supply. Beyond direct support for small-scale renewable generation, demand-side policies are dominated by regulatory instruments linked to smart meter roll out and the associated technical requirements.

In consumption, direct information and education campaigns play a prominent role, especially in relation to diet (e.g. Eatwell Guidance, food labelling) and food waste (e.g. Love Food, Hate Waste campaign). Circular economy packages are currently under development across all UK nations to develop new frameworks for sustainable consumption.

Service-led behaviour change options (e.g. mobility as a service, car clubs, car-pools, energy- or heat-as-a-service) have the least evidence of direct policy support across all sectors, perhaps due to their relatively recent development. Detailed assessment of policy gaps to encourage service uptake and understand behavioural barriers can be a beneficial step towards future development.

While overarching public campaigns exist (e.g. Year of Climate Action, Scotland's Climate Week), these are typically limited in scale and longevity (e.g. aren't multi-year campaigns). Consistency in messaging and a comprehensive plan on public engagement to raise public awareness and support action across sectors could be important in facilitating the transition to net zero[9].

COVID-19 Impacts

The impact of COVID-19 on the key behaviours was mapped out through a literature and data search.

COVID-19 has affected many of the behaviours identified as priorities for net zero, particularly around transportation and the use of electricity and heat in the home. Many of the changes have already, or are expected to, return to pre-COVID-19 levels when the restrictions on people's lives reduce. For example, estimates regarding aviation demand recovery have suggested that within 3-5 years things may return to where they were pre-COVID-19[10]. However, there may be lasting implications as a result of the expected persistence of a raised level of home working. An initial CIPD survey[11] suggests that employers now expect two fifths of employees to continue working from home post-COVID-19, compared to one fifth before.

Going forward, it will be important to track this and provide a more comprehensive assessment of any lasting impact of COVID-19 on behaviours related to achieving net zero.

[9] Demski (2021) Net Zero Public Engagement and Participation – Research Note
[10] Flight Global (2020). Demand for Air Travel to Remain Low Until 2023: S&P. https://www.flightglobal.com/airlines/demand-for-air-travel-to-remain-low-until-2023-sandp/138613.article (Accessed: Aug 2020)
[11] People Management (2020). Home Working Set to Double Post Coronavirus Crisis, Survey Finds. https://www.peoplemanagement.co.uk/news/articles/home-working-set-to-double-post-coronavirus-crisis (Accessed: Aug 2020)

Modelling and Analysis

This part of the project (work package 4) addressed the following HMG research question:

- *Research Question 2.1: How can different levels of societal change affect the deliverability, costs and benefits of reaching net zero?*

To address this, a series of modelling runs were conducted for the prioritised behaviours identified earlier, using ESC's Energy Systems Modelling Environment (ESME). For full details see the supporting work package 4 annex report.

Approach

ESME is a linear optimisation model of the whole UK energy system. The optimisation generates the lowest-cost energy system designs which satisfy constraints such as provision of energy service demands in buildings, transport and industry, subject to CO2 budgets. It is focussed on the physical components of such a system – infrastructure, energy flows and associated costs – and does not look at other layers of the system such as commercial aspects or communications between actors.

There are a number of concepts relevant to the energy systems modelling conducted in this study that should be considered. These are discussed below.

Discrete 'what if' analysis: The aim of the modelling was to explore the effects of different levels of behaviour change on the energy system. These speculative changes could occur due to a wide range of factors such as changing societal norms or the implementation of policy. Each behaviour was modelled discretely. Adding up the impacts of the individual behaviours would give a different total estimated impact to that of modelling them in combination. This means we cannot say what the combined impact of one or more of these behaviours might be.

Emissions headroom: In general, an energy system designed by a whole system, least cost optimisation model such as ESME, would see greenhouse gas (GHG) emissions reduced just far enough to meet to the CO2e target in a given time period. Over-delivery of the target would typically involve an added cost to the system and so, unless constrained in some other way, is not likely to occur in ESME. This means that if a modelled behaviour reduces emissions in one part of the energy system, this will lead to less abatement in another part of the modelled energy system (the converse occurs for a behaviour that increases emissions in one area). Under this approach a beneficial behavioural change will not lead to lower modelled emissions overall. Instead, it will usually lead to a different and less costly technology mix with the same emissions trajectory. Conversely a disadvantageous behaviour will usually increase costs rather than lead to higher modelled emissions.

System costs: These include the capital investment costs, operating and maintenance costs (e.g. repairs to machinery), resource costs (e.g. amount of biomass consumed) and transmission/infrastructure costs associated with the technologies deployed in the system. An investment rate of 8% (real) is assumed for the cost of capital for all technologies. This rate is used when annualising capital costs over the lifetime of a technology and when calculating the cost of interest during construction. A discount rate of 3.5% is used for all net present value (NPV) calculations in ESME, including the calculation of total energy system cost over the period to 2050. System costs do not include intangible costs perceived by the end user (e.g. travel time), wider economic impacts or policy costs (including taxes, feed in tariffs etc.) necessary to enact changes to the system. Some of the intangible costs are identified and discussed in the supporting work package 4 report.

Reference Case: A Reference Case net zero scenario was agreed with HMG based on ESC's published Clockwork scenario[12]. All the discrete behaviour change runs were conducted as sensitivities against this. The Reference Case represents the least cost way of meeting the net zero target under a set of default assumptions about the extent to which behaviour change is possible. Some types of behaviour are assumed fixed in the Reference Case such as the level of demand for travel by car and the temperature people heat their homes to. Other types of behaviour change such as choosing to switch to electric cars, or heat pumps are assumed to be possible up to some maximum rate of switching. For the latter types of behaviour, the reference case already implies the optimal feasible level of technology switching behaviour. Therefore, forcing a faster roll-out, to represent a beneficial behaviour change can counter-intuitively lead to higher modelled costs. This may be misleading because the potential benefits of earlier voluntary switching such as faster future cost reductions are not taken into account. In this analysis, the Reference Case is used to represent the high behaviour change scenarios for some behaviours, whilst for others it represents the medium or low behavioural change scenario. An alternative approach, based on a counterfactual with consistently low (or high) behaviour change throughout, would yield different system cost impacts. For instance, a counterfactual with consistently low behaviour change would require significant investments in (increasingly expensive) technology measures to reach net zero. In that context, shifting one behaviour to high ambition would have a more significant impact on marginal technology expenditure than when that same behavioural shift is tested in a more balanced counterfactual.

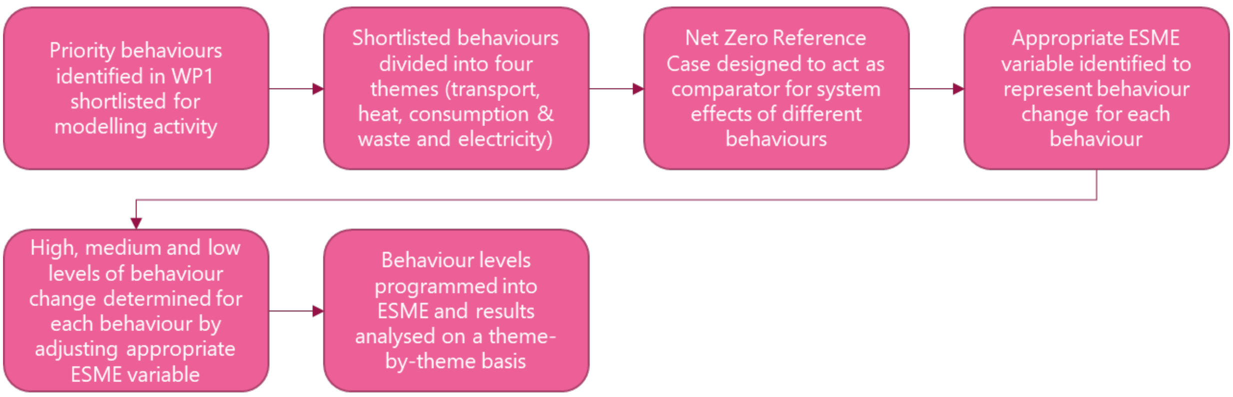

Figure 2: Process flowchart of the key modelling activities.

[12] ESC (2020). Innovating to Net Zero. https://es.catapult.org.uk/reports/innovating-to-net-zero/ (Accessed: Aug 2020)

The analysis was clearly not exhaustive, for example the technology adoption behaviour for heat pumps and EVs varied only the rate of adoption, without testing any absolute limit on market share. There were two shortlisted behaviours that were not modelled in ESME: a reduction in food waste in the consumption theme; and adoption of high efficiency appliances in the electricity theme. Instead, an assessment with bottom-up calculations was performed to evaluate these behaviours. The remaining behaviours are captured in the tables below (full details provided in the corresponding annex report).

Table 1: Transport behaviours modelled

Behaviour	High change	Medium change	Low change
Car-pooling	Car occupancy increases 25% 2020-2050 to 2ppv	(Ref Case) Car occupancy decreases 10% 2020-2050 to 1.5ppv	Car occupancy decreases 25% 2020-2050 to 1.25ppv
Modal shift - short journeys	10% reduction in 2050 relative to Reference Case	(Ref Case) 30% increase in car travel 2020-2050	10% increase in 2050 relative to Ref Case.
Modal shift - long journeys	10% reduction in 2050 car travel and 82% increase in rail demand relative to Ref Case	(Ref Case) 30% increase in car travel and 51% increase in rail 2020-2050	5% increase in 2050 car travel and 41% decrease in rail relative to Ref Case
Domestic aviation demand	30% reduction 2020-2050 (plus 58% increase in rail demand)	No increase 2020-2050 (plus 55% increase in rail demand)	(Ref Case) 30% increase 2020-2050 (plus 51% increase in rail demand)
International aviation demand	6% increase 2020-2050	25% increase 2020-2050	(Ref Case) 50% increase 2020-2050
Uptake rate of EVs	2030 ban on new ICE/hybrid sales. 50% new car sales in 2025 are ULEV	2030 ban on new ICE/hybrid sales. 30% new car sales in 2025 are ULEV	2030 ban on new ICE/hybrid sales. 10% new car sales in 2025 are ULEV
Working from Home	A sensitivity run was performed to reflect increased working from home following the COVID-19 pandemic (30% increase, 2 days/week average). This involved adjusting car travel down and residential heating up. Further details in the annex report.		

Table 2: Heat behaviours modelled

Behaviour	High change	Medium change	Low change
Avg indoor set point temp (SPT)	Avg SPT rises to 19°C by 2050	Avg SPT rises to 20°C by 2050	(Ref Case) Avg SPT rises to 21°C by 2050 from 18.5 in 2010
Retrofit installation	(Ref Case) 10.8 million homes installing whole house retrofit packages by 2050	5 million homes by 2050	2.5 million homes by 2050
Heat pump installation	(Ref Case) Economically optimal deployment. By 2050, 60% of residential heat demand supplied by heat pumps	Same 2050 outcome but deployment slower and delayed by 5 years	Same 2050 outcome but deployment slower and delayed by 10 years
District heat network (DHN) connections	(Ref Case) Economically optimal deployment. By 2050, DHN meeting 21% of heat demand	Same 2050 outcome but deployment slower and delayed by 5 years	Same 2050 outcome but deployment slower and delayed by 10 years
Retrofit hurdle rate 0%	A sensitivity run was performed to test the impact of a reduced hurdle rate for the installation of whole house retrofits. Further details in the annex report.		

Table 3: Consumption & waste and electricity behaviours modelled

Behaviour	High change	Medium change	Low change
Healthier Eating	Overall 50% reduction in red meat and dairy consumption (change in livestock emissions) by 2050. Informed by the CCC's Net Zero technical report (2019)	(Ref Case) Overall 20% reduction in meat and dairy consumption (change in livestock emissions) by 2050. Informed by the CCC's Net Zero technical report (2019)	
Rooftop solar PV installations	Current PV systems replaced when they reach the end of life plus continued new installations. 2050 capacity of domestic PV double that in 2020 (7.8GW).	Current PV systems replaced when they reach the end of life. PV capacity in 2050 remains the same as 2020 (3.9GW)	(Ref Case) Once domestic PV systems reach end of life, capacity is not replaced. Most of this capacity leaves the energy systems after 2035

Summary of Findings

The modelling reveals that for some behaviours the marginal cost/saving may be low. A modest reconfiguration of the technological system can take up the slack. Installing or not installing solar PV panels on individual rooftops (treated as a behaviour) is easily substituted in the model by installing larger solar PV farms. In other cases, there may be no immediate technological substitute, as with flying. In that case, more or less demand for flying has a big impact on the required amount of abatement measures elsewhere in the system. In summary:

- Change in habitual behaviour in the hardest to abate sectors has the largest system impact;
- Change in habitual behaviour in sectors that can decarbonise via technologies has transitional cost saving; and
- Change in the pace of one-off behaviours (e.g. slowing/accelerating up-take of low carbon technologies) has a smaller impact on transitional saving but does have important delivery implications.

A key metric for evaluating the impact of a behaviour on the energy system is the effect it has on the total system cost (the sum of resource, investment and operating costs of the energy system over the entire pathway to 2050). Findings here are reported in % of total system cost rather than absolute £ values as ESME assumptions around total system costs are likely to differ compared to those of HMG and other stakeholders such as the CCC (but the '% savings/costs are likely to be comparable).

Transport theme

In transport, international aviation demand reduction has the biggest impact on system cost, since there are currently very few options to decarbonise this sector. Limiting demand in 2050 to just 6% above 2020 levels (as opposed to 50% in the Reference Case) delivers savings equivalent to 3.3% of the Reference Case total system cost due to the reduction in abatement/offsetting measures required elsewhere.

Direct emissions savings in the near term are highest for behaviours that result in reduced car travel while internal combustion engine vehicles are still on the road. Note the indirect effect in the model is to create emissions headroom for other sectors. By 2050 though, the car fleet has entirely decarbonised and so no further emissions headroom is created by reducing demand further (although there are likely to be other benefits not captured here such as reduced congestion, reduced air pollution from brakes and tyres, shifting to healthier active travel modes etc).

In the near term, modal shift from internal combustion engine cars to public transport delivers significant emissions headroom. In the medium term, it will be important to ensure public transport decarbonisation keeps pace with EV adoption, otherwise encouraging people away from zero carbon private transport to higher carbon public transport could put net zero at risk. In the long term, assuming both options are zero carbon, public transport can offer numerous other additional benefits.

Heat theme

Reducing average indoor set point temperatures provides significant savings in system cost. Compared to the Reference Case where indoor temperatures climb by 2°C out to 2050, holding this at today's levels across the entire UK housing stock to 2050 delivers a reduction in total system cost equivalent to 3.9% of the Reference Case total system cost. These savings are predominantly a result of ESME assigning less extensive decarbonisation in parts of the transport sector, e.g. freight, due to the emissions headroom created, and as it supports easier and quicker heat decarbonisation.

Reducing indoor set point temperatures creates the most emissions headroom in the near- to mid-term as a result of less gas being used (a similar outcome might be achieved by heating separate rooms more selectively). By 2045, the heating sector is almost entirely decarbonised with a small amount of residual gas use to support peak heat requirements.

When whole house retrofit numbers are reduced from the Reference Case level of 10.8 million by 2050 to just 2.5 million, greater effort and investment is needed to ensure heat is decarbonised. A lower number of building retrofits will negatively impact the rollout of heat pumps as fewer houses will have the thermal efficiency necessary to optimise performance of heat pumps systems. In ESME this results in an increase in the amount of hydrogen supplied to homes and the number of homes connected to Heat Networks.

With more homes connected to Heat Networks, more infrastructure is needed to supply these networks with heat. This means almost doubling the amount of supply to heat networks from large scale HPs and geothermal systems in 2050 (relative to the Reference Case).

A sensitivity run was also conducted where the discount (hurdle) rate for retrofits was reduced to 0%, to test the impact on the speed of roll out. This shows considerable system cost savings and increased uptake but adjusting financial parameters for individual technologies in this way must be handled with care (see annex report for full details).

Consumption theme

The sustainable development goal (SDG) 12.3 targets a reduction in total edible food waste. The impact this target has on emissions will ultimately depend on the types of food that are wasted. For example, vegetable waste constitutes the largest contribution of food waste by mass but wasting meat and fish is associated with higher greenhouse gas emissions.

There is a synergy between the healthy eating guidelines and food waste strategy. For example, people aiming for the five-a-day target of fruit and vegetables could reach this by consuming the amount of edible fruit and vegetables currently wasted.

Across the food groups, the most common reasons for food wastage are not using the produce in time and preparing too much during mealtimes[13]. More effective shopping behaviours, appropriate storage and better use of leftovers would all help to reduce food waste.

Reducing red meat and dairy consumption by 30% relative to the Reference Case by 2050 delivers a saving of 2% of the Reference Case total system cost, assuming a commensurate fall in domestic red meat and dairy production. This is because the emissions headroom created by fewer emissions from livestock allows some slack in the hard to decarbonise parts of the transport sector.

Emissions savings are assumed to be a result of fewer livestock numbers producing less methane by enteric fermentation. Additional knock-on effects would be savings made by less wastage of meat products in households. It is important to caveat that an assumption was made that any dietary shifts would translate directly into a change in livestock numbers. In reality there is a complex agricultural economy mediating the relationship between demand and supply. Whether domestic dietary shifts cause farmers to reduce herd sizes or instead shift to producing for export would depend on diets overseas, government farming policy and other economic, social and cultural factors.

Electricity theme

Behaviours that would lead to a doubling of residential solar photovoltaic (PV) systems by 2050 (relative to Reference Case) actually cause a (negligible) increase in total system cost, by displacing generation capacity that is deemed more cost effective in ESME (e.g. solar PV farms, deployed at scale). However, it is possible that owners of PV systems achieve a broader appreciation of low carbon behaviours and might adopt additional behaviours in other aspects of their lives – this has not been explored in this study.

Working from home

An additional, exploratory model run was also carried out to explore the impact of increased working-from-home (however there are many uncertainties around the impacts of this so these findings should be treated with caution).

The increased working-from-home (WfH) behaviour modelled in this study represented 42.3% of the working population working from home two days of the week. This had a relatively small impact with net energy consumption savings less than 2TWh/year and net emissions savings (across heating and transport) providing less than 1mtCO2/year of headroom for other sectors, up to 2040. There are a number of reasons for this:

The scale of behaviour change appears large (42.3% of the working population WfH) but the effects only apply to miles travelled for commuting (other travel purposes unadjusted), and for

[13] WRAP. 2013. Household Food and Drink Waste in the United Kingdom 2012. Available at: https://www.wrap.org.uk/content/household-food-and-drink-waste-uk-2012

just 2 days per week. There is also an assumed rebound effect to account for a potential increase in non-commuting journeys and trip distances.

There is an assumed increase in residential heating demand as a result of people spending more of the day at home. This offsets some of the energy and emissions savings made by travelling less.

Depending on a number of factors, including the level of WfH expected to continue after COVID-19 restrictions have been relaxed and the true level of rebound effect (which is highly uncertain and perhaps subject to distributional factors such as region and age), the WfH behaviour could have a greater (or lesser) impact on energy and emissions savings. Furthermore, the level of increase in residential heat demand depends on what the daytime home circumstances were prior to WfH (was the house occupied anyway) and how many people in the household WfH and whether those WfH days coincide with each other or not.

Despite rather modest savings to emissions and system cost, there are potentially a number of other benefits produced by WfH not captured by the modelling. These would include reduced traffic on the roads at peak times which has benefits for air quality, road safety, quality of life and UK productivity. If peak traffic conditions are sufficiently reduced as a result of WfH, current spending on traffic management could be redirected to other improvements in public infrastructure for example.

Alternative Modelling Methodologies

There are many limitations to the way in which in behavioural/societal change is represented in whole energy system models (such as this study). A scoping study was produced (through a series of expert interviews and a focused literature review) that identified key limitations in representing behavioural/societal change in whole energy system models and options for overcoming these. Due to the technical nature of this – details are provided in the supporting work package 3 annex report and are not discussed in this short summary report.

International Review

This final section sets out high level findings from the international review (work package 2) that looked to address the following research question:

- *Research Question 3.1: What relevant climate change engagement, innovative cross-cutting societal/behaviour change, packaging of climate policies and public participation initiatives have been implemented in other countries? What evidence exists on the impact and success of these?*

This was achieved through an initial literature review, followed by further investigation of six initiatives, leading to the development of case studies. As there is a huge range and number of societal and behavioural interventions implemented internationally, this review focused on three specific categories of initiative: public engagement (ranging from targeted campaigns on electricity use reduction to multi-sector digital platforms); public participation in decision making (including large scale, national citizens' assemblies, and local citizen jury or town hall sessions); and cross-cutting policy packages (to ensure that individual policies are simple and not contradicting/counteracting each other). For full details see the supporting work package 2 annex report.

Summary of Findings

Through the literature review over 50 individual initiatives were identified along with high level descriptions of their objectives and impact (where available).

Although a wealth of evidence was found on the initiatives taking place and their aims and objectives, there is significantly less information available evaluating the impact that those initiatives had. It is therefore difficult to be clear on the extent to which they have been effective and what can be learnt from them. However, some observations include:

- In most (if not all) countries, the changes needed to people's lives span multiple policy areas / government departments. Therefore, some degree of collaboration and coherent policy making is required to ensure consistency in approach.
- Many of the public engagement initiatives have shown that effective engagement requires more than just information provision.
- While many approaches to public participation in decision making have been employed in the past, there has been an increased interest in particular methods (e.g. citizens' assemblies) over recent years[14].

[14] openDemocracy (2019). Citizens assembly: towards a politics of 'considered judgement'. https://www.opendemocracy.net/en/citizens-assembly-towards-a-politics-of-considered-judgement/ (Accessed: Dec 2020)

Case studies were carried out on six relatively small initiatives. The key findings of each are presented in Figure 6. The missing information in the summary reiterates the difficulty in finding reliable evaluations of initiatives after they have taken place. The majority of the literature surrounding them is concerned with their objectives and initial roll-out.

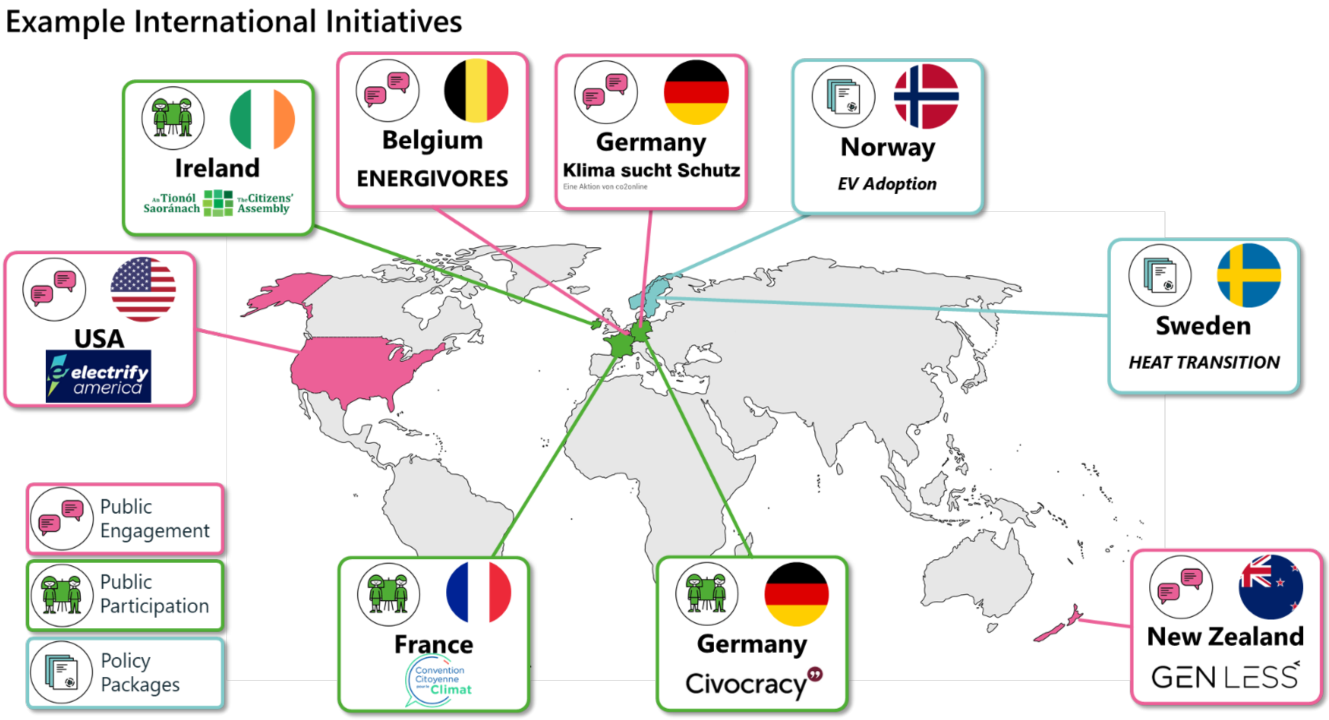

Figure 5: Examples of relevant initiatives from around the world

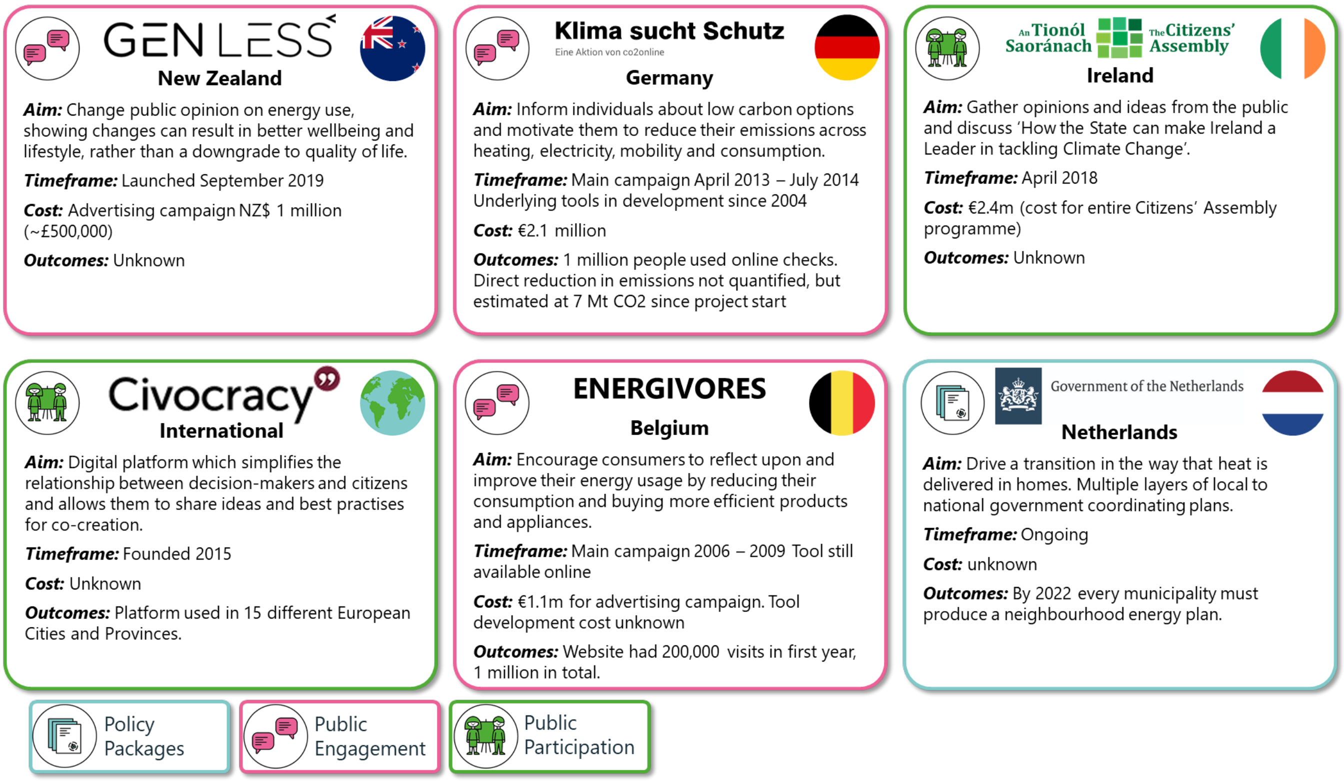

Figure 6: Case study overview

The activities undertaken in this work package identified some potentially useful examples of initiatives adopted internationally such as innovative online public participation platforms and methods of engaging the public. However, all of the initiatives were generally small in scale and no obviously exemplar approaches for the UK to consider were found.

Overall Project Insights

Most previous analysis on UK decarbonisation pathways has focused on the changes required in energy system technologies. While the technology challenge is considerable, research for the Climate Change Committee (CCC) suggests that over 60% of changes needed to achieve net zero will require some form of behaviour change[15]. That same research also highlighted the limitations of the existing evidence base in extrapolating future behaviour change – some of which this work has aimed to help overcome. This section provides a brief overview of the overall project insights from across the work packages under each of the research objectives – the annexes for each of the work packages contain more detailed insights.

The societal changes most relevant to net zero

This project had identified a non-exhaustive long list of over 100 societal changes that could conceivably make a (positive or negative) difference to net zero. These are highly diverse and span home energy, transport and more broadly consumption. It is important to note that this report is not suggesting that all of these behaviours are required to reach net zero and has not sought to make recommendations on the extent to which different actions should feature in the UK's approach to reaching net zero.

This project subsequently identified a priority set of behaviours based on carbon reduction impact, ease of adoption, and total potential to adopt across the population. However, there was a lack of evidence in a number of these areas and so this prioritisation should be treated as indicative.

A high-level distributional impact assessment showed that different groups could encounter different opportunities and challenges in adopting these behaviours. The profound impact of COVID-19 has also recalibrated our collective understanding of the speed and extent to which societal change can occur when priorities (and policies) shift.

Societal change and the costs/feasibility of transitioning to net zero.

The criticality of the prioritised behaviours was tested using the ESC's whole energy system modelling environment (ESME).

Models like ESME (or the comparable UK TIMES) are designed primarily to identify the optimal mix of technology solutions for a predetermined demand scenario. Modelling behaviour change in this project meant modifying that demand scenario each time to look at how this changed the optimal technology pathway, and how this impacted total system cost.

[15] CCC. (2019). Net Zero – The UK's contribution to stopping global warming. https://www.theccc.org.uk/publication/net-zero-the-uks-contribution-to-stopping-global-warming/ (Accessed: Aug 2020)

There are several important limitations of this approach, detailed in the methodological scoping study. But the approach enables a first order understanding of the marginal cost/saving of each behaviour change tested.

A number of overarching insights can be taken from the modelling:

- Change in habitual behaviour in the hardest to abate sectors has the largest system impact;
- Change in habitual behaviour in sectors that can decarbonise via technologies has transitional cost saving; and
- Change in the pace of one-off behaviours e.g. slowing/accelerating up-take of low carbon technologies have a smaller impact on transitional saving but do have important delivery implications.

The modelling reveals that for some behaviours the marginal cost/saving may be low. A modest reconfiguration of the technological system can take up the slack. Installing or not installing solar PV panels on individual rooftops (treated as a behaviour) is easily substituted in the model by installing larger solar PV farms. In other cases, there may be no immediate technological substitute, as with flying. In that case, more or less demand for flying has a big impact on the required amount of abatement measures elsewhere in the system.

It is important to caveat these findings that systems costs are only one element that should be considered when reflecting on possible approaches for reaching net zero. For example, wider economic impacts, policy costs, public preferences and welfare impacts have not been considered in this modelling. This work has also not been able to investigate other important ways in which societal change could influence the costs of reaching net zero – as one example, public attitudes/societal norms could influence the effectiveness, types and costs of policies needed to support change.

Although this project has used a ‘whole system’ model, the behaviours have been tested as discrete interventions. This has been useful as a starting point to provide clarity on the criticality of different measures and their relationship with the wider technological system. An important next step for HMG could be to consider the impact of multiple behaviour changes combined as part of a more holistic scenario assessment of socio-technical change. Several options for setting out how societal change considerations could be better integrated into, or alongside, modelling in future have also been identified (set out in the work package 3 annex report).

Supporting cross-cutting interventions

This project has demonstrated the complexity and importance of societal change in reaching net zero. An overall implication of this work is that it demonstrates the need to take a systemic and integrated approach to societal change, alongside policy targeting and supporting individual changes.

The international review shows that in most (if not all) countries, the changes needed to people's lives span multiple policy areas / government departments. Therefore, some degree of collaboration and coherent policy making is required to ensure a consistency in approach.

Overall reflections

The model used in this study includes a portfolio of around 400 technologies, including some early stage technologies that are not yet deployed commercially. In reality, unproven technologies can fail or under-deliver.

Behaviour change in support of net zero can be seen as reducing systemic risk by ensuring we are less reliant on uncertain technology breakthroughs. A resilient approach to net zero therefore means pursuing both measures: facilitating sustainable ways of living, as well as supporting the development of innovative technologies.

In the best of all possible worlds, technology breakthroughs might combine with proactive societal change to raise the prospect of an even earlier delivery of the net zero target. In a more likely scenario, pursuing both societal and technological change offers some room to fail on specific endeavours on the pathway to 2050.

In the end, it will be easier to win public support if it remains easy for people to get the outcomes they want. It is important, therefore, that citizens are engaged in the process, and that technology developers, energy suppliers, network companies, policy makers and regulators all work together.

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