

Should public policy support disruptive consumer innovations for climate change?

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Abstract

Digitalisation, decentralisation, technological and business-model innovation, and shifting generational norms of consumption are transforming mobility, food provision, domestic comfort and residential energy services. Disruptive innovations shake up established consumption practices by providing consumers with new and appealing value propositions. Disruptive consumer innovations range from shared, on-demand electric mobility and peer-to-peer trading of electricity, food and cars, to grid-responsive smart appliances, lights and boilers. Although currently at the fringes of mainstream markets, these disruptive consumer innovations have the potential to reduce CO₂ emissions if adopted at scale.

Given the potential public-goods benefit of disruptive consumer innovations, this paper explores the role of public policy in supporting, restricting or remaining agnostic towards disruptive processes. Policymakers face a trade-off between maintaining stability and driving rapid system-transformation to address climate change. Regulatory frameworks designed to ensure system reliability, continuity and affordability may create barriers to disruptive new entrants who can potentially deliver rapid emission reductions. The paper concludes by setting out conditions under which public policy for disruptive consumer innovations is both necessary and appropriate as part of broader efforts to mitigate climate change.

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1. Disruptive consumer innovations for climate change

'Disruptive innovation' provides a useful framing for how consumers can rapidly reshape the way firms and markets provide goods and services. The term originates in Clayton Christensen's 1997 book, 'The Innovator's Dilemma' (Christensen 1997). According to Christensen, disruptive innovations are remarkable for being uncompetitive on conventional attributes valued by mainstream consumers (such as price, reliability, performance). Instead they offer potential adopters a wholly new set of attributes. If successful, they effectively create a new market with a new set of demands and preferences. In the process they disrupt the business models of incumbent firms. Historical examples given by Christensen include the microcomputer (disrupting the mainframe computing industry), desktop photocopiers (vs. giant Xerox copy machines), digital photography (vs. film), mobile telephones (vs. landline services), transistors (vs. vacuum tubes), and discount retailing (vs. department stores) (Christensen 2013; Christensen 1997).

There are many different dimensions to disruptive innovation theory and its subsequent interpretation and application (Christensen 1997; Govindarajan and Kopalle 2006; Lambert 2014). Here we are interested in one particular emphasis: *novel attributes offering distinctive value propositions to consumers*. These value propositions typically combine both technological and business model innovations. Although Christensen was concerned only with low-end, lower-tech 'good enough' alternatives to mainstream goods and services, disruptive innovation concepts are now commonly applied to high-end, high-tech sources of novelty as well (Table 1).¹

Table 1. Characteristics and definitions of disruptive innovations. Notes: yes = strongly emphasised or relevant; (yes) = weakly emphasised or relevant; no = not emphasised or relevant. Source: (Wilson et al. 2019).

	disruptive innovation	disruptive innovation for climate change
novel application of knowledge (i.e., innovation)	yes	yes
initially attractive in a market niche then performance improves	yes	(yes)
disrupts incumbent firms and markets	yes	(yes)
combines technological & business model innovation to create value	yes	yes
offers novel product or service attributes to consumers or end-users	(yes)	yes
appeals to low-end market & price-sensitive users or non-users	yes ^a	(yes)
simple, low-tech alternatives to over-performing mainstream goods	yes ^a	(yes)
appeals to high-end market & price-insensitive technophile users	yes ^b	(yes)
radical technological breakthroughs which improve exponentially	yes ^b	(yes)
reduces greenhouse gas emissions if adopted at scale	no	yes
disrupts high-carbon practices, and associated infrastructures and firms	no	yes
requires supportive policy or regulatory environment	no	(yes)

Notes: ^a Christensen's original definition of disruptive innovation, e.g.: (Christensen 2014; Christensen 1997; Govindarajan and Kopalle 2006; Lambert 2014); ^b Silicon Valley 'addition' to Christensen's concepts, e.g.: (Arbib and Seba 2017; Seba 2014).

¹ Christensen defined disruptive innovations as low-end, low-tech goods and services attractive to users marginalised by mainstream goods and services. This has since been challenged by a 'Silicon Valley' argument that disruption can and does *also* come from above (Arbib and Seba 2017). High-end and typically high-tech products with more capabilities and functionality than mainstream alternatives appeal initially to a price-insensitive or technophile market niche (Seba 2014). But exponentially declining costs and exponentially improving performance mean these high-end products rapidly outcompete incumbents and move mainstream. The debate between these two perspectives crystallises around Tesla, the poster child of disruption to the auto industry. But Christensen has argued that Tesla is *not* disruptive (Christensen 2014).

Applying disruptive innovation concepts in the contest of climate change also means factoring in potential emission reductions resulting from widespread adoption. Disruptive consumer innovations for climate change therefore combine an emphasis on private benefits for consumers (novel attributes and value) with social benefits or public goods (lower emissions) (Wilson 2018). Whether this public-goods characteristic warrants public policy intervention is the focus of this paper.

In sum, we define disruptive consumer innovations for climate change as:
technological and business model innovations which offer novel value propositions to consumers and which can reduce greenhouse gas emissions if adopted at scale.

Our interest in disruptive *consumer* innovations shifts the object of disruption from incumbent firms and markets (the main concern of disruptive innovation theory) to mainstream consumption practices. Our interest in *climate change* further narrows the object of disruption down to mainstream consumption practices in the four major domains of consumer activity associated with greenhouse gas emissions: transport, food, homes, and energy (Table 2).

Table 2. Objects of disruption in four domains of high-emission consumption activity.

		[transport]	[food]	[homes]	[energy]
disruption to:	consumption practices	private car use	supermarkets food shops	manual controls whenever	use of energy however whenever
	firms, service providers	dealers, garages, automakers	large retailers & suppliers	(non-ICT) equipment manufacturers	centralised utilities
	markets, regulation	taxation	competition	data & privacy	grid access
	infrastructure, norms	parking, low-intensity transit	high streets, land use	boundaries of home	T&D network, large-scale supply

In earlier work we used a combination of literature review and expert survey to identify a range of disruptive consumer innovations which can potentially reduce greenhouse gas emissions if adopted at scale (Wilson 2018; Wilson et al. 2019). These are summarised in Table 3. Full descriptions and explanations of this set of innovations are given in (Wilson et al. 2019). They include both technological and business model innovations, and most commonly, combinations of both. They vary widely in their specificity, application, familiarity, cost, and accessibility. But beneath this variety are several common themes: decentralisation, digitalisation, decentralisation, and diversification of user roles.

Rates of technological improvements in small-scale, low unit cost, modular technologies from PV panels and batteries to chips and sensors show no sign of slowing (Farmer and Lafond 2016). Transportation and electricity systems are rapidly digitalising as electrons and bits are entering the historical realm of hydrocarbons (Freeman et al. 2017). The combination of electrification, digitalisation, and decentralisation are disrupting traditional modes of passive 'end-of-wires' consumption of electricity, gas, transport whenever needed (without regard to system functioning). Traditionally centralised energy infrastructures and utility service providers are being eroded away at the edges (Fares and Webber 2017). Passive energy consumers are diversifying into new roles of producer, citizen, activist, designer, community member, advocate (Schot et al. 2016). Digitally-enabled peer-to-peer and other sharing-economy platforms are raising 'usership' as an alternative to single-purpose ownership (Frenken 2017).

Disruptive consumer innovations play in these turbulent waters. Secular trends towards more digital, granular, use-based models of energy-service provision have opened up new value propositions for consumers with potential benefits for emission reductions.

Table 3. Potentially disruptive consumer innovations for climate change in four domains of high-emission consumption activity. Notes: P2P = peer-to-peer; IoT = internet of things; VR = virtual reality.

[transport]	[food]	[homes]	[energy]
Car clubs (or car-sharing in US)	Digital hubs for local food	Smart heating systems	Domestic electricity generation with storage
Peer-to-peer (P2P) car-sharing	Meal kits (or meal boxes)	Smart lighting	P2P electricity trading
Ride-sharing (or carpooling in US)	11th hour apps	Smart home appliances & IoT	Electric vehicle-to-grid
Shared taxis (also taxi-buses)	Food-pairing apps	Home energy management systems	Time-of-use pricing
Mobility-as-a-service (MaaS)	Food sharing	Heat pumps	Demand response
Electric vehicles (EVs)	Dietary change gamification	Pre-fab whole home retrofits	Energy service companies (ESCOs)
E-bikes	Food waste reduction nudges	P2P exchange of goods	Third-party financing
Autonomous vehicles	Urban farming (e.g., rooftop, vertical, modular)	Disaggregated real-time energy feedback	Community energy
Bike-sharing	Cultured meat		
Telecommuting, virtual meetings, VR interaction			
vs. mainstream	vs. mainstream	vs. mainstream	vs. mainstream
<i>owning & driving a car (often single occupancy)</i>	<i>doing big food shops in a supermarket</i>	<i>manually controlling devices whenever needed</i>	<i>using centrally-supplied energy whenever needed</i>

Figure 1 represents many of these innovations in icon form to emphasise digitalisation and service-based business models as common themes. Figure 1 also highlights the mainstream consumption practice to which the innovations pose a disruptive threat.

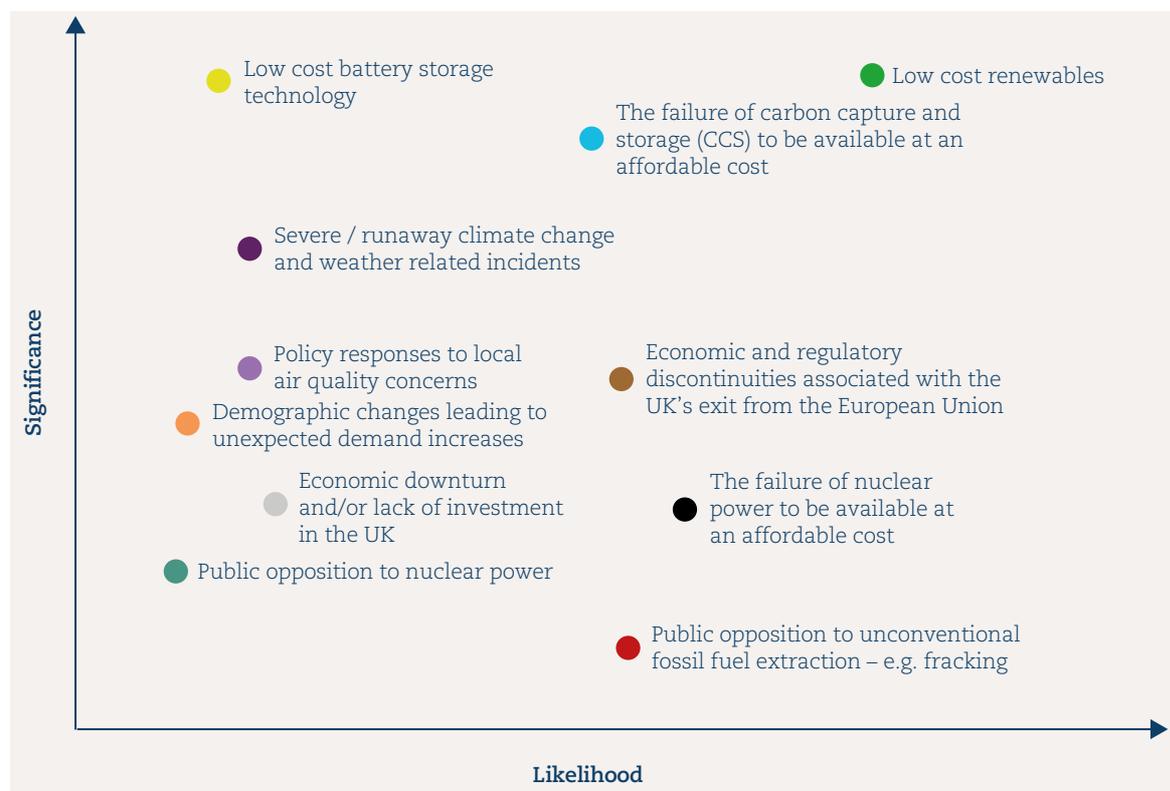
Figure 1. Examples of disruptive consumer innovations in transport (blue), food (green), homes (red) and energy (yellow) with potential to disrupt mainstream consumption practices (shown on the left).



Although our emphasis here is on mainstream consumption practices, it is important to reemphasise that there are many other forms and objects of disruption. Disruptive innovation can impact incumbent firms, markets and regulatory environments, as well physical infrastructures (like electricity grids or transport networks) and meso-level social structures (like norms, expectations and consumer culture) (Table 2).

A recent study by a team of researchers at the UK Energy Research Centre (UKERC) examined whether and how established technologies, markets and business models were being disrupted (UKERC 2019). They loosely defined disruptive change as significant deviations from past trends in a relatively short space of time and with large magnitude impacts on incumbent actors. Using responses from a survey of around 130 experts, they identified the most likely forms of disruptive shocks in the energy system (Winskel and Kattirtzi 2019). These emphasised technological breakthroughs (exponentially declining cost trajectories) and geopolitical upheavals (Figure 2). In contrast, consumption practices and consumer behaviour were generally perceived as resistant to change, particularly with respect to domestic heat and public or shared transport modes.

Figure 2. Landscape changes and system shocks - most likely issues identified in an expert survey in the UK. Source: UKERC (2019).



2. Potential emission reductions from disruptive consumer innovations

Emission reduction potentials for specific consumer innovations have been quantified in both empirical studies as well as simulation and other modelling analysis. Here we provide select examples of this growing body of literature.

Transport: The International Transport Forum (ITF) evaluated city-scale impacts of new forms of mobility using an agent-based simulation model of Lisbon, Portugal, based on real mobility and network data. They found that a combination of *shared taxis and taxi-buses* (30 minute pre-book, flexible route) could use 3% of the existing car fleet to provide a flexible, cheap, available, comfortable alternative to private vehicle ownership and use, reducing CO₂ emissions by 34% and congestion to close to zero (ITF 2016). A separate study found that a fleet of *shared autonomous vehicles* comprising multiple passenger 'Taxibots' and single passenger 'Autovots' could use 10-20% of the existing vehicle fleet to provide a viable alternative to both private cars and buses, with commensurate benefits for freed-up road infrastructure (ITF 2015).

Transport: A study for the US by RethinkX found that autonomous electric vehicles providing mobility-as-a-service ('MaaS') could reduce the size of the car fleet by 2030 by over 75%, lower energy demand by 80% (although with an 18% rise in electricity demand, principally off-peak) and reduce CO₂ emissions by 90% (assuming a decarbonising grid) (Arbib and Seba 2017).

Food: Life cycle analysis of the environmental impacts of *cultured meat* grown in a bioreactor estimated 7-45% lower energy use and 78-96% lower greenhouse gas emissions

(including methane) relative to conventionally produced meat in Europe (Tuomisto and Teixeira de Mattos 2011).

Food: Vertical farming involves the provision of fresh food in and around towns and cities through greenhouses that use a fraction of the resources used by traditional farms. Drury (2017) found that greenhouse horticulture in urban farming contexts has the potential to reduce energy consumption by around 71% with resulting GHG emission savings.

Buildings & Energy: Shifting or curtailing energy use through *demand response* to utilities' price signals while accounting for household comfort found that *home energy management systems (HEMS)* could reduce electricity costs by 23% and peak demand by 30% with corresponding reductions in emissions (Beaudin and Zareipour 2015).

A comprehensive synthesis of emission reduction estimates across the full portfolio of disruptive consumer innovations shown in Table 3 is ongoing. As all these innovations were identified *because* they were cited in climate change-related literature, for the purposes of this paper we regard all of them as having *the potential* to contribute emission reductions.

3. Public policy and disruptive consumer innovations

In the context of climate change, policymakers face a trade-off between driving rapid system transformation to minimise adverse climate impacts, and minimising disruption of incumbent systems to ensure continuity in the provision of affordable, reliable goods and services to end users (also voters, citizens). This creates evident tension between public policy objectives and resulting strategies. The need for rapid emission reductions may favour open market access for low-carbon providers, accelerated experimentation, support for diversity and market heterogeneity, and discriminatory support for disruptive innovators. Yet the need for stability, certainty, and confidence may favour incremental trajectories of change, market rules protecting low-cost incumbents with large sunk investments, controlled and staged experimentation, and support for market structures which temper competition with returns to scale. Recognising this tension, the UKERC study referenced in Figure 2 distinguishes disruptive from continuity-based narratives of change (UKERC 2019).

This tension faced by public policy is also clearly seen in markets with regulators appointed to ensure competition in quasi-monopoly conditions (e.g., electricity, gas and water utilities operating singular physical infrastructures). Regulatory frameworks set out detailed rules, terms, conditions, and specifications to 'regulate' market access and behaviour in line with public policy goals and mandates, and consistent with relevant legislation. Regulators and their agencies have varying degrees of freedom in how these regulatory frameworks are designed, implemented and enforced.

As an example, the mandate of the UK electricity regulator, the Office of Gas and Electricity Markets (OFGEM) is to "protect the interests of existing and future electricity and gas consumers" by promoting value for money, security of supply, and sustainability for present and future generations of consumers, domestic and industrial users.² In so doing, OFGEM has faced criticism for prioritising system reliability and continuity in ways which create barriers to disruptive new entrants offering novel consumer value propositions.³

How should public policy manage trade-offs between the potentially beneficial and

² <https://www.ofgem.gov.uk/about-us/who-we-are>

³ <https://blog.tempusenergy.com/blog/2019/6/5/tempus-ceo-why-we-challenged-the-uk-capacity-market>

potentially adverse impacts of disruptive consumer innovations which - if adopted at scale - can challenge mainstream consumption practices and rapidly reduce greenhouse gas emissions?

There is no generalisable formula for how and where to strike a balance. Neither extreme is desirable - unqualified support for disruptors at the expense of incumbents, or vice versa. The approach taken here is twofold: first, to identify strategies for reducing potentially adverse impacts of disruption while allowing for potentially significant contributions to emissions reductions; and second, to identify conditions under which public policy can and should intervene in markets for disruptive consumer innovations.

3.1. Strategies for 'de-risking' disruptive consumer innovations

We identify the following strategies for 'de-risking' disruptive consumer innovations with the aim of maximising the potential for rapid emission reductions while minimising adverse impacts on different interest groups, from individuals up to nations:

- (1) demonstrate and trial innovations in protected market niches to enable policy learning while limiting disruptive impacts;
- (2) engage with 'losers' of disruptive processes to reduce resistance to change and ensure more equitable distribution of transitional benefits and costs;
- (3) ensure diversity of disruptive innovators, processes, goods & services to avoid premature lock-in to a new form of incumbency;
- (4) direct market activity to incentivise disruptive consumer innovations which contribute to public policy goals for emission reductions.

We address each of these in turn.

3.1.1. Demonstration programmes, field trials, regulatory sandboxes, and other protected market niches enable policy learning on the outcomes of disruptive consumer innovations while limiting potentially adverse systemic impacts.

Demonstration is a distinct stage in the technology lifecycle between pre-commercial research and development (R&D), and commercial diffusion (Gallagher et al. 2012). In general terms demonstration helps technologies cross the 'valley of death' between the controlled environments of R&D lab and testing facilities, and the full force of market competition. Demonstration and trials allow new ideas, technologies or business models to be tested before making large-scale commitments with high sunk costs.

In the socio-technical change literature, demonstration is linked to niches which are spaces or contexts protected from mainstream market rules, firms, competition and political interests (Smith and Raven 2012). Market niches allow innovators to test business models or technologies in a commercial setting approximating real world conditions, and so learn about user preferences, improve technical performance, build political support, align business models with regulatory requirements.

Publicly-funded demonstration programmes for energy-supply innovations test the

commercial viability and system integration of new technologies like carbon capture and storage (CCS) with potential public good benefits including CO₂ emission reductions (Åhman et al. 2018). Demonstration of energy-supply innovations also commonly support up-scaling in size or complexity to capture available scale economies (Wilson 2012).

Demonstration programmes more relevant to disruptive consumer innovations are neighbourhood or city-scale trials. These have a wide range of forms, and may be designed to trial: (1) new organisations or business models, such as municipal aggregators to increase the market power of households seeking energy-efficient retrofits, or surplus food collection and storage points to support food waste reduction; (2) new infrastructures, such as EV charging points, or street banks for informal exchange of tools and products (Cooper and Timmer 2015); (3) new user roles, such as peer-to-peer electricity trading from distributed generation and storage (e.g., Brixton Solar Energy⁴); (4) new rules or conditions, such as car-free days in cities restricting vehicle users' access to road infrastructure.

These area-based trials are often incentivised or supported financially by central government in line with public policy objectives. As current examples in the UK, the Department for Business, Energy and Industrial Strategy (BEIS) is funding a £102.5m demonstration programme for smart, local energy systems⁵ consistent with the UK's Industrial Strategy, and the Department for Transport (DFT) is funding a £90m demonstration programme for future mobility zones⁶ as part of a transforming cities initiative, again in line with the UK's Industrial Strategy. Central funding of area-based trials faces a trade-off between effectiveness (targeting areas with high adoption propensity) and fairness (targeting areas with low adoption capacity) (Morton et al. 2018).

Publicly-backed demonstration programmes may also be explicitly designed to test and support new policy instruments seeking to transform mainstream consumption practices. In 2013, the UK Department for Energy and Climate Change (DECC) introduced a new 'Green Deal' scheme providing pay-as-you-go financing for energy-efficient retrofit measures (Pettifor et al. 2015). It also funded three different demonstration programmes for cities and neighbourhoods testing strategies for boosting engagement with the Green Deal (Morton et al. 2018).⁷

Publicly-funded demonstration programmes are designed to support policy learning on financial, technical, and social viability of new ideas, business models, and technologies in market environments. Regulatory sandboxes are a particular type of demonstration programme designed to support policy learning on the regulatory viability of disruptive innovations, recognising that regulations can be slow to adapt to changing technological and institutional possibilities.

Market access for disruptive innovators can also be restricted by regulatory frameworks designed around incumbent practices and continuity. The co-evolutionary alignment between regulations and incumbent interests is one of the causes of lock-in, a phenomenon which describes inertia and resistance to change in complex socio-technical systems (Seto

⁴ <https://www.smart-energy.com/industry-sectors/distributed-generation/edf-launches-blockchain-p2p-solar-and-storage-trading-pilot/>

⁵ <https://www.ukri.org/innovation/industrial-strategy-challenge-fund/prospering-from-the-energy-revolution/>

⁶ <https://www.gov.uk/government/publications/future-mobility-zones-fund-competition-process>

⁷ The £10m Pioneer Places programme promoted local Green Deal strategies targeting high adoption-propensity households while establishing networks and partnerships to stimulate market activity. The £88m Green Deal Communities programme provided direct assistance to 32,000 households participating in the Green Deal on a street-by-street basis. The £12m Core Cities programme targeted promote residential retrofits in entire communities, focusing on less advantaged urban settings outside London.

et al. 2016; Unruh 2000). Electricity and gas markets provide a good example relevant to climate change. Through the 20th century, regulatory frameworks aligned with the business models of large (or monopoly) utilities managing centralised generation on hub-to-spoke networks sending electricity and gas out down wires and pipes to provide for end-users' demand (Hughes 1983). 21st century regulatory frameworks face a variety of disruptive challenges to this *status quo*. In particular the technical and economic viability of highly distributed and intermittent renewable supply is providing 'edge-of-grid' competition to the centralised incumbents (Graffy and Kihm 2014). Regulatory frameworks designed around industrial and commercial competences (e.g., with specialist legal and finance departments) also struggle to accommodate new entrant energy suppliers, producers and traders which increasingly include small firms and households (Schot et al. 2016).

Regulatory sandboxes in the electricity and gas markets allow disruptive innovators to apply for specific regulatory barriers to be relaxed so they can trial their new business models with real customers (see Box 1 on Regulatory Sandboxes). Regulators learn about how they impact markets, infrastructures, and regulatory stability while innovators learn about user response, appeal, and business model viability.

Box 1. Regulatory Sandboxes.

(Note: This box draws heavily on a 'DSM University' webinar hosted by the European Copper Institute on 27 June 2019 by Alexandra Schneiders from University College London. The webinar and accompanying slides are available here: www.dsmu.org)

Regulatory sandboxes allow mutual learning between regulators and disruptive innovators on both the market performance of the innovation and its implications for regulatory frameworks. As an institutional innovation, sandboxes were originally developed in the financial services industry, before being adopted by energy market regulators. In both cases, sandboxes were a response to the recognition that regulatory frameworks struggled to keep pace with rapid technological change (especially digitalisation) opening up possibilities for disruptive business strategies.

In the UK, the Ofgem sandbox gives successful applicants a 2 year derogation from whichever regulatory rule is deemed to be a barrier to their business model. Findings are then made public (apart from commercially sensitive information). Other countries follow a similar basic model but with important variations in purpose and design (ISGAN 2019). In the Netherlands, derogations from specific electricity regulations last for up to 10 years and are mainly open to owners' associations & cooperatives on local distribution networks, providing access to up to 10,000 consumers to trial community-level initiatives. In Belgium, trials place a strong emphasis on consumer benefits through open data platforms. In Germany, trials support derogations from financial obligations such as balancing costs payable by intermittent renewable energy generators. In Singapore, public consultations are run after trials to inform decision-making on whether laws should be changed.

Regulatory sandboxes and area-based trials open up spaces for potentially disruptive consumer innovations to be tested in real world conditions while limiting potentially disruptive impacts on broader system functioning. If this testing process is successful, policymakers or regulators then face choices about whether to broaden support, remove regulatory barriers to further diffusion, and sustain adoption incentives ... or to make support more contingent, sustain regulatory barriers, and reduce or remove adoption incentives.

Demonstration does not remove these tensions but should help inform the assessment. However, demonstration also carries significant risks or issues:

(1) *Demonstration as political.* Area-based public funding of demonstration projects is commonly associated with 'pork-barrel politics' - a US term to denote the channeling of funds to support narrow political interests rather than policy or economic rationality (Nemet et al. 2018).

(2) *Demonstration as delay.* Faced with the urgency of widespread action on emission reductions, demonstration is associated with a wait-and-see approach which stifles rather than accelerates transformative change. The need for more (and more) demonstration also provides a narrative which can be co-opted by incumbent interests seeking to communicate their investment in change while delaying its effects.

(3) *Demonstration as unfair.* Those innovators selected for demonstration support gain significant advantage over rivals at a critical early stage of the competitive process in which disruptive ideas are being tested and winnowed out. This shifts competition from who is in the market to who is in the demonstrators. Access to demonstration project funding may itself create barriers to access if new entrants lack the requisite capacity to identify, apply, and conform with demonstration programme rules.

(4) *Demonstration as unhelpful.* Lengthy demonstration processes may not resolve technical and commercial uncertainties, or may throw up additional challenges. Disruptive impacts may only be identifiable if programmes are sustained for lengthy periods during which market and policy conditions may change. Demonstrations may not therefore constructively support long-term planning and decision-making.

3.1.2. Working constructively with firms, interest groups and organisations threatened by disruptive consumer innovations can help reduce transitional frictions and delays while improving distributional fairness.

Disruptive innovation theory was originally developed by Christensen to help explain why incumbent firms failed to anticipate disruptive threats to their market dominance (Christensen 1997). Firms failed to see these threats precisely and paradoxically because they were doing all the basics right: listening to their mainstream customers' needs, and improving their goods and services in response to those needs.

The political economics of disruptive innovations in these commercial contexts was of secondary importance - although Christensen's later work covered public services including health and education (Christensen et al. 2009; Christensen et al. 2008). However in a climate change context, political economics has become of paramount importance as one brake - or even the principal brake - on the ability of disruptive innovations to deliver rapid emission reductions (Geels 2014).

Powerful interests vested in fossil-fuel based energy, transport and food systems use diverse means to block, slow, resist, or co-opt progress on decarbonisation. The sowing of doubt, difficulty and disinformation by coal, oil and gas interests has echoes of tobacco industry strategies to resist progress on public health and harm reduction fifty years ago (Oreskes and Conway 2010). Major oil exporting nations in the Middle East benefit from massive resource rents yet in international climate negotiations argue for development assistance (e.g., from the global Green Climate Fund) while refusing to recognise scientific

assessments including the recent IPCC Special Report on Limiting Warming to 1.5°C.⁸

Whether countries, corporates, or communities, incumbents associated with mainstream consumption practices resist change for clear and evident reasons. They seek to sustain their business models and protect shareholder value (in the near-term at least). They seek to reduce transition costs and the diversion of internal resource away from core competences. And they don't (yet) face strong enough external pressure from consumers or shareholders or governments to motivate a major shift in business strategy. Even climate protesters and activists militating for change are inevitably complicit to some extent in the affordable, reliable, and convenient services delivered by an oil-based transportation system, a coal or gas-based electricity system, and banking, pension and insurance products dependent on the stock market havens of large blue chip energy corporates. (Eight of the ten largest companies in the world by revenue are energy majors or utilities).

Against this backdrop, more attention is now being paid to strategies for working effectively *with* incumbents as active agents in system transformation, rather than confrontationally against them.

While sympathies for well-resourced countries and corporates with a strong stake in fossil-fuel dominance may be thin, sympathies for people whose livelihoods will necessarily be curtailed by decarbonisation have broader support. The most salient examples are workers, communities and towns with identities and livelihoods inextricably linked to coal mining, unconventional oil, extractive and energy-intensive heavy industries, and forest clearance from agriculture. These places cover the world, from Athabasca and Silesia to the Appalachians and the Amazon.

Efforts to engage with large fossil fuel-dependent incumbents recognise their power and influence over political and market processes necessary for decarbonisation. In the language of socio-technical transitions, a 'reconfiguration' of the rules and relationships which constitute a dominant regime does not necessarily have to come at the expense of incumbent actors (Geels 2018). Former or current incumbents in the fossil fuel regime may take on active roles in developing, building, operating or selling new low-carbon goods and services. Volvo is investing heavily in car-sharing, Norway in vehicle electrification, GE in a range of low-carbon technologies, Shell and BP in biofuels and CCS (though with marked variations in emphasis over time), and utilities like Scottish Power in renewable and distributed generation (either in the main business, or in dedicated subdivisions or spinout companies). These strategies have mixed motives, ranging from hedging against future regulatory pressure and diversifying risks to testing out potential markets and business models. Inevitably they are also open to accusations of greenwashing a veneer of low-carbon respectability.

Efforts to engage with communities of people set to 'lose' out from low-carbon transitions are more concerned with distributional fairness and human welfare, while also recognising the indirect influence of affected communities on political processes. This can be direct in the form of lobbying and advocacy, or indirectly by legitimising narratives favouring the *status quo*. Disruption to specific communities, whether defined by interests or geographies, can be mitigated by a range of public policy initiatives and programmes: employment training, skills

⁸ In the June 2019 international climate change negotiations, Saudi Arabia led a coalition of oil producing nations (Kuwait, Russia, US) in blocking the Intergovernmental Panel on Climate Change (IPCC)'s 2018 Special Report on Limiting Warming to 1.5°C - which was commissioned by the international community as part of the 2015 Paris Agreement on Climate Change [e.g., <https://www.climatechangenews.com/2019/06/27/un-report-1-5c-blocked-climate-talks-saudi-arabia-disputes-science/>].

diversification, relocation, compensation, infrastructure investment, industrial policy (Johnstone and Kivimaa 2018). These are contemporary low-carbon variations of the managed transition approach of 'swords to ploughshares' initiatives following World War 2 (but with more ancient pacifist origins dating back to the Bible: "*they shall beat their swords into ploughshares, and their spears into pruning hooks: nation shall not lift up sword against nation, neither shall they learn war any more*" Isaiah 2: 3-4). The war this time is not between human tribes, but between humans and the climate system.

As well as targeted policy support to assist or engage with the 'losers' from disruptive consumer innovations for climate change, public policy can play a role in managing the rate of change. Disruption is distinguishable from change by its timing and timescale. Disruption implies rapid, abrupt, shock-ing, unanticipated, all of which undermine the capacity to adapt of those affected. Pushing back the proximity of potential disruption and slowing its rate is another means of 'managing the decline' of adversely impacted industries and communities (see above). Moving from demonstrations, trials, and controlled sandbox experiments into full market diffusion and commercial availability is - in many cases - a decision whose timing policymakers and regulators can exert some control. But the capacity of policymakers to slow rates of disruptive change are also limited by uncertainty or lack of knowledge (about business strategies and future directions of change), lack of relevant competence, and the typically long drawn out cycles of policy making and legislating. All these are set against the urgency of required emission reductions which militates against any delay.

The information asymmetries point is particularly important for fast-moving digital innovation. Policymakers and regulators are continually playing catch up, as is evident with current efforts (particularly in the EU) to recapture some regulatory, fiscal and competition-related control over monopolistic technology companies. The unanticipated rapidity of change caused by disruptive consumer innovations invites an alternative type of policy response, encouraging - or requiring - providers to go beyond compliance with the existing corpus of law and regulation to embrace wider social responsibility requirements. As Google's motto used to be: Don't be evil (Alphabet has now softened this to: Do the right thing). The basic social license to operate of big technology companies is currently founded on a private exchange between provider and user: appealing and affordable new services for access to data. An additional publicly-oriented layer could include: contribute wherever possible to emission reductions.⁹

3.1.3. Ensure a diverse and competitive ecology of disruptive innovators, products and services to help avoid closing down future pathways and prematurely locking in a new form of incumbency.

Innovation outcomes are irreducibly uncertain, dependent both on technological performance and progress as well as on external developments in markets and institutional environments (Grubler and Wilson 2014). Experimentation and learning in diverse market niches helps reduce this uncertainty (Wilson 2012). This is particularly important early on in the period of 'technological ferment' during which innovations are selected for their adaptive fitness to market forces and other features of the selection environment (Suarez 2004). During these early stages, alternatives to mainstream energy or carbon-intensive practices compete for users, political support, and attention.

Once selective pressures winnow out the losers from the winners, increasing returns to

⁹ From the "12 in 12" report by Johan Falk and colleagues at Future Earth as part of the Exponential Carbon Roadmap (https://exponentialroadmap.org/wp-content/uploads/2019/02/20190207_ShortSprint_FINAL.pdf)

scale can see disruptors become rapidly entrenched as incumbents. Returns to scale result from scale economies, learning effects, and network effects. Scale economies (lower unit costs at larger unit scales or production volumes) and learning effects (cost reductions as a function of deployment experience) have more strongly characterised traditional energy supply and end-use (Grubler et al. 1999). But network effects have been more influential in driving the phenomenal growth of digital technology companies, particularly those providing social networks in which the value of the network to each new user increases as a function of its size.

In this way, disruption can lead (potentially quite rapidly) to a new configuration of incumbency and regime stability. Even if the new incumbent is a lower-carbon alternative to the previous (e.g., large-scale renewable and nuclear power generators forcing retirement of fossil-fuel plants), lock-in reduces the dynamic possibilities for further emission-reduction benefits (e.g., rapid electricity-demand reductions).

Consequently, policymakers may seek to ensure no single disruptive innovation quickly comes to dominate. Taking a portfolio approach to supporting innovation also helps diversify risks (e.g., that any one innovation fails) and avoids political, informational, and procedural difficulties with 'picking winners' (Nemet et al. 2018).

In a conventional R&D portfolio, this means diversifying funding across a portfolio of technologies (e.g., the US ARPA-E's funding of breakthrough energy technologies, or the global Mission Innovation initiative to develop low-carbon solutions). Mission-oriented strategies similarly define targets aligned with public policy objectives and offer support for innovators to deliver on those targets, with Kennedy's Moonshot a canonical historical example (Mazzucato 2018).

In the case of disruptive consumer innovations, portfolio-based approaches to public policy should also support heterogeneous actors with different technological knowledge and resource availabilities (Lundvall et al. 2002). Actor heterogeneity or diversity in *who* is disrupting is not inherently linked to portfolio diversity in *what* is being disrupted or *how* disruption may occur. But actor heterogeneity serves other functions as interactions between actors helps generate and exchange knowledge, align expectations, and build advocacy coalitions (Carlsson and Stankiewicz 1991; Wieczorek and Hekkert 2012).

For disruptive consumer innovations, the role of public policy is to direct these interactions and system functions towards low-carbon outcomes. The promise of future regulatory support (or regulatory censure) can have a strong leveraging effect. In particular, strong and shared expectations (on the desirability of low-carbon outcomes) reduce uncertainties among both consumers and innovators. Conversely, the legacy of a failure (e.g., consumer backlash, technology failure) can undermine confidence, erode policy attention, and divert mobilised resources (Anadon and Nemet 2014).

3.1.4. Incentivise or direct market activity to favour disruptive consumer innovations which contribute to public policy goals for emission reductions.

There are many regulatory and 'soft' policy approaches for stimulating more sustainable behaviour among individuals and households, and more sustainable consumption (including of disruptive innovations) among end users of energy and material-intensive goods and services. These can be roughly grouped into four generic strategies:

(1) *inform* end users through feedback, labelling, audits, advice, awareness and education (Asensio and Delmas 2015; Hargreaves et al. 2010)];

(2) *incentivise* end users through price signals, rebates, grants, pay-as-you-save schemes (Jessoe and Rapson 2014; Wilson et al. 2015);

(3) *nudge* end users towards energy savings by changing influences and cues in the decision environment (e.g., default settings, social comparisons) (Dolan et al. 2010; Metcalfe and Dolan 2012);

(4) *regulate* required levels of performance or efficiency through technology standards, and so remove poorly performing alternatives from available choice sets (Stern et al. 2016).

The first three strategies are non-regulatory ('soft') and consistent with a liberal framing of individual actors making broadly intentional decisions subject to (dis)incentives (including as a result of public policy) (Thaler and Sunstein 2008).

Disruptive consumer innovations which reliably deliver on public goods (like CO₂ emission reductions) should legitimately attract public-policy support. But delivery of CO₂ emission reductions from changing consumption practices are often neither reliable nor verifiable, particularly when actions are distributed over large numbers of discrete consumers. Even when emission reductions are clearly evident, robust quantification requires uncertain counterfactual baselines which describe what would have happened in the absence of the innovation.

The biggest problem, however, is that disruptive consumer innovations do not inherently prescribe how they are used. Although on a like-for-like basis they may result in lower emissions than their incumbent rival, adoption may change the terms of this like-for-like comparison. Energy-saving technologies (from smart heating systems to fuel-efficient vehicles) have long faced the challenge of users trading off the cost savings against other appealing attributes like comfort, controllability, autonomy (smart homes & heating) and accessibility, choice variety, convenience (shared mobility) (Wilson 2018). From an emissions perspective, 'unexpected' or 'undesirable' outcomes of low-carbon innovations being adopted include rebound, resistance, intensification, and expansion. Each can reduce or even reverse the low-carbon promise of disruptive consumer innovations:

- *rebound* - low-carbon innovations which reduce the effective cost of a useful service can lead to an increase in demand for that service (Sorrell and Dimitropoulos 2008);
- *resistance* - low-carbon innovations which offer alternatives to deeply embedded routine aspects of everyday life can face strong unwillingness to shift or change (Torriti 2017);
- *intensification* - low-carbon innovations which make everyday activities more appealing, convenient, or easy can inadvertently entrench those activities further in everyday life (Hargreaves et al. 2018);
- *expansion* - low-carbon innovations which offer a novel possibility can add to, rather than substitute for, incumbent energy-intensive activities (Sprei 2018).

Given all these problems with reliability, verifiability, and measurability of consumer-driven emission reductions, policymakers have tended to treat 'behaviour change' as a catch all residual in climate-change strategies dominated by projections of energy-supply and infrastructure transformation (BEIS 2017).¹⁰

¹⁰ As a coarse indicator, the UK's 2017 Clean Growth Strategy mentions behaviour 9 times as compared to 258 mentions of technology and 218 mentions of cost.

A way round this problem is for public policy to focus not on incentivising or nudging consumers but rather in strategically intervening upstream in technology development and service provision to guide, direct, or force consumption to deliver low-carbon outcomes. There are many means to this end, including regulation, mission-oriented R&D, public procurement, infrastructure investment, and designing low-carbon outcomes into technologies and services.

Conventional approaches for intervening in technology development are applicable to disruptive consumer innovations, but run the risk of rapid technological change outpacing the capacity of policymakers to anticipate effective ways of directing innovation activity in advance. Yet paradoxically it is the rate of disruptive change and its potential to deliver rapid emission reductions which warrants public policy intervention. Regulating technology performance standards and mission-oriented research and innovation programmes have both been discussed above. Mazzucato (2018) has argued for '100 carbon neutral cities by 2030' as a research mission for the EU pursuant to the 'grand challenge' of climate change. A third conventional approach to seeding potentials for disruptive consumer innovations is the use of public procurement (e.g., electric bus fleets) or infrastructure investments (e.g., electric recharging infrastructure) to overcome chicken-and-egg problems for technologies co-dependent on new infrastructure (Leibowicz 2018).

Public policy support, including funding, is written into the fabric of many ostensibly commercial goods and services. Private sector innovators, including in the digital and technology industries, draw directly or indirectly on public R&D outputs, market niches protected by public interests (military, space, universities), public procurement, educated workforces, and so on (Mazzucato 2015).

Less conventional approaches for directing disruptive consumer innovations recognise a *quid pro quo* in which disruptive innovators are rewarded for developing products and services to deliver on public policy goals. In this context, 'scripting' consumption would mean users tacitly ceding control over pre-agreed aspects of technology function in order to ensure low-energy or low-carbon outcomes.

New opportunities for 'scripting' technology development and use are opening up under the 'smart' rubric, linked to pervasive digitalisation, real-time information on technology use and context from innumerable sensors, actuators, meters communicating over wireless or phone networks, and algorithmic optimisation of technology performance and system efficiency (transport, electricity grid, city infrastructure). Possibilities for scripting include smart heating systems which prevent households from exceeding defined energy consumption targets, shared mobility platforms which limit single-person vehicle occupancy, or home energy management systems which require domestic consumption to be in net balance with generation.

Technology developers and service providers scripting low-energy outcomes into their consumer value propositions could share the internalised public-good benefits with consumers who forego certain service attributes. This in itself can be the basis of novel appeal. 'Demand response' provides an example in an energy context. In certain regulatory contexts, households can agree contractual terms with energy utilities for the remote curtailment of smart home appliances to reduce demand during critical peaks in exchange for reduced tariffs or other incentives (Srivastava et al. 2018).

Beyond regulation, R&D funding, infrastructure investment, and scripting, public policy can

also direct disruptive consumer innovation towards emission reduction goals in a host of other ways. Creutzig et al. (forthcoming) provide many such examples in making the argument that new forms of urban mobility based around sharing, electrification and autonomy, have considerable potential but need careful and strategic intervention: "*Only strong public policies can steer digitalisation towards fostering sustainability in urban transport*" (see Box 2 on New Urban Mobility & Public Policy).

Box 2. New Urban Mobility & Public Policy.

Note: this box draws heavily on a commentary by Felix Creutzig and colleagues in Global Sustainability (Creutzig et al. forthcoming).

Shared, electric, autonomous vehicles provide interlinked opportunities for transforming urban mobility. Value propositions for consumers (transport users) are also appealing. As an example, free-floating shared vehicle fleets, made possible by geo-located vehicle data and smartphone apps, can: (1) substantially reduce the cost per passenger-kilometre travelled; (2) enfranchise non-car owning households; (3) displace the need for car ownership; (4) increase utilisation rates so vehicle fleets turn over more rapidly (accelerating the introduction of technological innovations) (Arbib and Seba 2017; Namazu and Dowlatabadi 2018).

Exuberant market forecasts based on the strength of this value proposition herald the demise of the privately-owned vehicle in cities within little more than a decade (Arbib and Seba 2017). More calibrated modelling studies show the potential for shared mobility to provide for existing travel patterns on a city-by-city basis but with up to 90% fewer vehicles (ITF 2016; ITF 2017a; ITF 2017b).

The promise of this disruptive innovation comes tempered by many risks: (1) induced demand for additional mobility (rebound); (2) worsened congestion; (3) users moving off public transport and into (shared) vehicles; (4) surveillance and monitoring of users as real-time data on service usage is collected and analysed by service providers' algorithms (Herrmann et al. 2014; Sprei 2018).

Both the transformative potential of new mobility innovations and their evident social risks invite a public policy response. Creutzig et al. (forthcoming) argue that municipal authorities should use market access and regulatory oversight (e.g., operating licenses, use of parking infrastructure, road charging) to leverage sustainability commitments by new mobility service providers. As examples, shared vehicle fleet operators may: (1) be banned from competing with high-capacity transit routes (e.g., Chariot in San Francisco)¹¹; (2) serve as feeders from suburban residential areas into public transit hubs to address the 'last mile' problem (ITF 2017a); (3) be formally integrated into public transport networks (e.g., Bridgj in Sydney)¹²; (4) provide real-time and survey data on users to help optimise city transit infrastructure and analyse the social case for car-sharing (Car2Go in Seattle) (Cooper and Timmer 2015).

In the case of shared, electric, autonomous vehicles, public policy can intervene to steer change underway. Other sectors or domains face not disruptive innovation and threats to incumbency, but inertia. New home construction (and home retrofit) is an example of an economic sector characterised by low rates of innovation activity linked to a fragmented and

¹¹ Eric Jaffe (2015). "How the microtransit movement is changing urban mobility". Citylab. 27 April 2015. URL: www.citylab.com/transportation/2015/04/how-the-microtransit-movement-is-changing-urban-mobility/391565/ [accessed 9 Jan 2019]

¹² www.bridj.com/sydney [accessed 9 Jan 2019]

highly heterogeneous set of service providers with low barriers to entry and so varying skills. In a climate change context, this is a major problem. Homes as physical structures can stand for centuries, but net-zero emission targets by mid-century leave just a few decades to reduce direct and indirect emissions from domestic energy use close to zero. This *requires* disruption to prevailing practices, which has to be driven by public policy whether through mandates, targets, legislation, agreements, or otherwise (Killip and Owen 2019).

3.2. Conditions under which public policy should intervene in disruptive consumer innovations.

It is important to reemphasise that the focus of this paper is on disruptive *consumer* innovations. By definition these innovations succeed because of the appeal of their novel value propositions, pulled into the market by early-adopting consumer segments. The principal form of disruption of interest is on mainstream consumption practices. This is traditionally an area over which policymakers are more reluctant to exert control or influence.

We identify several conditions under which public policy should intervene in markets to support disruptive consumer innovations. These go above and beyond the need for policy in ensure consumers enjoy necessary rights and protections on issues such as safety, security, privacy, non-coercion, and so on.

We argue that public policy for disruptive consumer innovations is justified and necessary if:

- (1) There is clear and robust evidence that adoption leads to emission reductions;
- (2) There is clear and robust evidence that changes to mainstream consumption practices improve wellbeing, welfare, or other social objectives;
- (3) There is a significant risk of adverse collective impacts on consumers' or workers' rights.
- (4) There is strong overlap with strategic research and innovation objectives.

We briefly explore each of these in turn.

3.2.1. Public policy should intervene ... if there is clear and robust evidence that adoption leads to emission reductions.

The evidence for potential emission reductions from a range of disruptive consumer innovations is rapidly growing; careful empirical studies of actual emission reductions from early-adopting niches are needed to verify the findings of modelling and simulation studies (see above). Public policy should intervene to support disruptive consumer innovations if the evidence for emission reductions is clear and robust (in terms of magnitude, timescale and enabling conditions). By supporting R&D, field trials, urban experiments, data-access agreements, public policy can also play a critical role in building the evidence base.

3.2.2 Public policy should intervene ... if there is clear and robust evidence that changes to mainstream consumption practices improve wellbeing or welfare.

The narrow emphasis in this paper is on CO₂ emission reductions. But disruption to

mainstream consumption practices can have many other 'co-benefits' for health, urban sustainability, social exclusion, local economic development, and system functioning. Each of these legitimises public policy intervention. As examples: shared and electric mobility can eliminate congestion and local air pollution in cities (ITF 2016); digital farmers' markets and urban agriculture can reduce food miles and support local agricultural employment (Kulak et al. 2013); 11th hour apps, energy-service companies, distributed renewables can all reduce the demand on centralised systems of provision (of food or energy), in turn weakening the need for new supply investments.

3.2.3. Public policy should intervene ... if there is clear and robust evidence of adverse collective impacts on consumers' or workers' rights.

Semantically, disruption is negative. In Silicon Valley, disruption is positive. The disruptive impact of an innovation can similarly be framed positively (dynamism, ingenuity, creativity) or negatively (unfair, exploitative, challenging). Sharing-economy platforms which have risen to market dominance as a result of network effects are a case in point, particularly AirBnB (sharing spare beds) and Uber (sharing spare seats in cars). In France and elsewhere, 'Uberisation' is a term used to describe the worst aspects of the gig economy: poor working conditions, low job security, lack of rights, and a general exploitation of workers in an employers' market. Yet also in France, political leaders use the dynamism, appeal, and innovation of Uber and other digital start ups as an analogy for a national project to transform the French economy. The disruptive effects of consumer innovations are clearly multifaceted. Yet as debates around sharing-economy and technology giants illustrate, it is possible to distinguish positive from negative facets, and if not, public agencies need to be tasked with monitoring, analysing and building an evidence base to do just that. For innovations clearly associated with public goods, public policy should regulate the negative facets, particularly when these risk broader ramifications on trust, privacy, welfare, fairness.

3.2.4. Public policy should intervene ... if there is strong overlap with strategic research and innovation objectives.

There are many cases in which public policy intervention to support disruptive consumer innovations may align with wider research and innovation agendas including employment generation, skills and training, export-led growth, competitive advantage, and rebalancing geographic distribution of wealth. The climate change 'mission' advocated for the EU's research and innovation programme is one example (Mazzucato 2018). In 2017 the UK launched its first comprehensive Industrial Strategy since the 1970s identifying four 'grand challenges' to frame strategic research and innovation objectives, investments and activities (HMG 2017). Two of the challenges are clean growth and future mobility, both highly relevant to disruptive consumer innovations for climate change. (The other two grand challenges are artificial intelligence and big data, and an ageing society).

4. Conclusions.

The disruptive consumer innovations for climate change introduced at the beginning of this paper spanned four domains: transport, food, homes, and energy (at the point of use in homes). These innovations were selected as they offer novel value propositions to consumers. If these value propositions prove appealing and the innovations are adopted at scale, they would disrupt mainstream consumption practices in each domain.

However, this paints an overly simplistic picture. The availability and attractiveness of many of the innovations depends on regulatory, infrastructural, or other factors. The transport and energy innovations in particular seek to deploy in regulated or managed environments, whether urban streets or electricity distribution networks. Some of the energy innovations inherently require regulatory innovation to open up space for service providers to innovate (e.g. time-of-use pricing, demand response). Some of the transport innovations require access to infrastructure, tacit approval, or even a lack of regulatory intervention (e.g., car sharing, shared taxis).

These co-dependencies between innovators, public authorities, and shared infrastructures strengthen policymakers' hand in trying to direct disruptive processes. But public policy is also customarily limited in its ability to intervene in certain aspects of everyday life particularly at (or in) homes, unless it is to ensure the delivery of basic needs. The EU has placed smart, engaged, proactive energy consumers at the heart of its sustainable energy strategy¹³, but households are proving remarkably stubborn in subscribing to this vision for them. In some cases, policymakers may not have appropriate legal mandates to adapt regulatory rules or principles to direct disruptive innovations towards public goods. Some municipalities have been unable to dedicated parking space for car-sharing networks as it would be discriminatory against private car users.

Notwithstanding these caveats, the disruptive impacts of certain consumer innovations becoming widespread can and should be managed. We identified several strategies for 'de-risking' disruptive consumer innovations which include the use of demonstrations and trials to enable policy learning, and support for communities of interest which 'lose out' to reduce distribution inequalities.

We also identified conditions which justify public policy interventions in cases where there is good evidence that disruptive consumer innovations can deliver emission reductions or other public goods, or conversely that unregulated adoption could be to the detriment of public policy objectives.

Ultimately, limiting global warming to 1.5°C requires a 45% reduction in CO₂ by 2030 from 2010 levels, and net-zero CO₂ emissions globally around 2050 (IPCC 2018). Yet emissions are still rising by ~2% a year (GCP 2018). Delivering rapid and deep emission reductions is a pressing public policy challenge to which disruptive consumer innovations can contribute.

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¹³ Smart homes are one of the EU's 10 priority action areas in its Strategic Energy Technology Plan: "*Create technologies and services for smart homes that provide smart solutions to energy consumers*". Behind this strategic policy objective lies "*the Commission's vision for the electricity market [which] aims to deliver a new deal for consumers, smart homes and network, data management and protection*" (EC, 2015). Underlying the EU's strategic goals for a smart home future are clear assumptions that households seek a more active role in the energy system: "*Communities and individual citizens are eager to manage energy consumption ...*" (EC, 2015; EESC, 2015).

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