# New times, new policies? Policies to change energy use in the context of zero carbon

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## Abstract

Policies to improve energy efficiency have been discussed and implemented since the oil crises of the 1970s. Over this period, a wide range of disciplinary approaches has been used to design and analyse effective policies, with a developing consensus that a policy mix is the most effective approach.

However, the required shift to zero carbon energy systems within a few decades is disruptive. The rates of change in technology and practices implied by global carbon targets are inconsistent with analyses assuming incremental change. Combustion of fossil fuel needs to be largely eliminated, rather than improved. New challenges such as temporal flexibility in electricity use are emerging. Future energy systems seem very likely to be more decentralised, electrified and service-oriented, and therefore involve new actors. With new sets of fuels, technologies and potential actors, it is imprudent to assume that existing policy approaches will be adequate.

The paper starts from an existing assessment of a low-energy, net-zero energy system in the UK (Barrett et al, 2021). It identifies the key implied changes to energy-using technologies and practices. It investigates policy options to promote each type of change and discusses whether these are adequate for the rates of change now needed. Where it appears unlikely that rates of change can be delivered within existing policy frameworks, the paper identifies what new options might be considered.

The paper concludes that changes to the technology, fuels and associated practices required to increase end use conversion efficiencies will be critical and are largely achievable by adapting policy approaches and instruments that have been used successfully. However, changing the structure of demand for energy services is also needed if demand reduction is to play a bigger role. This will need to draw on a wider set of policy approaches, including policy options not normally considered as part of energy policy.

## Introduction

The overarching challenge for future energy systems is to deliver the goals set by the Paris Agreement, i.e. net-zero carbon emissions by mid-century and a mean global temperature rise of well below 2 °C. Together these imply very rapid emissions reduction (IPCC, 2021) and near complete elimination of fossil fuels by mid-century (IEA, 2021). Change needs to be led by developed economies with the longest history of large-scale fossil fuel use, highest living standards and greatest technical and financial capabilities.

Incremental improvement in energy efficiency, even alongside supply-side change, is inadequate to deliver these goals. More fundamental changes are required in energy demand: more substantial demand reductions, switching to zero carbon vectors (e.g. electricity and hydrogen), and increased flexibility in electricity demand (Eyre and Killip, 2019).

The most sophisticated global assessments (e.g. Grubler et al, 2018; IEA, 2021) emphasise the critical role of both renewable energy and energy demand change, particularly demand reduction and switching away from direct use of fossil fuels. However, international analysis is insufficient. The framework for action in the Paris Agreement is Nationally Determined Contributions, and therefore key policy decisions will be national.

There has been a growth of national studies of net-zero energy futures, especially 100 % renewable energy analyses (e.g. Jacobsen et al, 2015; Hansen et al, 2019). Detailed national demand side analyses are fewer. This paper builds on one (Barrett et al, 2021), which has developed low-energy scenarios for the UK, compliant with a 2050 net-zero target. The scenarios show that, a combination of energy efficiency improvements and plausible changes to energy service demand can reduce demand by more than 50 %. The precise levels of demand reduction depend on detailed assumptions, but it is a robust conclusion that both technical energy efficiency and social change can play a large role, and together a transformative one. Barrett et al (2021) also argue that there are substantial energy, social, health and environmental reasons to prefer low demand decarbonisation pathways. The scenarios are demonstrations of futures that are technically, economically and socially feasible. Although such feasibility is clearly critical, it is not sufficient. Major policy interventions will be needed. At present, this is a significant gap in the literature.

This paper therefore addresses the question "What national policy interventions will be needed to deliver the changes in energy use implied by the goals of the Paris Agreement?".

Our methodology is to review policy approaches based on existing experience, with particular reference to delivering change on a large scale and quickly. We then apply this to the socio-technical changes in energy demand that are required to reach net-zero, specifically those in UK low-energy scenarios (Barrett et al, 2021).

The next section sets out our analytical approach and reviews the relevant literature on policy packages, disruptive change and transformative policy options. The following sections summarise the key areas of change needed with a more detailed analysis of policy options for buildings, mobility, materials and products and for cross-cutting policies. We have excluded nutrition from our analysis as the key demand side policy options have been set out elsewhere (Garvey et al, 2021). The final section draws conclusions.

## Analytical framework

Classical analyses of public policy for changing energy demand (e.g. Jaffe and Stavins, 1994) focused on improvement of energy efficiency where this is economically sub-optimal and the implications of different market failures for policy instrument preference, e.g. between pricing, regulation and information provision. The underlying assumption was that, although energy markets are sub-optimal, the changes in demand that are required to deliver better economic outcomes can be delivered through incremental changes in user technology or behaviour, within broadly the same energy system.

The key policy instruments to influence energy demand within the framework have been:

- taxation of energy and carbon and differential taxation of energy using products;
- regulation – via product, vehicle and building standards (and negotiated agreements) and through regulation of the energy sector to require energy efficiency;
- a range of information, advice and education measures; and
- support for R&D and early stage deployment.

The assumptions that underpinned this framework are no longer valid. Economic optimisation with climate impacts as an externality is no longer an appropriate framing (Edenhofer et al, 2014). Instead, ecological sustainability needs to take priority, implying that energy systems will undergo radical change. Changes in energy demand will be wider than cost effective energy efficiency, also encompassing fuel switching, changes in energy service demands and greater flexibility of energy use. Solutions, and therefore policy options, may need dynamic analysis and considerations of social equity as well as economic efficiency. They may lie in areas outside the narrowly-defined energy system.

It does not follow that previous approaches to policy design are irrelevant. We need to learn from existing successful frameworks, for example the way that policy instruments have been combined in packages that are both effective and socially acceptable. However, we need to accept that existing approaches alone are very likely to be inadequate, and therefore that some assumptions may need to be challenged.

A radically different energy system implies disruptive change and the role of policy in this needs to be considered. New actors and business models will undoubtedly emerge as relationships change between energy supply and use, and policy may be able to influence this process. The scale of the climate crisis means that options that have hitherto been considered too radical, may also be needed and become acceptable.

### POLICY PACKAGES

Energy efficiency is typically supported not just by one single policy instrument but by a package of policies. Historically, such approaches were developed by practitioners through observation of effective strategies, conceptualised as market transformation (Geller and Nadel, 1994) and then theorised with reference to innovation theories (Blumstein et al, 2000).

There is now a rich literature on policy packages and policy mixes more generally (Campano and Howlett 2020, Howlett 2013, Rogge and Reichardt 2016), and on policy mixes and energy efficiency specifically (Constantini et al. 2017, Kern et al. 2017, Rosenow et al. 2016, Rosenow et al. 2017, Trencher and Van der Heijden 2019).

Much scholarly work has been devoted to identifying characteristics of policy mixes that are *consistent* and *coherent*. Consistent policy mixes are defined by the absence of contradictions whereas coherent policy mixes achieve synergies and positive connections between the individual parts of the policy mix (Rogge and Reichhardt 2016). In addition, effective policy mixes are also *comprehensive* in that they support the full range of technologies and applications needed to achieve an ambitious energy transition (Rosenow et al. 2017).

With a shift in focus towards full decarbonisation, energy efficiency policy mixes will need to support:

- energy efficiency at the scale needed to meet zero carbon goals;
- only energy efficient technologies fully compatible with zero carbon goals;
- integration of energy efficiency into the wider energy system changes such as electrification; and
- synergies with supply-side decarbonisation.

In addition, policy packages will need to incorporate instruments designed to avoid high-carbon and intensive energy service demands, in particular where energy efficiency and/or zero carbon supply options are limited.

Currently, most policy mixes continue to support outcomes that are not well-aligned with those objectives. For example, policy mixes continue to encourage deployment of end-use technologies dependent on fossil fuels, focus on immediate energy savings rather than transformation to zero-carbon systems, and miss opportunities for synergies with policies in other domains of energy policy such as renewable energy. Other energy demand reduction options, such as to support materials efficiency, active travel and dietary change are rarely included.

This misalignment with zero carbon suggests the need for a reassessment of existing policy mixes but also highlights the potential need for policy options designed to support a rapid systemic transition. In the next sections, we therefore review the literature on policy approaches to transitions and some examples of policies that might be used.

## POLICIES TO PROMOTE TRANSITIONS

A central aim of transitions research is to conceptualise and explain processes of radical sociotechnical systems change, as opposed to incremental improvements and technological fixes (Köhler et al., 2019). A systems perspective highlights that the process is: (i) non-linear, as different elements of a sociotechnical system, such as technologies, markets, cultural values, policies and supply chains evoke further interdependent changes in other parts of the system; (ii) lengthy; (iii) involves interactions between opposing forces – radical change vs stability and path-dependence; (iv) involves many kinds of agency, as well as contested values of these agents; (v) characterised by an open-ended and uncertain future, as there are multiple pathways to achieve it (Geels and Schot, 2007; Köhler et al., 2018; 2019).

The complex nature of a transition means that it cannot be comprehensively addressed by single theories or disciplines, nor is there a single intervention that can steer such a process to sustainability (Geels, 2011). Rather, a range of intervention points should be considered in the design of a policy mix, e.g. Kanger et al. (2020) distinguishes six intervention points: (i) stimulate different niches; (ii) accelerate the niches; (iii) destabilise the regimes; (iv) address the broader repercussions of regime destabilization; (v) provide coordination to multi-regime interaction (Papachristos et al., 2013); (vi) tilt the landscape. A consideration of a broad spectrum of intervention points can lead to a more complete portfolio of instruments and strategies.

Sustainability is a common good, and therefore actors have limited incentives to address it individually, as noticeable results can only be achieved with collective actions (Köhler et al., 2019). Therefore, public policy must play a central role in shaping the direction of the transition through a policy mix (ibid.). To successfully steer a complex system, an appropriate feedback structure is essential (Boulding, 1968). The scope of the analysis should broaden to include policy effects on social change and the feedbacks that underpin further change in the policy mix (Edmonson et al., 2019).

Traditionally, energy sector business models have been associated with the neo-classical prioritisation of shareholder profits and associated cost-benefit analysis. A more evolutionary reading of economic theory points to their importance in the creation of routes to market for innovations, using the intervention points set out above at various stages of the innovation chain, to support business model innovation and market creation (Mazzucato and Semieniuk 2017).

Path-dependent choice architectures and selection environments often determine underlying policy-mixes, even those in support of mission-orientation for ecological sustainability. In energy policy this can lead to the prioritisation of centralised supply side solutions over decentralised and highly diverse demand side solutions (Stirling 2014). In the former, total costs, and transactions costs in particular, are often obscured through vertical integration (Nolden and Sorrell 2016); in the latter, they are self-evident and can result in repeated business model failures where energy policy is poorly designed (Rosenow and Eyre 2016).

While competitive markets and associated business models are very powerful tools to reduce costs, they tend to achieve such outcomes where innovation is linear, which is more likely to be the case with such supply side solutions, for example in fuel-switching in power generation. The integrated nature of such demand side solutions, with increasing service-orientation and end-user engagement, is characterised by less determinate processes of change (Stirling 2011).

Fostering the emergence of new business models in support of transformations that include more substantial demand side contributions thus requires a diverse policy-mix extending beyond the traditional remit of energy policy (Nolden et al. 2016; Rosenow et al. 2017; Tingey and Webb 2021).

## RADICAL POLICY OPTIONS

A number of more radical policy options can be envisaged than those already used.

The most obvious are regulations that proscribe the use of fossil fuels in specific applications or settings. These are only practicable and socially acceptable, if there are alternative sources of energy supply and the conversion equipment to use them. The logical policy strategy is therefore first to develop zero carbon supply chains and infrastructure, and then to regulate for the removal from sale and/or purchase of specific types of new fossil fuel using equipment. Already measures of this type are being considered in a number of countries, in particular with respect to cars and heating systems. Fortunately, the shift to decarbonised vectors has important synergies with other required changes to demand. Most notably, it has been estimated that this change alone enables an additional improvement in energy efficiency of ~40 % (Eyre, 2021), primarily due to the much higher efficiency of electric vehicles and heat pumps. In addition, new large electricity loads for vehicles and heating provide large sources of flexibility.

Pricing of energy and carbon are obvious policy options for reducing energy demand. In transport, high taxes have been used successfully in many European countries. But in other sectors, high levels of taxation have been more problematic due to concerns about impacts on business competitiveness and household energy bills, particular in low-income households. Carbon taxes with a broad scope have been used in some jurisdictions, e.g. British Columbia, but not widely, The EU emissions trading scheme was initially designed to avoid high costs to energy-intensive industry (Hepburn et al, 2006), and without revenue recycling to energy efficiency is not expected to deliver significant energy efficiency improvement (Wiese et al, 2020). For households, there are emissions trading options that avoid inequitable outcomes, typically through distributing property rights or revenues equitably. These carbon trading approaches are known as personal carbon trading. A large number of design options have been considered (Eyre, 2010) and the technical barriers to implementation are soluble (Fuso Nerini et al, 2021), but to date none has been implemented.

Another approach to reducing energy demand is to ration energy service demands. This type of policy has generally been considered more radical, and sometimes argued to be incompatible with liberal democracies. However, to some extent, they are already used. Many jurisdictions set limits on internal temperatures in workplaces and public buildings, for example these formed part of the "CoolBiz" policy package implemented to save energy in Japan (Murakami et al, 2009). Exclusion of powered vehicles from areas of cities is increasingly seen as part of good urban planning. And mandatory recycling policies essentially mandate the use of low-energy materials. All these examples indicate that the key policy attribute is not constraining energy service demands per se, but rather social acceptability, which is time and place specific.

Our broad conclusion from reviewing these different literatures is that policy packages will not only remain an effective approach, but become more important as the focus moves from incremental change to transition. However, existing policy packages need to be reviewed against the objectives of a zero-carbon transition. In promoting demand reduction, particular emphasis will need to be given to frameworks that support business models consistent with the zero-carbon objective. Clarity and speed will be critical, and both point to a high priority for regulatory policy instruments. Ensuring a bigger role for service demand reduction will require an expansion of the scope of what constitutes 'energy policy'. The next section applies these general insights at a granular level to changes needed to deliver demand reduction.

## What policies might deliver?

A very wide range of changes to energy demand will be needed to deliver net-zero goals. We use specific scenarios developed in other work (Barrett et al, 2021) to examine low-energy, net-zero carbon futures for the UK. Four scenarios were developed. The first, 'ignore demand', assumes continuation of current UK national policies, with a low priority for demand reduction, results in very limited demand reduction and does not deliver net-zero climate goals. The second, 'steer demand', uses all energy efficiency measures that are cost effective in a net-zero transition, leading to a 31 % reduction in energy demand by 2050. The third and fourth scenarios, 'shift' demand' and 'transform demand', incorporate more measures to improve energy efficiency and reduce demand for energy services, resulting in reductions in energy demand of 41 % and 52 % respectively, with the 'transform demand' scenario including the more ambitious goals. The complete scenario assumptions are presented in Barrett et al (2021) and its more detailed sectoral reports, Brand et al (2021) and Norman et al (2021).

In this paper, we use the descriptions of changes of drivers of energy demand set out in the 'shift' and 'transform' scenarios. We split our analysis of policies according to three broad energy use sectors, i.e. buildings, mobility, and materials and products. In the following sub-sections, the principal changes from Barrett et al, 2021 are set out briefly in the first column of Tables 1 to 3. The contribution of this paper is to identify the key policy instruments that might be used to deliver the changes assumed in the scenarios. We do this using the framework set out above and the literature on more detailed energy demand policies. The findings are presented in the second column of each of the tables and identify the likely main policies. The remainder of each sub-section provides a more discursive description of the policy instruments.

### BUILDINGS

Buildings have been a key sector targeted by energy efficiency policy instruments in the past. National building codes facilitated in Europe through the Energy Performance of Buildings Directive have been an important vehicle to drive energy performance improvements in new buildings and to a lesser extend also in existing buildings (Sunderland and Santini 2021). Regulation of energy-using appliances has been and continues to be a key driver of energy efficiency improvements (IEA 2021b). A large number of financial support programmes in the form of grants, tax rebates, loans, Energy Efficiency Obligations and auctions have been implemented to support energy efficiency improvements in buildings through fabric insulation as well as lighting, appliance and heating system efficiency improvements (Rosenow et al. 2017).

All of these programmes will continue to play an important role for decarbonising buildings to the levels needed for zero emissions. However, significant adjustments to existing policies will be needed:

First, building codes will need to not only require new buildings to achieve zero emissions performance but also increasingly push the housing stock towards the same level. Forthcoming reform of the Energy Performance of Buildings Directive through the addition of minimum energy performance standards (MEPS) for all existing homes can play a key role here but current proposals fall short of setting out sufficient levels of ambition aiming only to upgrade all buildings currently rated 'F' and 'G' to higher levels (European Commission 2021).

Second, regulation and financial support to encourage more efficient appliances need to be fundamentally revised. At the moment, many programmes and regulations encourage or require appliances using fossil fuels to be more efficient. Whilst this has delivered significant carbon reduction over the last decades going forward the aim needs to be to both improve efficiency and reduce carbon emissions to zero. This means that financial support of fossil fuel appliances even if more efficient will need to be discontinued and regulation should gradually phase out fossil fuel-using equipment rather than simply require higher efficiency.

Third, policies aimed at energy efficiency and policies aimed at switching to renewable energy sources at building level need to be much better integrated and mutually reinforce each other.

Finally, embodied carbon emissions have largely been ignored or treated outside of traditional policy instruments to encourage building decarbonisation. It will increasingly be important to address these (see discussion under *Materials and products* below).

**Table 1. Principal policy instruments for buildings.**

| Scenario Change | Primary Policy Area(s) |
|---|---|
| ***Improved efficiency of building components and appliances*** | |
| Building fabric improvements | Financial support programmes; national building regulations |
| Installation of heat pumps | Building regulations; financial support programmes |
| Switch to hydrogen or syngas in hybrid systems | Building regulations |
| Phasing out gas boilers in existing buildings | Building regulations; financial support programmes |
| No gas boilers in new buildings | Building regulations |
| Gas hobs and ovens are phased out by 2035 | Product standards; financial support programmes |
| 10% efficiency savings in electric hobs and ovens by 2030 | Product standards |
| Incandescent sales are phased out by 2025 (out of use by 2027) | Product standards; existing trend |
| Fluorescent sales are phased out by 2030 (out of use by 2035) | Product standards; existing trend |
| 5% efficiency improvements in LED technology by 2025 | Product standards |
| Adoption of more energy efficiency appliances | Product standards |
| Continuous installation of on-site renewable energy generation | Financial support programmes |
| Embodied carbon emissions are considered in retrofit | Building regulations |
| ***Additional measures in non-residential buildings*** | |
| New build dwelling construction is replaced by repurposing non-domestic energy space | Energy retrofit taxation; repurposing building use legislation |
| Increase practice of homeworking | Existing trend, employment legislation |
| Switch to a 4-day working practice | Employment legislation |
| Smart systems ensure that buildings are heated only as needed | Investment incentives |
| Reduce office space | User incentives; public investment |
| Smart meter rollout | Regulation; public investment |
| More regular maintenance of air-conditioning units | Information campaigns |
| Automation of building management controls | Regulation; public investment |
| Reduction of total number of appliances | Public investment |

There are additional considerations in non-residential buildings. Key measures to reduce demand include energy management systems, building retrofits, building system control, ventilation and cooling, and more efficient appliances. A range of commercial business models and intermediary organisations specialise on energy service and performance contracts involving one or more of the key measures which can help transform energy efficiency in the non-residential buildings sector into a commercial opportunity (Nolden et al. 2016).

### MOBILITY

Light vehicle efficiency improvements have historically been delivered principally by continental-scale product standards, typically applied as manufacturer corporate average, such as Corporate Average Fuel Efficiency standards in the USA (Greene et al, 2020) and $CO_2$ Performance Standards (Regulation 2019/631 and its predecessors) in the EU (Paltsev et al, 2018). These can continue to be the main driver of efficiency. Forthcoming requirements for zero-carbon emissions (at the point of use) will principally result in a shift to battery electric vehicles (BEV), which are typically three times more energy efficient than internal combustion engine (ICE) vehicles. The policy framework for net-zero is therefore, itself, a major driver of efficiency improvement. However, it will be important to retain use of efficiency standards for new vehicles, not just before electrification, but also subsequently to ensure adoption of BEVs that are efficient, as inefficient BEVs will drive up electricity use unnecessarily, increasing consumer costs and slowing the speed of electricity sector decarbonisation. Standards will also be important in vehicle charging technology to enable inter-operability.

Efficient vehicle technology standards can be supported by national taxation policy. Substantial taxes for liquid road fuels already form an important component of vehicle efficiency policy in many countries. As well as driving efficiency, these raise government revenues, which are therefore threatened by the shift to electricity as the main transport fuel. Differential vehicle taxation can be a useful alternative, at the point of first vehicle registration and/or in use licensing. This can provide incentives to purchase more efficient vehicles, but do not address the other important impact of fuel taxation – the incentive to use private road vehicles. This can be addressed by wider use of taxation proportional to vehicle use (road use taxation), which has traditionally been used only to disincentivise car use in major cities (congestion charging).

The shift to zero-carbon vehicles has important infrastructure implications for both vehicle charging/refuelling and the wider supply system. In the first instance the challenges will be to provide widely accessible electric charging and electricity distribution network strengthening. In the longer-term similar measures will be needed for hydrogen for heavy vehicles. In both cases, infrastructure investment is required in advance of user need. This will require active policy, as existing infrastructure providers are largely downstream subsidiaries of oil companies with a direct interest in slowing the transition. Infrastructure investment will also form a key part of the measures need to drive to the transition to lower energy modes of transport, i.e. mass transit, cycling and walking. Disinvestment will also be needed in new roads and airport capacity.

Transport planning is also central to modal shift, as it provides the framework for aligning use of existing infrastructure with social and environmental goals, through policies such as reallocation of road space (for trams, buses, cycles and pedestrians), speed limits, low emissions zones and low traffic neighbourhoods. Vehicle and road use taxation can support the same goals. In general, especially where public transport provision has been marketised, greater coordination and planning will be needed to move towards more sustainable systems.

Policies to incentivise travel demand reduction represent a challenge that has largely not been addressed, and therefore policy experience, other than fuel taxation, is more limited. It is particularly important for aviation, where fuel taxation has been hampered by international agreements. Taxation of aircraft movements, distance travelled and aircraft use are options that can be used, and there is growing interest in the use of progressive taxation via frequent flyer levies (Larsson et al, 2019). In other transport sectors, land use planning change can play an important role in reducing the need to travel, for example by supporting urban densification and the provision of local services, e.g. in '15 minute neighbourhoods'. In some cases, there is the opportunity to encourage and build on existing travel-reducing, social trends, e.g. in e-commuting, e-retail, and aiming to 'lock-in' some pandemic driven travel changes (Marsden et al, 2021).

#### MATERIALS AND PRODUCTS

Materials and products are the outputs of industry and drive the demand for its energy use. A more traditional framing is "industrial energy demand", but this tends to exclude options that go beyond improvements in industrial energy efficiency.

Table 2. Principal policy instruments for net-zero mobility.

| Scenario Change | Primary Policy Area(s) |
|---|---|
| ***Improved vehicle efficiency measures*** | |
| Phase out of ICE, PHEV and HEV cars from 2025 | Product standards; vehicle taxation, fuel taxation; road use taxation |
| Buses and taxis all electric by 2030 | Product standards; local licensing |
| New light commercial vehicle all electric from 2030 | Product standards; vehicle taxation |
| Standardised electric charging infrastructure | Product standards |
| Accessible electric charging infrastructure | Public investment; investment incentives |
| ***Modal shift measures*** | |
| Investment in public transport, walking and cycling | Public investment; transport planning |
| No more major road or airport infrastructure | Public investment; strategic planning |
| Increased rail capacity | Public investment |
| Integrated transport planning in every city and region | Transport governance; land use planning; road use taxation |
| Freight consolidation centres in cities and major towns. | Investment incentives; transport planning |
| Increased utilisation of car fleet/ lower car ownership | Vehicle taxation; transport planning |
| Disincentives for single occupancy car use, household multicar ownership and high use of cars | Vehicle taxation; fuel taxation; transport planning; |
| Bus and taxi use increased | Vehicle taxation; fuel taxation; transport planning |
| Increase in light commercial vehicle due to more online shopping | Existing trend; vehicle and fuel taxation; transport planning |
| ***Transport demand reduction measures*** | |
| No more development on greenfield sites | National and local land use planning |
| Reduced demand for aviation driven by increased public awareness and higher costs | Aviation taxation; fuel taxation; airport policy |
| 10% reduction in commuting trips per person by 2030 (due to four-day working week and teleworking) | Existing trend; employment legislation |
| Reduced business travel due to greater reliance on video-conferencing | Existing trend; vehicle and fuel taxation |
| Increased load factors for road freight through improved logistics | Existing trend; vehicle and fuel taxation |

The framing of "materials and products" allows for both energy efficiency options and alternative ways to deliver the same service to be considered, including efficient use of materials by industry, material substitution to lower energy alternatives, increased product longevity and, most fundamentally, the role of material consumption in delivering societal goals. The low-energy demand scenarios therefore consider policies that incentivise the optimal use of materials and products as well as opportunities to improve energy efficiency. Resource efficiency strategies reduce the required output of materials and products. Energy efficiency strategies reduce the energy demand to produce each unit of output.

While there is a diversity in policy responses across different energy services, there is further variation across different products. Some products spend very little time in circulation, like packaging and some items of clothes, for example, while buildings and cars are in use for considerably longer. They require very different policy options to deliver reductions in energy demand. Table 3 lists the scenario change and the associated primary policy to deliver this change. These are organised around the main product groups that were considered, namely clothing and textiles, packaging, vehicles, electronics, appliances and machinery, furniture and buildings and infrastructure.

Taxation and pricing have played a small role in the proposed policy measures for a few important reasons. These include inelastic nature in prices of materials, barriers to implementation, concerns over international competitiveness and the complex nature of border carbon adjustments. Instead, broader options that sit outside the framing of industrial energy efficiency offer the most significant gains. These broader changes rely more on product standards, consumer rights, building regulations and planning as well as the use of public infrastructure investment, the promotion of new service-based business models and tax breaks where appropriate. A barrier to the implementation of industry-based mitigation policies is the additional costs placed on domestic firms that may not be replicated in other countries, thus creating a competitive advantage to others. To overcome this, border carbon adjustments are often considered to ensure a level playing field. While they are difficult to implement, they do alleviate fears of cheap high carbon imports replacing local firms.

In the more ambitious "transform" scenario, the majority of energy demand reductions do not occur from traditional framings of industrial energy efficiency, which only represent ~20 % of the total. In part, this is due to the fact that many of the efficiency options, particularly in the energy intensive

Table 3. Principal policy instruments for net-zero materials and products.

| **Scenario Change** | **Primary Policy Area(s)** |
|---|---|
| ***Textiles and clothing*** | |
| Increase recycling rates of textiles | Public infrastructure funding of national recycling facilities; requirements to collect textiles |
| Reduce supply chain waste through efficiency improvement in production, dyeing and finishing | |
| Productivity longevity through increased durability of clothing and influencing psychological obsolescence | Product standards and legally bindings extended warranties |
| ***Vehicles*** | |
| Reduce steel without material or alloy changes | Product standards related to maximum embodied energy per vehicles; EPC extended to full vehicle life |
| Increase in recycling rates of vehicles | Public investment in EAF; material standards for recycling related to separation |
| Additional weight saving of car bodies | Product standards related to maximum embodied energy per vehicles; EPC extended to full vehicle life |
| Steel fabrication yield improvement in cars | Product standards related to maximum embodied energy per vehicles; EPC extended to full vehicle life |
| Vehicle light-weighting | Variable rates of vehicle taxation based on weight and energy use |
| Car clubs | VAT reductions; public investment |
| Using cars for longer | Switch to electric vehicles brought forward |
| ***Electronics and appliances*** | |
| Remanufacturing electronics and computers to reduce material input | Public investment in repair centres; tax incentives for repair; right to repair through consumer protection law |
| Service models to increase durability of products | VAT exemption |
| ***Construction*** | |
| Light-weighting of building | Embodied energy requirements in building regulation |
| More efficient use of existing capital | Planning rules |
| Reduction in road building | Public investment |

sectors, have already been realised. The 80 % reduction derives from the conversion efficiency benefits of electrification (electric cars lasting longer for example) but mainly relate to broader changes in societies' use of materials and products and the ability to optimise their use.

#### CROSS-CUTTING POLICIES

The sub-sections above show that different policy instruments are needed in different sectors. Regulation and financial incentives are recurring themes, but the way they are implemented needs to reflect sectoral differences. Our general conclusions on these issues are summarised in the next section.

Energy efficiency obligations are a major cross-sectoral policy tool in a large number of jurisdictions, and this is likely to remain true (Fawcett et al, 2019). However, the wide range of changes necessary, including actors needing to be engaged from outside the energy sector, means they are not a panacea.

The usual third pillar of energy demand reduction packages, with regulation and incentives, is user information programmes, although labelling and targeted advice has been at least as important as generic provision of information. The complexity, scale and pace of change required, means these areas will grow in importance. Change will depend not just on knowledge and information, but on the capacity to adapt. Engagement will be needed too, through mechanisms such as citizens assemblies.

Innovation policy will also be important to support the improvement and deployment of not just of energy efficiency technologies, but also the wider set of technical changes, such as flexible demand and decarbonised energy vectors. Innovation policies will also need to incorporate non-technical changes, for example new business models to deliver the lower demand approaches of the sharing economy and circular economy.

## Discussion and Conclusions

Our analysis shows that there is no straightforward answer to the question "What national policy interventions will be needed to deliver the changes in energy use implied by the goals of the Paris Agreement?", given the variety of different energy uses. A systemic change is needed in energy systems, with major implications for energy use. Both energy efficiency improvement and shifts to less energy-intensive practices will be needed. There is no 'silver bullet' policy. Whilst there are some cross-cutting policy instruments, e.g. carbon pricing and education, most are more focussed, and therefore policy needs to be granular. Many different policies instruments will be needed: some as extensions of existing policies, but some wholly new approaches.

Standards have been critical in driving energy demand reductions historically. Our analysis indicates that this will remain true, but that the scope and design of these standards will need to change. Standards for products, buildings and vehicles will still need to drive continuous energy efficiency improvement. However, they will also have an important role in driving changes to zero-carbon energy vectors, through mandated phase-outs of fossil-fuel using technology, particularly in heating systems and vehicles. As these changes occur, standards for buildings, vehicles and products will need to move towards being denominated in energy, as carbon becomes a decreasingly useful metric as zero-carbon energy systems are approached. In this context, the key role of energy efficiency will be to drive down demand and energy system costs. Standards will also need to broaden their scope to cover whole life cycle energy use, including embodied energy, and will have a key role in driving retrofit of buildings.

Financial incentives will also play an important role. These can be delivered through any or all of fiscal policy (differential tax rates), grant programmes and energy sector regulation (e.g. energy efficiency obligations, feed-in tariffs, auctions etc). This provides policymakers with some freedom to select on the basis of equity concerns, public budget pressures and political preferences. Incentives can help to promote fuel switching in advance of regulation and to scale-up niche innovations. Where fiscal policy is the chosen route, policies can include disincentives. These may be very helpful in addressing services associated with high consumption, e.g. through meat taxes, frequent flyer levies and road vehicle use taxes. The scale of investment in end-use systems will need to increase. The balance between public and private 'green finance' to achieve this will be largely a matter of political choice. At current interest rates, there is no shortage of finance; the task is to redirect finance from high-carbon energy supply to low-energy end-use systems.

In some discussions of climate policy, it is assumed that a uniform carbon price will be economically efficient and should be implemented. This has long been known to be a huge over-simplification with respect to energy demand reduction. In practice, standards and targeted policies to reduce demand and incentivise renewables have always delivered more. Our analysis indicates that, especially given the challenge of rapid and transformative change, standards that require a shift to zero-carbon vectors will be critical. In this context, carbon pricing can help during the transition to disincentivise use of fossil fuels, but carbon pricing alone, at any socially acceptable level, will be inadequate to deliver change at the required rate. Pricing mechanisms should be thought of as secondary instruments of a zero-carbon energy policy, and key design issues will be the social acceptability of different pricing policy instruments. Equity issues will be critical. Some energy service demands, notably aviation, are very unequally distributed across the population, making socially just and environmental policies relatively easy to align. In other cases, notably thermal comfort, needs are more equal and pricing policies can be inequitable and unpopular. Carbon pricing will have different levels of effectiveness and social acceptability in different sectors, depending largely on opportunities for fuel switching and demand reduction. High taxation of frequent fliers and low taxation of fuels for low-income households and manufacturing industry are not necessarily inconsistent.

Information instruments are often treated as secondary to regulatory and financial instruments, but are usually a critical part of policy packages. Labelling is critical as it has multiple roles in providing user information and the framework for standards and fiscal measures. Information instruments have usually been thought of as 'correcting' the barrier of inadequate user information. In the context of rapid change, these need to be rethought to deliver much stronger public engagement. Social and cultural norms that underpin public engagement cannot be changed instantaneously, but policies can incrementally shape such norms. Persuading individuals, households and businesses one at a time is not a credible approach. Low-carbon community development may be a better way to think about what is needed, as it can create knowledge exchange mechanisms, which can become self-sustaining after initial investment (Bobrova et al., 2022). These ideas are, however, not fully-developed either conceptually or in practice.

Policy packages need to address the energy services used, as well as the efficiency of energy use. To some extent, this can be done by extending the scope of the types of policy packages that have been used to advance energy efficiency. They require changes to whole systems (e.g. towards public transport, low-energy materials and plant-based diets) with much wider implications – disruptive regime change, not just the expansion of new, more efficient, niches within existing regimes. Significant infrastructure change is needed, but also changes to social and working practices, with implications for employment, skills and investment. This scale of change will involve thinking 'outside the box' of what is usually considered energy policy. Zero-carbon energy systems will need policy changes in land use planning, transport, employment, training, innovation and the economy as well. This agenda is therefore complex and clearly not yet adequately developed. But one over-arching feature is clear. Zero-carbon energy systems are needed because a stable global climate is a critical public good. So, zero-carbon policy should not be thought of as an 'optional add-on' in these 'non-energy' policy domains, but rather as an essential constraint on policy development.

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