Unsustainable Transitions – A blind spot for transitions research?

Jochen Markard, Peter Wells, Xiao-Shan Yap, Harro van Lente

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Abstract

In recent years, transitions research has successfully focused on developments that can be associated with potential improvements in terms of sustainability. As a consequence, the field has largely missed out on unsustainable transitions: transformations that 'make things worse'. We argue that it is time to widen the scope (again) and to also study unsustainable developments from a transition perspective. This paper offers conceptual reflections and two cases of innovations in different industries and different stages of development: Sports utility vehicles (SUVs) and space tourism. Both may significantly increase energy consumption and greenhouse gas emissions, thereby counteracting ongoing attempts to fight climate change. Studying unsustainable transitions is important for three reasons. First, it is necessary to direct policy attention to potentially unsustainable innovations – especially in early stages of development, when emerging pathways can still be shaped. Second, concepts and insights from transition studies can be mobilized to understand unsustainable transitions and to inform policies. Third, widening the scope will challenge existing frameworks, e.g. when studying multiple, overlapping transitions or the formation of needs.

Keywords: Unsustainable transitions, needs, path-dependency, transport, space

1 Introduction

Sustainability transitions research has gained quite some prominence in the literature on innovation studies and beyond (EEA, 2019; Köhler et al., 2019; Markard et al., 2012). More and more researchers are focusing on fundamental socio-technical transformations that have the potential to improve sustainability in sectors such as energy, transport, agri-food or water. Research on sustainability transitions has primarily focused on the emergence and diffusion of innovations, e.g., in renewable energies or electric mobility, that have a potential to improve sustainability issues such as air pollution or greenhouse gas emissions (Markard, 2018; Mitchell, 2016). Scholars have also started to explore the decline and eventual phase-out of established but unsustainable technologies or practices such as incandescent light bulbs, single use plastics or coal fired power generation (Rosenbloom, 2018; Stegmaier et al., 2014; Turnheim and Geels, 2012). Both, supporting the diffusion of more sustainable practices and accelerating the decline of unsustainable practices are key policy strategies to improve sustainability.

However, and unfortunately, there are also many ongoing transformations that are unsustainable: for example, we consume ever more goods (e.g., clothes, electronics), live in bigger homes, commute more and longer distances, and enjoy exotic vacations that require air travel. We see that new products have emerged and lifestyles have changed accordingly, with negative implications for sustainability. Especially when innovations have diffused widely, their ecological (and social) footprint becomes very apparent. Think of fracking, exploitation of tar sands, sports utility vehicles, energy intensive computing, cruise ship vacations or hot tubs.

So far, research in the field of sustainability transitions has very much neglected these negative developments but concentrated on the positive (Antal et al., 2020). This is why, in this paper, we widen the scope of transitions research to focus on the *emergence and diffusion of unsustainable innovations*[1] and explore the implications for both research and policy. We want to create attention for what we believe is a blind spot in sustainability transitions research. For research, unsustainable transitions represent an opportunity to challenge existing frameworks in transition studies and to learn more about e.g., conflicting sustainability issues or overlapping transitions. For policy, it is important to react to unwanted developments early on and to guide unsustainable innovations as to minimize their negative impacts.

We proceed as follows. First, we conceptually clarify what a scholarly focus on 'unsustainability' could imply (section 2). Here we distinguish different lines of research, both within and outside the field of transition studies. This allows us to formulate better the analytical challenges of unsustainable transitions. In section 3, we present and explore two examples of transitions in different stages of development. In both cases, we focus on sustainability challenges with regard to

[1] In this paper, we use "unsustainable transitions" as the main label, referring to large-scale, multi-dimensional transformations in the sense of developments we want to avoid. However, in our examples the focus is on innovations: they are early stage and about a specific product or service. Especially in the case of space tourism, we don't know yet whether a transition will unfold and how far-reaching it will be.

climate change. Section 4 discusses implications for research and policy and section 5 concludes.

Sports utility vehicles (SUVs) are characterized by high fuel consumption. They have already diffused widely in many markets, thereby not only replacing more efficient conventional vehicles but also counteracting the positive climate effects associated with electric vehicles. The SUV case stands for a failed transition to cleaner transport with ineffective policies, a car centric culture, strong dependence on automobility and unsustainable user practices (Mattioli et al., 2020; Wells and Xenias, 2015).

Space tourism is a prospective market in the early stages of development. Space flights generate high and particularly harmful greenhouse gas emissions in the stratosphere (Spector et al., 2017). Space tourism is of particular interest as it might contribute to a significant shift in consumer aspirations and needs, similar to the advent of air travel in the middle of the last century. The case is highly policy relevant as there is still an opportunity to intervene before major lock-ins have emerged.

2 Theoretical background

This paper builds on the literature on sustainability transitions (Köhler et al., 2019) and seeks to further improve this field of research. The paper also draws from related strands of research, including studies on the role of users in innovation (Hyysalo et al., 2016) and on the development of needs in society (Graber, 2007).

2.1 Gaps in sustainability transitions research

Transitions research is concerned with processes of fundamental change in socio-technical systems (Smith et al., 2010). Core frameworks such as the multi-level perspective or technological innovation systems were developed independent of sustainability considerations (Carlsson and Stankiewicz, 1991; Geels, 2002; Rip and Kemp, 1998). Also, many early empirical studies had no particular interest in sustainability (Carlsson and Jacobsson, 1994; Geels, 2002; Geels, 2005).

Since around the 2000s, however, sustainability issues have become more and more prominent in transitions research (Smith et al., 2005; Smith et al., 2010) and today, the intention to foster sustainable system transformations is a central driver for the development of the field. The concept of transition management is inherently linked to sustainability issues (Loorbach, 2010; Rotmans et al., 2001) and "sustainability transitions" (Markard et al., 2012) has emerged as a focal term for socio-technical transitions associated with environmental or social sustainability targets. That existing socio-technical systems around e.g., energy, transport or agri-food must change fundamentally in order to cope with grand sustainability challenges has become a widely shared assumption in transition studies.

The scope of sustainability transitions research has widened over time. At first and for many years, scholars have studied the interplay of i) path-dependence and resistance at the level of established socio-technical systems (and the associated regimes), and ii) radical alternatives such as solar or wind energy, which emerge in niches and challenge existing regimes (Kemp et al., 1998; Smith and Raven, 2012). In this line of research, the central strategy to improve sustainability is to foster the *emergence of innovations,* which have a potential to contribute to more sustainable modes of production and consumption. Solar and wind energy or electric vehicles are typical examples in this regard. Research has made much progress to better understand processes that block or delay innovation, and those that drive innovation and diffusion (e.g. Bergek et al., 2008; Hekkert and Negro, 2009). Accordingly, policy suggestions have concentrated on policies that foster experimentation, innovation and diffusion (Hoogma et al., 2002; Jacobsson and Bergek, 2011; Sengers et al., 2019).

More recently, transition scholars have also started to explore a second strategy to improve sustainability, which is to push and accelerate the *decline of unsustainable technologies,* i.e. of those arrangements that cause particular sustainability problems. This new interest in decline has been portrayed as the 'flipside' of innovation (Turnheim and Geels, 2012). Incandescent light bulbs, coal fired power generation or internal combustion engines are examples for studies on decline (Meckling and Nahm, 2019; Rosenbloom, 2018; Stegmaier et al., 2014). Policies such as phase-out programs, technology bans or carbon pricing have been suggested to support processes of decline (Kivimaa and Kern, 2016; Rogge and Johnstone, 2017; Rosenbloom et al., 2020).

The question, however, is whether it is sufficient to study either innovations that promise to contribute to sustainability and or the decline of unsustainable technologies. Does the field of transitions studies already cover all relevant aspects of (un)sustainable transformations?

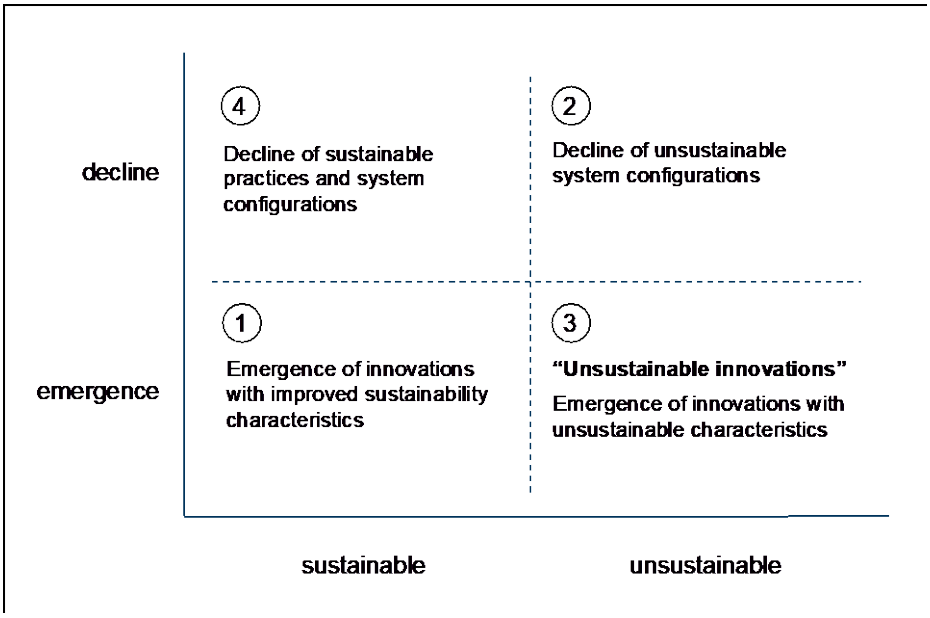

Figure 1: Four different foci for strategies to improve sustainability through socio-technical change

When we construct a 2x2 matrix around emergence versus decline and sustainable versus unsustainable developments, two complementary sets of research questions appear (Figure 1). Quadrants 1 and 2 represent developments policy makers might want *to support* out of sustainability concerns. These are the two fields transitions research has so far focused on. Quadrants 3 and 4 contain developments policy might want *to avoid*. These quadrants have received rather little attention in transitions research.[2]

Developments in the upper left (4) are about the decline of practices and system configurations that are more sustainable than current ones. A classic example is sailing ships being replaced by steam ships, which – from a climate perspective – was not sustainable (Geels, 2002; Figure 2). Or think about practices, which were the norm some generations back (and in some places still are) and which we abandoned for alternatives that, among other issues, are much more energy intensive: Living close to your workplace, not using a car, not relying on air conditioning or not taking a hot shower every day (Shove and Walker, 2010; Walker et al., 2014). Often, practices have turned from luxuries (e.g., flying and the 'jet-set') into commonplace activities and needs have formed around them (Lie and Sørensen, 1996; Sørensen, 2006). Internet access, for example, has turned into necessity, raising concerns for example about the 'digital divide' for those who don't have it (Treré et al., 2020).

[2] Note that the matrix is a simple device to support our argument. However, these dimensions are not sufficient to cover all unsustainable developments happening in socio-technical transitions. We will come back to this in section 2.3.

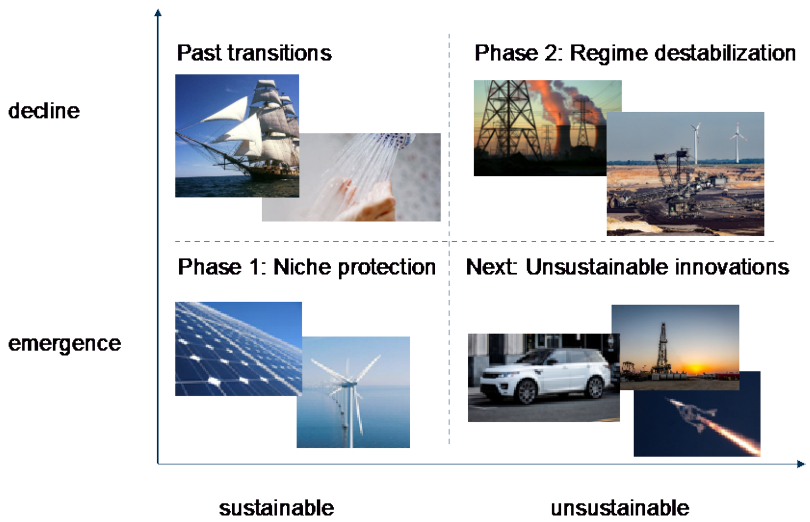

Figure 2: Examples of different kinds of transition processes

Developments in the lower right (3) are in the focus of this paper: innovations that are problematic in terms of sustainability.[3] If they diffuse widely, they become even more problematic. Their sustainability impacts multiply and potential lock-ins emerge, which means that they will be very difficult to abandon or replace.

2.2 How to analyze unsustainable transitions?

In general, unsustainable innovations or transitions can be analyzed with the 'usual' repertoire of frameworks from innovation studies. We expect that many key processes are the same or very similar. Take, for example, the need for learning and knowledge development (Bergek et al., 2008), the struggle for legitimacy (Aldrich and Fiol, 1994; Binz et al., 2016), or the mobilization of positive expectations in early stages of innovation (Borup et al., 2006; Van Lente and Rip, 1998). Typical innovation studies would look into these processes and develop suggestions of how to strengthen them.

However, our interest is different. We want to understand the innovation, including its sustainability challenges, and its potential persistence. Persistence is important because it is very hard to change the course of a transition, once regime-like structures and path-dependencies have emerged (Fuenfschilling and Truffer, 2014; Rip and Kemp, 1998). We explore two analytical dimensions with regard to persistence. We ask how the innovation connects with existing regime structures and influential industries, having in mind that such connections lower the chances that the innovation can be scaled back or re-directed to a more sustainable pathway. We also take a closer look at the formation of needs, which is an

[3] Note that, in the following, we just concentrate on climate change as one sustainability dimension. We come back to this limitation in the discussion.

analytical dimension that informs us about how well an innovation has become embedded in society (Kemp and van Lente, 2011; see next section for further details). Finally, we are interested in future development options and the leeway for policies to shape them. Overall, our interest lies in the policy relevance of unsustainable transitions. The underlying rationale is that it is easier for policies to change the course of a transition when it is in an early stage of development and system elements are still fluid.

Table 1 lists five analytical dimensions that guide our analysis. While we believe that these are useful for our purpose, we do not claim that these are the only or best dimensions to study unsustainable innovations.

Table 1: Dimensions to analyze unsustainable innovations with a policy interest

	Key questions
Innovation and context	What is the innovation about? How is it influenced by context developments? What are key drivers of the transition?
Sustainability implications	What are the main implications, including opportunities and threats, for sustainability? Which of these will be inherent, i.e. difficult to avoid?
Regime formation and path-dependency	How does the innovation relate to existing regimes? Are new regime structures emerging and how persistent are they? What is the risk of path-dependencies?
Needs and practices	How does the innovation affect user practices? Are new needs emerging and how persistent are they?
Policy challenges and pathways	What are the key policy challenges? How can policies shape transition pathways?

Our two cases were selected to obtain a high degree of variation along these dimensions and to showcase the differences, e.g. with regard to policy implications. SUVs grow out of a strong, well-established regime around automobility. They have already diffused widely around a dominant design and needs have formed. So, it is very difficult for policy to successfully change the course of the transition. Space tourism, in contrast, is an emerging innovation related to different industries (space travel, tourism). It is in a very early stage of development with competing ideas and designs and non-existent user needs. Here, we expect more leeway for policy to shape future developments. Section 3 explores these issues in detail.

As the formation of needs is not yet very established in transition studies, we briefly introduce it next.

2.3 Needs and unsustainability

A pertinent issue regarding unsustainable and sustainable transitions is the ambivalent status of 'need'. The standard image is that innovation happens to address needs. The task of engineers and firms, according to this image, is to find out what is problematic in society and to develop solutions (Van Lente, 2019). This position fits with the prevalent instrumentalist view on technology, which argues that humans have to rely on their ingenuity and tools to survive. In modern life, survival has been replaced by a broader set of needs: needs express what it takes to fully participate in society, in terms of mobility, living, working, fulfillment etc. (Godin and Vinck, 2017). The assumption is that exist somehow and somewhere prior to innovation and new technology (Kemp and van Lente, 2011).

Historical studies of technologies, however, show that needs typically do not exist when new technologies emerge (Shove, 2003). The iconic case study on the history of the bicycle at the end of the nineteenth century, for example, stresses that it took 25 years before a model emerged that we now recognize as a bicycle (Pinch and Bijker, 1984). During decades a bewildering range of different models was tried out, featuring different wheels sizes, different locations of the pedals, or different suspensions. Pinch and Bijker (1984) show that there was no consensus about what one should do with "bicycle" and what one could expect from its use. The idea of what a bicycle 'is' and the criteria of a 'good' bicycle had to be developed, together with the development of new models. At first, there was curiosity to try the strange devices; and gradually new usages emerged. With the emergence of new practices (such as commuting), the bicycle became a familiar element in the design of daily life. Only after such "domestication" a bicycle will be missed when it is not available, only then it will appear as an unmet need (Sørensen, 2006). The need for a new technology, therefore, may not be the beginning but the end of a long and twisted road of technology development.

Companies know that creating new needs is part of the attempt to develop new technologies. In most sectors, the budgets for R&D and for marketing are about the same. Peter Drucker, a well-known business scholar stated: "There is one valid definition of business purpose: to create a customer" (Drucker, 1954, 37). Again, the history of technology provides many examples, for instance the success of George Eastman (1854-1932), developer of the Kodak photo camera (Utterback, 1994). At the end of the 19th century, photography was a cumbersome activity for specialists. Eastman's idea was to make photography a low-threshold activity and he used celluloid instead of glass as the substrate of light-sensitive emulsion, which allowed rolling up light-sensitive layer. He placed the roll in a closed box and users could send the entire device to the manufacturer, who would return the developed photos with a new, empty roll in the box. Eastman presented photography as a simple activity ("you push the button, we do the rest"), no longer for the crucial moments of life only but fitting with daily life, too. Indeed, photography became ubiquitous and an inseparable part of everyday life (Utterback, 1994).

Note, however, the curious reversal: needs now appear as having been there all along. Instead of being the outcome, needs are now presented as the starting point and even the explanation of the development. The effect gets the status of cause. Marketing studies have coined the term 'latent need' to accommodate the reversal. This mysterious factor has not been visible, nobody knew it existed, but it was there, perhaps already for centuries, and now pulled of a new development. Magic? No, circular reasoning.

Instead of being a visionary and creative developer, Eastman only 'served' the need and successfully solved a problem. (But which one? The problem that there were no cameras!). Likewise, firms under attack readily point to their customers: they are to blame, not the firms who humbly and dutifully serve their needs.

In societal debates on technology and sustainability, the reversal of cause and effect also brings a self-imposed powerlessness (Avelino et al., 2016). If we see need as a cause, then new technology appears as inevitable: how can we be against fulfilling needs? Indeed, questioning the needs of others is seen as paternalistic, not fitting with a liberal society (Shove et al., 2020; Stirling, 2014). Yet, when we acknowledge needs as effects, we are encouraged to pay more attention to what needs will follow with new technology. Are these the needs we can allow ourselves to have? Or do we prefer other needs?

2.4 Challenges when dealing with (un)sustainability

There are several challenges when it comes to assessing whether an innovation is sustainable or not. These include uncertainty, values, multi-dimensionality, scope and use issues (Ely et al., 2014; Pope et al., 2004). We briefly discuss these below because they are central for our two cases and sustainable innovations more generally. We are aware that there are longstanding debates around these issues, of which we just wrap up some essentials.

First, innovations are inherently uncertain. In early stages of innovation, we just know very little about the potential benefits and shortcomings of an innovation (Collingridge, 1982; Genus and Stirling, 2018). For example, who would have thought that the innovation of computer-to-computer communication at DARPA would result in one of the most central technologies of our time, including Facebook and millions of people uploading pictures of their cats or dinner? There might also be unwanted effects such as the competition of biomass use for energy with food production or conservation of forests.

Second, sustainability issues are a matter of values and preferences. Different societal groups or constituencies carry different values when it comes to e.g., climate change, clean water, air pollution, security etc. Also, these values are socially constructed and might change over time. One way to address this dilemma in technology assessment studies is to make the influence of values on outcomes transparent and to leave the decision to political decision makers, instead of technology experts (Ely et al., 2014).

A related issue is multi-dimensionality. In sustainability (transitions) research, we often tend to focus on one sustainability dimension such as climate change. However, there are many other dimensions such as those listed in the 17 sustainable development goals (Sachs et al., 2019). Often, there are trade-offs between different sustainability goals (Kemp and van Lente, 2011). For example, both wind and nuclear power are low-carbon technologies. While wind has negative impacts on nature and landscapes, nuclear power plants produce highly problematic waste, bear the risk of dramatic accidents and can be used to arm atomic weapons.

A fourth issue is the scope of analysis. Whenever we draw boundaries, e.g., around a sector or country, there is a risk of 'environmental problem shifting' (van den Bergh et al., 2015). A selected sustainability problem is solved within these boundaries (e.g. Western countries) while other places are confronted with additional problems. Take electric vehicles, which reduce air pollution and GHG emissions but require problematic resources for their batteries such as cobalt, which – partly – is produced by artisanal mining and child labor in the Democratic Republic of Congo (Sovacool, 2019). Similar issues apply to sectoral boundaries.

The temporal scope is closely related to this. For example, an innovation can be more sustainable in the short run but generate bigger problems later on. Re-usable rockets are clearly an innovation that generates sustainability improvements (less waste and pollution) in today's space industry. In the future, however, they may turn into a problematic technology, when they enable dramatic cost reductions and become the stepping stone for space tourism (see below). In the long run though, we can also envision a future, in which space tourism is again the stepping stone for reaching out beyond Earth, the sustainability implications of which we can hardly grasp.

Finally, there are many different ways of how technologies can be used. Developing reusable rockets for scientific missions can be viewed as sustainable, using them for touristic purposes is less sustainable. Pattern recognition can be used to identify faulty products in a production system, or to track political activists in a totalitarian state. The use issue is related to the temporal scope and to uncertainty.

We extract three major lessons from this. First, whether an innovation should receive policy support (or should rather be abandoned) for sustainability reasons is a political decision by a specific constituency in a specific context at a specific time. Second, unfolding transition pathways are laden with uncertainties and unwanted effects. Third, all innovations come with a variety of sustainability effects on a variety of dimensions.

When we suggest focusing on unsustainable transitions, we want to direct attention to the risk that policy making might overlook systemic sustainability problems in early stages of development, thereby missing the window of opportunity for early intervention and re-orientation.

To be clear, we do not want to assess whether an innovation is sustainable or not. Fracking technology, for example, comes with unwanted effects such as seismic tremors or minor earthquakes, excessive water use, potential water pollution or gas leaks (Hammond and O'Grady, 2017). These issues are addressed by research in the broader field of technology assessment studies (Ely et al., 2014; Schot and Rip, 1997; Tran and Daim, 2008). For our purpose, it is sufficient to point to potential sustainability problems, especially to those that are *inherent to the innovation*, which means that they are not just teething problems of early stages of development, or unwanted effects, but very likely to remain and increase once the innovation is successful and diffuses widely.

To stay with the above example: in our understanding, fracking technology qualifies as an unsustainable innovation with regard to climate change because it is inherently linked with greenhouse gas emissions. Fracking is a process innovation for a product (natural gas) that contributes to global warming. Due to the innovation, natural gas becomes cheaper, which increases its competitiveness and decreases the chances to replace it with low-carbon alternatives.

To summarize, the task when studying unsustainable innovations is to identify inherently problematic issues and to mobilize (policy) attention to guide unfolding transitions in a way to avoid unsustainable outcomes. This is particularly relevant in areas such as climate change, where we do not want to undermine ongoing policy efforts by new problems that arise unnoticed while policy is busy fire-fighting elsewhere.

3 Two cases of unsustainable innovations

Thus far, we addressed some of the conceptual issues that come with unsustainable transitions. The second route of this paper is to explore two cases, SUVs and space tourism. We use these examples to illustrate the policy challenges associated with unsustainable innovations in different stages of development.

3.1 SUVs

3.1.1 Innovation and context

Sports utility vehicles are an example of a product innovation in a mature industry. The SUV is an incremental innovation that resulted from the fusion of two established types of vehicles which both have been in use for decades: medium-sized family cars and hatchbacks that formed the bulk of the market until recently and off-road or pick-up style vehicles that formed a niche segment for special purposes. SUVs or 'crossover' vehicles lack true off-road capability but have the styling cues, bulk and height of genuine off-road vehicles.

One of the definitive cars of this new crossover SUV segment is the Nissan Qashqai. First brought to the market in 2006, this model was hugely successful and stimulated many other incumbent vehicle manufacturers to offer similar models. At the time

> "…there were still considerable barriers to SUV ownership for many hatchback and saloon buyers… SUVs were considered too large for around-town maneuverability and general everyday usability, plus people didn't like the poor fuel efficiency and lackluster interior quality … We managed to persuade the business that we could break down some of these (consumer) barriers by taking the best bits of a family hatchback and adding the elements of SUVs that are most attractive to customers. And so, the idea of the first 'crossover' was born." (Peter Brown, Vehicle evaluation manager, Nissan, 2017)

A key driver behind the development of SUVs is that they can be sold at a premium to a large base of customers. Incumbent automakers market them as rugged spacious, adventurous, versatile, and at the same time a safe alternative to smaller, sedan-type family cars. Research for the US market showed that new SUVs and crossover cars commanded transaction prices 39 to 51 percent higher than the equivalent saloon or hatchback, despite similar build costs (Snyder, 2017).

Meanwhile, SUVs have diffused widely and quickly, primarily replacing smaller cars. In Western Europe, the market share of SUVs grew from 8% in 2008, to around 35% by 2018, while the share of sedan cars fell from 38% to 26% (Figure 3). Globally, SUV sales reached 30 million in 2018 with a market share of 36% (JATO, 2019).

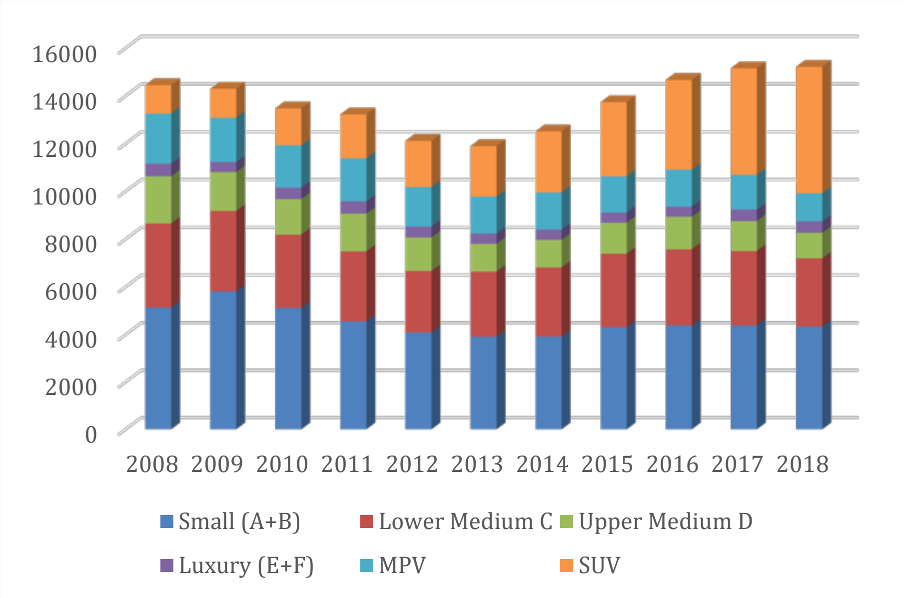

Figure 3: New car sales by segment, Western Europe (Source: ACEA)

The transition to SUVs is happening at times in which the auto industry is confronted with a broad range of major structural challenges, some exacerbated by the SARS-CoV-2 pandemic. These include over-capacity, technological changes such as digitalization and the increasing relevance of software, advances in autonomous driving, connectedness to mobile networks, and the beginning transition from internal combustion engines to electric vehicles (EVs). The auto industry is confronted with regulatory constraints and increasing conflicts over scarce space in cities, air pollution and climate change (Bordovskikh, 2020).

Several of these developments are disruptive for incumbent firms, e.g. as they threaten their core business model, entail an entirely different view on the automobile (computer device vs. assemblage of hardware), or require new competences, e.g. in software development, electric drive trains or battery system optimization.

For vehicle manufacturers, SUV vehicles are an ideal segment to develop and market many of these novel technologies. Bigger vehicles command higher prices, which means that the additional costs can be more readily recovered (Snyder, 2017). Moreover, with regard to EVs, larger vehicles can hold larger battery packs, enabling performance and range expectations created by internal combustion engine vehicles to be met.

3.1.2 Sustainability implications

SUVs come with an inherent increase in energy consumption as they substitute smaller cars. For example, the Nissan Qashqai 1.5 liter in 2006 had a weight of about 1,454 kg and averaged emissions of 201.0 gCO_2/km. This is 16% heavier and 14% more polluting than the Nissan Almera, which it replaced.

Analysis from the International Energy Agency (IEA, 2019b) suggests that SUVs were second only to the power sector in contributing to the increase in global CO_2 emissions since 2010. Carbon emissions from SUVs grew faster than the iron and steel, cement, aluminum, commercial vehicle and aviation industries. As a significant incremental change in the existing automobile regime, SUVs are almost 'hiding in plain sight' from more high-profile instances of CO_2 emissions growth. According to the International Energy Agency (IEA, 2019a: 28):

> "A key development of the past decade is the increasing share worldwide of the small SUV/pickup segment… [they] primarily replaced city cars, medium and large cars."

In parallel with the growth in the market share taken by SUVs, following the VW diesel emissions scandal, there has been a market shift away from diesel use, exacerbating carbon emissions in the transport sector (Gapper, 2019; IEA, 2019a; Taylor, 2020).

3.1.3 Regime formation and path-dependencies

Automobility can be viewed as an established and very rigid socio-technical regime, which is centered around individual automobility and complemented by massive infrastructures, regulations (e.g. traffic), services, user practices and societal norms (Geels, 2018; Mattioli et al., 2020). Multiple incremental innovations in materials, components, and whole vehicles have acted to sustain the viability of the regime (Cohen, 2012; Wells and Nieuwenhuis, 2012; Pel et al., 2020).

Within the established regime, the SUV is an innovation that builds on and strengthens existing regime structures. For example, SUVs fit readily into many existing regulations and road infrastructures, thereby benefiting from these complementarities. SUVs are also are easily accommodated within existing supply chains, manufacturing systems, distribution networks, retail structures, finance and insurance provision, consumer expectations, and service and support systems. The SUV also continues the already entrenched path dependency around individual, long-range mobility as the dominant mode of transport in numerous countries and regions (Hoffmann et al., 2017).

At the same time, new regime structures have emerged that favor SUVs. One example are labels to inform consumers about fuel efficiency and CO_2 emissions of cars. Germany's mass-based weighing scheme has been designed to benefit heavy SUVs. As a result, a BMW X5 SUV which emits more than 150 gCO_2/km receives an A label, while a VW Golf with 114 gCO_2/km only gets a B (Haq and Weiss, 2016). The CO2 emissions regulations flexibilities applied in the EU specifically use limit curves that allow manufacturers of heavier cars higher emissions than manufacturers of lighter cars.[4]

In 2020, Ford abandoned production of sedan (saloon) cars in North America to focus on SUVs and crossovers. All major auto makers include these vehicles in their model ranges. More tellingly, even niche sports and luxury auto makers such as Bentley (with the Bentayga), Lamborghini (Urus), Porsche (Cayenne), Maserati (Levante), Rolls Royce (Cullinan), and Aston Martin (DBX) now feel compelled to have models in this segment.

3.1.4 Generic dependence on cars and new needs around SUVs

In deeply entrenched socio-technical systems such as automobility, needs are woven tightly into the fabric of everyday life and lifestyles, and are all the more difficult to alter (Hoffmann et al., 2017). In this sense the uptake of SUVs is latest manifestation of the generic condition of car dependence (Mattioli et al., 2020). Extant research suggests that to achieve deep de-carbonization goals in mobility will require a combination of electrification, policy measures and, crucially, lifestyle changes (Brand et al., 2019; Marsden et al., 2020). The latter includes issues such as where to live and work, whether and how to commute, whether and how often to drive children to destinations, or whether the car is viewed as a status symbol.

SUVs are linked to many of these issues. For example, the SUV concept is supportive of more active lifestyles and adventure holidays (Jensen and Guthrie, 2006). Many activities such as windsurfing, off-road biking, mountain climbing, etc. have become more widely popular in recent years, and are often associated with large quantities of equipment and a desire to access more remote locations (Dunn, 2008).

As SUVs have become the new norm, consumers have come to 'need' SUVs, e.g., for perceived safety benefits, no matter how erroneous that perception may be and despite the increased risk to other road users (Wells, 2006). In fact, there is even a vicious cycle at work here. As more and more parents drive their children in ever larger vehicles, it becomes less and less safe for others not to do so.

These old and new needs drive SUV usage, despite the fact that, in their daily use, SUVs may even be inconvenient, especially in cities with increasing congestion and greater concerns for the safety of other road users (Monfort and Mueller, 2020; Salisbury, 2020). Also, the inefficiencies of SUVs are not felt as strongly by users as the real cost of petrol and diesel have declined, especially since the 2008/9 financial crisis.

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[4] see https://ec.europa.eu/clima/policies/transport/vehicles/cars_en

3.1.5 Policy challenges and potential pathways

For decades, public policies have targeted transport in general and automobility in particular in order to reduce air pollution and CO_2 emissions. Along with more stringent emissions controls and a new regulatory regime for carbon emissions from vehicles in the EU, there had been a long-run decline in average new car CO_2 emissions from 159gCO_2/km (2007) to 118gCO_2/km (2016) (ICCT, 2020). However, improvements in efficiency are counteracted by an increase in traffic and the ongoing transition toward SUVs. In Germany, for example, emissions from road transport have not decreased since the 1990s (Gössling and Metzler, 2017).

Future policy targets seek to decrease overall emissions.

> "Cars and vans produce 15% of EU's CO_2 emissions. The Parliament approved new legislation to toughen car emissions standards, introducing CO_2 reduction targets of 37.5% for new cars and 31% for new vans by 2030. ... The Parliament is also calling for measures to facilitate the shift to electric and hybrid vehicles." (European Parliament, 2019)

Whether these targets will be reached is unclear. By and large, past policies have not yet disrupted the dominant pathway towards more cars and larger vehicles. Vehicle manufacturers have lobbied against strong emission regulations for decades, mostly with success.[5] They favor technological solutions for carbon targets, even though these might not be sufficient without additional behavioral change (Whittle et al., 2019).

Alternatively, policies could target vehicle users and reduce the need for (and the generic dependence on) automobility, but are more difficult and complex to implement (Whittle et al., 2019). Policies to reverse the SUV trend would likely have to embrace the cultural framing of automobility through which needs emerge (Sovacool and Axsen, 2018).

With regard to future pathways, there are interesting overlaps between the transition toward SUVs and the transition toward EVs. Many vehicle manufacturers - in the EU and elsewhere - seem determined to sell as many conventional SUVs as possible, up to the boundaries set by the various regulatory regimes for carbon emission reductions. At the same time, they also develop electric SUVs because the additional costs of electric battery packs and powertrain can be more readily recovered with premium segment vehicles. Finally, some

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[5] During the period 2020 to 2022 vehicle manufacturers selling in the EU can gain 'super credits' towards their 120 gCO2/km regulated fleet average target for new vehicles, on the basis that every electric vehicle sold (zero gCO2/km) will count double in 2020, 1.67 times in 2021, and 1.33 times in 2022. In this sense, Nissan can sell more Qashqai models on the basis of having sold more Leaf (BEV) models.

automakers develop light-weight 'L-category' EVs such as the Renault Twizy or Citroen Ami, or the BMW i3 (Sovacool et al., 2019), in order to achieve an efficient vehicle with a smaller battery pack that is also more suited for short-distance traffic in congested cities.

3.2 Space tourism

3.2.1 Innovation and context

Space tourism is a service innovation in the rapidly growing space flight industry (Spector et al., 2017). The core idea is to send non-astronaut citizens to outer space for recreational purposes. Commercial space tourism is currently planned at the orbital or suborbital levels, although some firms even speak about lunar tours. Space tourism is in an early stage of development. Different spacecraft, rockets, launching and landing technologies are currently in the stage of prototype development.

In the late 1990s, American businessman Dennis Tito became the world's first space tourist by visiting the International Space Station (ISS) for seven days via the Russian spacecraft Soyuz TM-32.[6] The service was offered as a means to generate income for maintenance of the aging Russian space station. From 2001-2009, a Virginia-based firm Space Adventures, in collaboration with the Russian space agency, sent eight people to the ISS on flights lasting ten or more days.[7] Tickets were sold at 20 Mio USD in 2001 and 35 Mio USD in 2009.[8]

Since the last decade, the space sector has experienced increasing commercialization. In the so-called 'New Space' era, private firms play an increasingly important role, e.g. to drive innovation, although they are still backed by dedicated support from national governments.[9] Private space companies such as Virgin Galactic (with Boeing as minority shareholder), Blue Origin and SpaceX present highly ambitious visions, racing to be the first to provide commercial offerings in the next few years. Billionaire entrepreneurs such as Richard Branson and Elon Musk back these ventures financially and herald recreational space travel as an individual human right for ultimate freedom. While firms explore different technologies (see box), they pursue similar business models. They target

[6] https://www.britannica.com/topic/space-tourism accessed April 20, 2020

[7] https://www.nbcnews.com/mach/science/how-much-does-space-travel-cost-ncna919011 accessed April 20, 2020

[8] https://www.nbcnews.com/mach/science/how-much-does-space-travel-cost-ncna919011 accessed April 20, 2020

[9] https://www.airbus.com/public-affairs/brussels/our-topics/space/new-space.html accessed November 18, 2020

pioneering customers (businesses or ultra-rich individuals) starting with short times in zero gravity.

Space tourism is part of the larger space industry context, which also includes the launch of satellites and the transport of astronauts or goods, e.g. to the ISS. To improve the reliability and costs of their technologies, many space companies exploit the synergies between these different markets as most of them rely on rocket launching. With more advanced technologies and lower costs, there has also been an exponential growth in satellite activities in the last few years given the enormous business value that space-based infrastructure can provide. This is especially true in the field of application services related to telecommunication and earth observation.

Besides short-term plans to massively increase the number of satellites in the next decade, there are long-term endeavors to build a base on the moon, to bring astronauts to Mars or to mine precious minerals in space[10]. Overall, there are many newcomers in the space industry but only some of them have also announced that they will be active in space tourism. The key drivers for space tourism include new technological developments, significant cost reductions, industry competition, and an emerging demand by ultra-rich individuals.

3.2.2 Sustainability implications

Although space tourism may be the cornerstone of large-scale space exploration in the future, commercializing or scaling up leisure space travel is likely to have major consequences for Earth's climate (Spector et al., 2020). Space tourism is inherently energy intense and there are three main types of problematic emissions: Chemicals (chlorine) which lead to Ozone depletion, CO_2 emissions, and soot emissions. The latter two contribute to climate change.

In terms of carbon footprint, each rocket launch would result in about 150 metric tons of carbon[11]. This makes every rocket launch equivalent to about 3 times as much carbon dioxide as a transatlantic flight (with about 50-100 times more passengers). Following the goal of companies like SpaceX to launch once every two weeks, this would accumulate to approximately 4,000 tons of carbon annually, just for one firm. Space companies claim that rockets will become increasingly fuel efficient and their carbon footprint is dwarfed by the carbon emissions of aviation

[10] https://www.moondialogs.org/ accessed November 18, 2020

[11] https://www.smithsonianmag.com/science-nature/spacex-environmentally-responsible-180968098/ accessed April 22, 2020

(860 million tons per year).[12] However, the increase in efficiency has to be weighed against the increase in passenger numbers as costs come down.

In terms of soot (also known as black carbon), latest computer simulations show that the soot emitted by rockets could significantly raise temperatures in the polar regions. The soot is then deposited on the surface, and absorbs more sunlight energy than the snow or ice in these areas. The business plans for space tourism estimated a flight rate of 1,000 suborbital trips per year once the space companies routinely fly passengers for leisure purposes. Every 1,000 launches would leave about 600 tons of soot in the stratosphere which remains more than 40 kilometers above sea level for up to ten years.[13] These black carbon particles steadily absorb sunlight that could significantly exacerbate global warming (Chapman, 2015).

> "Due to particularly harmful 'black carbon' being emitted at very high altitudes, 1000 spaceflight launches per year would constitute an analogous contribution to climate change as currently exerted by the entire aviation industry." (Spector et al., 2017, p. 280).

> "Rocket emissions inherently impact the stratosphere in a way that no other industrial activity does." Martin Ross and James Veda, The Aerospace Corporation (a non-profit organization).[14]

There is an increasing number of voices in the field that call for more attention to the sustainability implications of commercializing space tourism:

> "If we understand rocket emission now, while their impacts are still smaller than aviation's impacts, then proper guidelines and metrics could be established that encourage space industry growth…If we wait until rocket impacts are large, then such actions might be a burden. Research now would be good for the environment and the launch industry." Martin Ross, The Aerospace Corporation.[15]

> "As long as the space tourism industry is developed without the necessary cautions, it remains at risk of becoming the most anti-sustainable tourism sector, with pervasive negative impacts at the global scale. And I for one do not feel comfortable promoting the fancy of the few at the risk of our planet and all that call it home." Asli Tasci, Professor of tourism

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[12] https://www.digitaltrends.com/dtdesign/environmental-costs-of-space-tourism/ accessed April 22, 2020

[13] https://www.newscientist.com/article/dn19626-space-tourism-could-have-big-impact-on-climate/ accessed April 20, 2020

[14] https://www.digitaltrends.com/dtdesign/environmental-costs-of-space-tourism/ accessed April 22, 2020

[15] https://www.digitaltrends.com/dtdesign/environmental-costs-of-space-tourism/ accessed April 22, 2020

3.2.3 Regime formation in flux

The space tourism industry is in a very early stage of development with a cascade of promises, projections and announcements. Regime structures or pathways are yet to be formed. One indication for this early stage is that we see several competing technological designs and business ideas. Examples of the most important technology systems currently tested in the industry are the New Shepard rocket system by Blue Origin and the winged vehicle SpaceShipTwo by Virgin Galactic. While the New Shepard rocket is developed for sending space tourists on brief suborbital flights, the development also received substantial financial and technological support from NASA to improve precision landings on planetary objects as part of the space agency's Artemis program that aims to return human to the Moon by 2024.[16,17] The SpaceShipTwo vehicle is a six-passenger, two-pilot craft developed especially for suborbital tourism. The tests of this space vehicle have so far encountered a few delays but the third test is already underway.[18]

SpaceX is targeting a different tourism segment by promising to send civil passengers on a trip to the ISS, and - in the longer term - even around the moon. SpaceX focuses on developing its Dragon spacecraft and the Falcon Heavy (or Falcon 9) rocket, both of which in May 2020 were successfully used to send two NASA astronauts to the ISS (see box for further details).

Progress in space tourism very much depends on bringing down costs. Compared to the beginning of the NASA Space Shuttle program in 1981 for which the payload cost was more than 50,000 USD/kg, SpaceX claimed a payload cost of less than 3,000 USD/kg in 2018 (Jones, 2018).[19] Based on the latest market assessment in 2018, the cheapest ticket offered by Virgin Galactic to cross the 62-mile-high Karman line that separates the Earth's upper atmosphere and outer space would costs 250,000 USD.[20]

Not only space tourism is still very much in flux, but also the broader space industry is changing. While in the past, space activities primarily took the form of missions led by national governments, activities today are increasingly driven by private firms and industry competition, complemented with support from public space agencies such as NASA. Financial support and exchange of expertise with

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[16] https://www.bbc.com/news/science-environment-54534012 accessed November 19, 2020

[17] https://www.nasa.gov/specials/artemis/ accessed November 19, 2020

[18] https://www.space.com/virgin-galactic-delays-spaceflight-covid accessed November 19, 2020

[19] https://www.nasa.gov/mission_pages/shuttle/flyout/index.html, accessed June 20, 2020

[20] https://www.nbcnews.com/mach/science/how-much-does-space-travel-cost-ncna919011, accessed April 20, 2020

national space agencies were conducive to the progress and knowledge development in private space companies.

> The success of SpaceX in delivering its space tourism promise lies heavily on the Falcon 9 rocket, which is arguably the most advanced rocket in the world as of 2020. It consists of a two-stage design to transport the Dragon spacecraft into the orbit. It is the first orbital rocket that can be reused (upon certain reconditioning). After separation it returns and lands in a controlled way at a specific location. This substantially reduces the cost of rocket launching. Since 2010, the Falcon 9 rocket has been launched for 84 times and has returned to Earth 45 times, out of which 31 of them were recycled and subsequently reused.[1] The Dragon spacecraft furthermore can also be returned to the Earth and reused. Following the successful mission to ISS in May 2020, SpaceX entered a longer-term contract with NASA to send the agency's astronauts to the ISS for future space missions.[1] After securing further collaboration with NASA, SpaceX announced that it will use its current spacecraft and rocket systems to send its first three tourists on a 10-day trip to the ISS sometime in late 2021.[1]

Box 1: Reusable rockets as an innovation that might shape the space industry

3.2.4 First indications of demand but no needs yet

As of today, space tourism is a niche that targets rich and ultra-rich individuals. For a flight to the ISS, a few people paid between 20 and 35 Mio USD in the past (see above). Tickets for several hours in zero gravity are expected to be much cheaper. According to Virgin Galactic, about 650 tickets (250'000 USD each) have already been sold. This is an indication that there clearly is a demand for space tourism and that people are ready to pre-pay tickets, thereby financing missions, whose concept still needs to be proven. It also shows that demand goes up with prices going down.

Of course, it is too early to say that there is a need for space tourism. However, we see that space companies are targeting people's imagination and hopes, thereby working towards creating demand for private space travel. The promotion of space tourism has intensified over time, visions have become more ambitious and seem to convergence around a common set of ideals, or ideographs. Firms appeal to shared values such as sustainability, freedom, a better future, or democracy, to legitimate space tourism (Spector et al., 2020). We list a few examples

Examples of narratives concerning sustainability:

> "Blue Origin believes that in order to preserve Earth, our home, for our grandchildren's grandchildren, we must go to space to tap its unlimited resources and energy. Like the Industrial Revolution gave way to trade, economic abundance, new communities and high-speed transportation - our road to space opens to the door to the infinite and yet unimaginable future generations might enjoy. Paving the way starts now." Blue Origin[21]

> "As space adventure will boost the economy, it likewise will increase our appreciation of how rare and valuable our own planet is. The experience of traveling out of Earth's atmosphere and looking back on the world we inhabit produces a sense of awe and respect. Space travelers will gain a deeper appreciation for our planet and hopefully want to take a more active approach to protecting it when they return to terra firma." Allan Fyall, Professor of tourism marketing[22]

Examples of narratives concerning freedom, a better future and democracy:

> "In time, we expect to be operating a variety of vehicles from multiple locations to cater for the demands of the growing space-user community. Whether that be transporting passengers to Earth orbiting hotels and science laboratories, or providing a world-shrinking, transcontinental service – at Virgin Galactic we will always be striving to open space to change the world for good." Virgin Galactic[23]

> "We are at the dawn of a golden age of space exploration which will transform our relationship with the Earth and with the cosmos." Richard Branson, Virgin Galactic[24]

> "In our drive to democratize space, we seek to inspire young people through space-inspired Science, Technology, Engineering and Mathematics (STEM) initiatives." Virgin Galactic[25]

If the current promises and visions materialize and cost come down in the future, the demand for leisure space travel is likely to become increasingly common among the wealthy. Those who aspire to a trip to space might associate space tourism with personal freedom, or flaunting their higher social status through extravagant leisure activities. This might eventually lead to new kinds of lock-ins around emerging needs such as the 'necessity' of new adventure, new perspectives, and lifetime experience even at the expense of environmental sustainability.

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21 https://www.blueorigin.com/our-mission accessed January 12, 2020

22 https://www.ucf.edu/pegasus/space-tourism/ accessed January 12, 2020

23 https://www.virgingalactic.com/vision/ accessed January 12, 2020

24 https://www.virgingalactic.com/mission/ accessed January 12, 2020

25 https://www.virgingalactic.com/vision/ accessed November 19, 2020

3.2.5 Policy challenges

There are many pressing policy issues for the changing space industry. These include environmental issues (e.g. rocket emissions), space debris (e.g. how to avoid or remove it) or safety regulations, but also questions around access, ownership and control. For example, NASA's Artemis program - which seeks to return to the Moon in collaboration with commercial partners - has steered increasing debate about who should have access to natural resources on the Moon.

Resolving these policy and regulatory issues is challenging and requires a high level of international coordination. International organizations that have started to address space governance issues include the European Space Agency (ESA), United Nations Office for Outer Space Affairs (UNOOSA) which has formed the Committee on the Peaceful Uses of Outer Space (COPUOS), and the International Council for Science which established the Committee on Space Research (COSPAR).

With regard to space tourism, policies and regulations are needed to address the increasing repercussions for climate change and other sustainability issues. At the moment, many aspects of private space travel are not yet regulated and national and international policies on space tourism are either non-existent or at a very early stage of development. Governments have not devoted much focus on regulating emissions resulting from rocket launches for example. Since rocket launches in the past were considered a matter of national security, they have been largely exempted from environmental legislation. However, this perspective has changed since scientists began to question the environmental consequences of the increasing number of private launches by companies at the absence of regulations:

> "Until legislation is put in place, the inequality of environmental harm caused by space tourism will continue...Most of us are here on the surface dealing with the full brunt of the climate crisis...while just a tiny number of people are up there having these opportunities." Mahir Ilgas, environmental action group 350.[26,27]

Overseeing private spaceflight activities or constraining touristic space travels seems to be challenging (Spector et al., 2020). The space industry is transforming rapidly and gains increasing political influence, not just because of its enormous economic potential but also because space tourism targets influential customers. If successfully commercialized and scaled up with current technologies and fuel systems, space tourism is inherently unsustainable if and when space travel becomes an established practice.

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26 https://www.digitaltrends.com/dtdesign/environmental-costs-of-space-tourism/ Accessed April 20, 2020

27 https://350.org/about/ Accessed April 22, 2020

3.3 Summary

Both cases illustrate a set of challenges for unsustainable innovations in different industries and in different stages of development. Table 2 summarizes the main findings.

Table 2: Analytical dimensions and main differences across the two cases

	SUVs	Space tourism
Innovation and context	New product segment in the automobile industry; incremental innovation; driven by profitability; mass market stage, transition in full swing	New service innovation in the rapidly developing space flight industry; radical innovation; driven by new technology and industry complementarities; early stage (prototypes), pre-transition
Sustainability implications (energy and climate)	Inherent increase in energy consumption, conventional engines: above average CO_2 emissions and air pollution	Inherent, massive energy consumption, CO_2 and soot emissions in stratosphere contribute to global warming
Regime formation and path-dependency	Strengthens established regime around individual automobility; strong path-dependency	Fluid structures; no dominant designs yet; potential path formation around reusable rockets
Needs and practices	Increasingly embedded in society, needs around status, safety, leisure, lifestyles	Luxury for the ultra-rich; emerging demand but no established needs or practices yes
Policy challenges and pathways	Policy failure after decades of emission and climate regulations; in conflict with low-carbon transport pathways	Under-regulated sector; window of opportunity to shape future pathways; international coordination as a challenge

The SUV example is about a carbon-intensive socio-technical system, which has been under pressure for decades to reduce its emissions and climate impact. However, it has not only continued on an unsustainable trajectory but even spawned a transition that exacerbates the carbon footprint. This points to deeply entrenched regime structures and strong path-dependencies. One element of the regime includes firms which cling to established business models and use their close ties into policy to prevent effective climate policies (Skeete, 2017; Wells et al., 2013).

Space tourism, in contrast, is a case, where regime structures are still in flux and there are many uncertainties with regard to future pathways. It has been launched as a novel realm of experience and commercial activity, instead of an extension within an established market. Nonetheless, it is likely that the negative climate impacts of space tourism will be enormous if the transition materializes as envisioned by its proponents. So, there is a strong argument to call for public policies to prevent an unsustainable transition.

Also, needs have not yet emerged for space tourism, which means that there is still room to shape and moderate the expectations of future customers. If policies for sustainable space tourism were developed soon, we would expect little to no resistance from potential users.

This is very different in our other case, where the SUV has already become the norm for many users (e.g. for driving your kids to school) and new needs have emerged around it. Automobility more broadly is closely tied to places and situations in which users need a car e.g., to commute to work, because their lifestyles and the surrounding systems (urban planning, housing, infrastructure etc.) have co-developed and reinforced each other (Mattioli et al., 2020). As a consequence, policies such as fuel taxes that seek to break up these structures face substantial resistance.

To summarize, both cases have shown that unsustainable innovations, and the transitions they potentially cause, are of high relevance for policy making and come with major challenges, especially when regime structures have started to form and resist sustainability policies. The cases have also illustrated that unsustainable transitions represent a new, largely undiscovered area with interesting phenomena for transitions research to explore.

4 Implications for policy and research

Unsustainable transitions have important implications for policy making and research.

4.1 Policy implications

Given that we are confronted with existential and increasingly urgent sustainability challenges such as climate change, air pollution, resource depletion or waste production, there is a strong need for public policies to fundamentally transform existing socio-technical systems (Geels, 2020; Schot and Steinmueller, 2018). Policies have to tackle at least three interrelated targets: i) the support of more sustainable innovations and practices, ii) accelerating the decline of established unsustainable systems and technologies, and iii) guiding and constraining unsustainable innovations before they create additional problems on top of those we already have to solve. While the first two are commonly addressed by transitions research (Kivimaa and Kern, 2016; Markard and Rosenbloom, 2020b; Rosenbloom et al., 2020), the latter has received only scant attention so far.[28]

With regard to policy implications, the SUV case is a very interesting example because it was not a development that was somehow overlooked by environmental and climate policy. On the contrary, the car industry has been under scrutiny by scientists, environmental NGOs and policy makers for many years (Geels et al., 2012). That the SUV transition unfolded nonetheless can be viewed as a blatant failure of at least two decades of emission and climate policy in transport. It is also an important reminder of what can happen when influential and ubiquitous socio-technical regimes have formed around technologies with problematic sustainability impacts (Mattioli et al., 2020).

Key reasons why this transition could unfold are related to i) an (incremental) innovation driven from within an existing, resourceful regime, ii) new business opportunities for incumbent firms who could sell the new product at a premium, iii) strong, existing complementarities in the socio-technical system for automobile transport, iv) a deep-routed political influence of the car industry, successfully defending itself against effective climate policies and v) new needs and user practice that emerged (Mattioli et al., 2020; Skeete, 2017). As mentioned before, the SUV example also points to the relevance of needs that emerge around new products. As SUVs have become a new standard in many auto markets, stringent regulations to reduce the use of SUVs will certainly face strong opposition.

Contrary to automobility, space tourism has received very little attention in terms of climate or environmental policy up to now. At the same time, the sustainability repercussions are substantial (Spector et al., 2020). As the systemic structures are still fluid and consumers have not yet developed any practices or needs, there is still room to guide the emerging developments into a more sustainable direction, or to constrain them (Matignon, 2019).

At the same time, policy intervention might not be easy as more and more firms and nations are focusing on the new opportunities and there is an ongoing race towards commercialization that might leave environmental sustainability considerations behind. Also, there is a major challenge with regard to international policy coordination, as firms can evade to those places where regulations are less strict.

However, the already close involvement of public agencies and the importance of government spending[29] also represents an opportunity: Governments and space

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[28] It is important to note that all of these targets require a mix of policies at the intersection of i) innovation and transition policy and ii) environmental and sustainability policy.

[29] In the US, the government expenditure for space programs was 41 billion USD in 2018.

agencies could demand their private partners to tread more carefully when it comes to ambitious visions for space tourism. To let the current window of opportunity pass comes with a great risk as we might see a similar development as in air travel: Once a technology has entered the mass market, its environmental impacts multiply and any restriction will conflict with users' newly established needs.

4.2 What the transition perspective has to offer

In the case of unsustainable innovations, insights from transition studies can complement technology assessment approaches (Ely et al., 2014). First, transition studies highlight the systemic nature of innovation and transition processes. One of the key issues is that (unsustainable) innovations are all the more difficult to change the more they become intertwined with complementary business models, economic interests, infrastructures, consumer practices, needs, etc. (Rosenbloom, 2020). The transitions literature can provide insights into the formation of innovation systems and socio-technical systems that are relevant for policies to address unsustainable transitions (Bergek et al., 2008; Markard, 2020).

Secondly, transitions studies provide us with a perspective on an entire sector (or whole system configuration, McMeekin et al., 2019). This approach provides us with a long-term perspective and with a holistic view, i.e. beyond the assessment of a single technology. It enables us to look at the interplay of various innovations (including sustainable and unsustainable as well as technological, organizational, institutional or policy innovations) and various regime technologies. And it also enables us to think of future (sector) configurations (and their interplay) at a time scale of decades and beyond.

Thirdly, transition approaches have been increasingly engaged with the study of politics and social struggles over emerging innovations and policies (Kern and Rogge, 2018; Markard and Rosenbloom, 2020a; Meadowcroft, 2011; Roberts et al., 2018). To inform policy making, it will be helpful to explore, for example, how early discourses over the shortfalls and benefits over technologies have emerged, and which actors seek to push which kinds of arguments. That way, policy makers can seek alliances with e.g., NGOs that warn against certain developments and industry actors that develop potentially more sustainable alternatives. This for example is especially true for the case of space tourism, as different system actors seek to frame positive and negative narratives on the 'need' for and implications of recreational space travel (Spector et al., 2020).

4.3 What we can learn from unsustainable transitions

As we don't have many insights into unsustainable transitions yet, it is too early for an encompassing discussion of the potential learnings for transition studies. However, we see several promises emerging. The first is about widening the scope of the sustainability dimension. Many studies in our field typically focus on one sustainability challenge (e.g. climate change) in one specific sectoral and spatial context (e.g. the transport sector in the UK). While such a narrow focus has been helpful to address the otherwise high complexity of transitions (e.g. with technological, institutional, organizational and political changes unfolding over long timespans), it bears the risk of overlooking i) related developments in other sectors and places (Andersen et al., 2020; Binz et al., 2020) and ii) other sustainability dimensions (van den Bergh et al., 2015). An example is the promise of electric vehicles (EVs) to become a cornerstone in the transition toward more sustainable transport (Kester et al., 2020). Such a framing overlooks that, especially in cities, many problems such as congestion, accidents, need for parking space, unattractive public transit, poor city planning etc. still remain. Even worse, new sustainability problems may arise such as the increased need for cobalt in EV batteries, which is sourced under precarious conditions in the Democratic Republic of Congo (Sovacool, 2019).

As we study unsustainable transitions, we will certainly find more examples of i) unsustainable elements in sustainability transitions but also ii) sustainable elements in unsustainable transitions (e.g., electric SUVs or reusable rockets). Such a wider view on the complexities of sustainability issues will certainly be helpful to advance research in transition studies.

A second area for conceptual improvements is about the overlap of different transitions happening at the same time (Andersen et al., 2020). In automobility, for example, we have at least three ongoing transitions (SUVs, electric vehicles, autonomous driving and digitalization). These affect each other and create transition dynamics that require us to adapt our conceptual frameworks. One approach to tackle overlapping transitions is the study of deep transitions (Schot and Kanger, 2018) but, of course, there are many more mundane interactions of transitions. One example is that of multi-purpose innovations that trigger changes in a variety of fields. From a sustainability perspective, overlapping transitions pose additional challenges as they may have diverging and perhaps even contrasting impacts on selected sustainability issues (see above).

A related aspect is policy interaction and the increasing complexity when designing policies and policy mixes (Lindberg et al., 2019; Kern et al., 2019). Sustainability transition policies already face substantial challenges when integrating both innovation and decline policies (Markard and Rosenbloom, 2020b). Adding policies to the mix that target unsustainable innovation does not make this task any easier.

From studying further cases of unsustainable innovations and policy responses, we can gather new insights which hopefully facilitate this task.

The fourth issue is about the emergence or deliberate creation of needs in transition studies (see above). This is clearly an under researched issue that relates to the role of users in transitions (Schot et al., 2016; Shove, 2003), the change of practices (Shove and Walker, 2007; Shove et al., 2020) and sustainable consumption (Geels et al., 2015). It is of particular importance for unsustainable innovations because the establishment of new needs and practices is a key element in the formation of rigid regime structures.

5 Conclusion and outlook

With this paper, we have explored a blind spot in sustainability transition studies: unsustainable innovations and transitions. First and foremost, it is an appeal to not only focus on the positive but to also watch out for adversary developments. Given the extent and urgency of many sustainability challenges, we need to work on all fronts to counter emerging as well as maturing practices that are unsustainable. It is a call for policy and research. The policy challenge will be to identify, assess, guide and potentially also constrain unsustainable innovations and the associated transition pathways in order to prevent problems from growing and technologies and lifestyles to become locked-in. The research challenge will be to develop concepts and frameworks that are able to address, e.g. overlapping transitions, multiple sustainability issues and trade-offs, and contrasting transitions, i.e. those that, from a sustainability perspective, go in opposite directions.

Future research can look into a broad variety of unsustainable developments and assess the implications for transition studies in further detail. Potential candidates from an energy and climate perspective could include cruise ship vacations, outdoor heating, cloud computing, fracking, or flying cars. Other studies might want to revisit historical transitions such as the sailing ship classic or the development of jet engines. They all created novel practices and needs with implications for sustainability and we could track the formation of needs and other regime structures, to learn more about windows of opportunity for policy intervention.

Yet another line of research might want to look into sustainability transitions creating unwanted effects or competition between different generations of sustainable technologies (Suurs and Hekkert, 2009; Wirth and Markard, 2011). Examples of the former include biofuels or energy from biomass, which were initially hailed as a solution to reduce GHG emissions in transport and beyond but generated unwanted competition (for arable land) with food production, led to monocultures and were, partly, transported over long distances (Wirth and Markard, 2011). A related example is that of different generations of energy saving lightbulbs, where compact fluorescent lamps are now being replaced by LED lamps (Stegmaier et al., 2014). So, policy making will be confronted with continuously adapting regulations as technologies unfold.

To conclude, studying unsustainable innovations and transitions will open a new strand of interesting research in the field of transition studies. It is high time to address the associated challenges.

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