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Environmental Innovation and Societal Transitions

Disrupting transitions: qualitatively modelling the impact of Covid-19

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Opposed Reviewers:	

Manchester, 23 December 2020

Dear editors,

I am pleased to submit for your consideration the manuscript *Disrupting transitions: qualitatively modelling the impact of Covid-19 on UK food and mobility provision*. The article aims to make a theoretical and methodological contribution to the study of societal transitions based on a comparative analysis of how the Covid-19 pandemic has affected ongoing transition pathways in the UK.

As a team of authors we have worked on this since the early days of the European lockdown, which helped us to engage in a series of deep discussions about the effects of the pandemic. As a result of the need to combine several elements (theorising about critical events, an exposition of methodological rigour in doing transition case studies, as well as thorough empirical analysis of two cases) we have slightly exceeded the maximum word count (with less than 5%), and added an annex with necessary details.

We look forward to hear your reflections on this work,

With kind regards,

Frank Boons
Bob Doherty
Jonathan Köhler
George Papachristos
Peter Wells

Highlights_24-12-2020

- Critical events such as the Covi-19 pandemic are best understood as endogenous to processes of societal transitions
- Qualitative system dynamics modelling provides the basis for rigorous comparative analysis of transition case studies
- The Covid-19 pandemic has had a differential effect on ongoing transitions in UK food and (auto)mobility provision, including the establishment of kernels of new transitions

Disrupting transitions: qualitatively modelling the impact of Covid-19 on UK food and mobility provision

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Disrupting transitions: qualitatively modelling the impact of Covid-19 on UK food and mobility provision

Abstract

The 2020 Covid-19 pandemic provides an empirical testing ground for assessing the impact of critical events on societal transitions. Such events are typically seen as exogenous to the transition process, an assumption which is challenged in this paper. Using a qualitative system dynamics modelling approach we conceptualize transition pathways as sets of interacting sequences of events. This enables the analysis of event sequences that constitute the evolving pandemic as impacting on those pathways. We apply this approach to the provision of (auto)mobility and food in the UK. This shows the way in which the pandemic has had a differential effect on ongoing transitions in both systems, sometimes slowing them down, and sometimes accelerating them. In addition, it reveals how it has established new transition pathways. The empirical work further shows how a qualitative system dynamics modelling approach facilitates an explicit and systematic comparative analysis of transition case studies.

Keywords: Covid-19; transition pathways; system dynamics modelling; automobility system; food system

1. Introduction

The Covid-19 pandemic has led to substantial short-term changes in social practices, especially since March 2020, when national lockdowns proliferated worldwide (ECDC, 2020). Routines of office work, food provision and leisure were suspended, altered, or replaced with new routines. These changes fed into public debate on strategies for dealing with the impact of the pandemic. Such strategies sought to build on changed practices to capture benefits such as reduced air emissions and increased wellbeing among parts of the population. During this period scenarios and proposals for 'green' recovery mechanisms were articulated (i.e. EU, 2020), signalling that the pandemic is a critical event providing the impetus for an overarching transition to a radically different society.

Such articulations neglect that in many sectors, transitions were ongoing when the Covid-19 pandemic started. In the UK sectors of mobility and food provision emergent and centrally guided initiatives were well underway. The national food strategy sought to establish a sustainable and healthy diet for UK citizens, while the electrification of personal mobility was seen as key towards reducing UK carbon emissions (Dimbleby, 2020). This raises the question of how the pandemic, and the societal response, affects ongoing transitions (Milev and Al-Habaibeh, 2020; Gov.uk, 2020a). We might expect them to stall as disrupted economic activity extends into the innovative niches which form the kernel of transitions. Niches might be weakened when critical resources are depleted to sustain current systems. Alternatively, overarching initiatives for a 'green' recovery might strengthen existing

initiatives, embedding them in a wider favourable trend. The impact of Covid-19 as a critical event is thus in need of an analysis that disentangles potentially counteracting effects.

In this paper we conceptualize the pandemic as a disruption of ongoing transition processes or pathways (Geels and Schot, 2007). The aim is twofold. First, we theorize the disruption of transitions in terms of critical events that accelerate, retard, or shift ongoing transition pathways. Secondly, we provide an initial empirical test of these ideas into two UK systems of provision that have been dominated by identifiable socio-technical regimes for decades. Our research questions are:

1. What are the intersecting sequences of events that constitute transition pathways in two UK systems of provision, and how does a critical event such as Covid-19 affect these pathways?
2. How can we meaningfully assess the change in socio-technical systems as a result of Covid-19?

As critical events continue to have an effect years after they occur (as with the 2008 financial crisis (Van den Bergh, 2013), we develop an approach that can be used while the critical event we are interested in is still ongoing. We use system dynamics methodology which allows us to conceptualise critical events as endogenous to the socio-technical system (Richardson, 2011), and is generally well-suited to capture the endogenous dynamics nature of transition processes (Papachristos, 2014; 2018; Kohler et al., 2018; Papachristos, 2019; Papachristos and Struben, 2019). In doing so we extend prior work on sociotechnical system transitions and Covid-19 that has used system dynamics in various ways (Bradley et al., 2020; Sahin et al., 2020; Struben, 2020; Papachristos and Adamides, 2016; Papachristos, 2011). This approach allows us to improve on the way in which case studies are used in transition research (Köhler et al., 2019).

The explanatory approach of transition research and the MLP is based in a process theory (Geels and Schot, 2010, Geels 2002), looking for patterns in sequences of events (Pettigrew, 1997; Abbott, 2001; Langley, 2007). In this mode of theorising, a case description has to include and demonstrate the logic that drives the observed temporal progressions (Van de Ven, 1992). In the context of transition research, transition narratives need to trace and include event sequences and their conjuncture within, and between, MLP levels (Geels, 2011).

Replying to criticism on the lack of methodological consistency (Genus and Coles, 2008), case studies in transitions research require improvement (Köhler et al., 2018) to catalyze the comparative analysis of transition cases to allow the inference of general transition insights (Smith et al., 2010). The use of system dynamics methodology (Sterman, 2000) and causal loop diagrams (CLD) in particular, is one way to analyse systematically transition cases (Sorrell, 2018; Papachristos, 2019). The application to transition research embraces the open-ended character of the MLP that is one of its strengths (Geels, 2011). Explicit representation of the causal connections in narrative sequences with the use of CLDs

will enable replication and critique of the inferences made in a way that is difficult to achieve with a purely narrative representation of transition cases (Griffin, 1993).

In section 2 we provide our conceptual view on how critical events affect transitions. Section 3 discusses how altered system pathways can be assessed. Section 4 presents a methodology for analysing transition pathways, and the way they are affected by shocks. Section 5 presents the analysis for the two sectors. Section 6 discusses interactions between the two sectors. Section 7 concludes.

2. Critical events and disruption of existing transition pathways

Conceptually we draw on transition theory as a set of established theoretical ideas that has been tested extensively using empirical case studies (Köhler et al. 2019). Transition theory posits that changes in sociotechnical systems result from the interrelationship of two modes: change and stability. Key in this process of change are so-called strategic niches: the social sites where configurations of sociotechnical system elements alternative to the existing regime are constructed and tested (Smith and Raven, 2012). Sociotechnical change is conceptualised in terms of regime changes in the social and technical parts of the system that co-evolve and bring about alternate periods of relative stability and periods of major change.

Critical events and system boundary

The established view on sociotechnical transitions conceives of events such as a pandemic as part of the metaphorical ‘landscape’ in which sociotechnical change unfolds: an evolving structural context which affects transitions, but is itself not immediately affected by those transitions. Van Driel and Schot (2005) categorise landscape elements in levels of duration of change: almost unchanging, long-term changes, and rapid external shocks.

The common denominator in this theorising is to **externalise** critical events from the socio-technical system in transition. For rapid shocks, this approach is misleading.

Theoretically it sits uncomfortably with the otherwise constructivist perspective of transition theory (Geels, 2010; 2011). A pandemic is not a neutral and objective phenomenon, but is collectively defined and shaped (Romme 2020). It therefore needs to be drawn inside the system boundary, to conceptualise how it interacts with niche and regime dynamics.

The pandemic is not only an exogenous shock that merely disrupts an ongoing transition. It is not the opposite either, where transition dynamics as a response to the pandemic contribute to landscape changes. Instead, an exogenous shock is mediated to become a partially endogenous phenomenon within spatial and temporal confines. The pandemic is likely to become an inherent feature of our systems that will endogenously drive transition dynamics further. To develop the endogenous view on critical events we proceed in two steps:

Step (1) Define transition pathways as interacting sequences of events using causal loop diagrams and narrative representations of individual sequences;

Step (2) Define sequences of events triggered by pandemic potentially interact with the event sequences constituting transition pathways.

Step (1) Transition pathways as sequences of events

The dynamics between niche and regime, influenced by ‘external change’ have been formulated as ideal types in transition pathways typologies (Geels and Schot, 2007; Smith et al., 2005). We deepen the Geels and Schot typology by identifying key variables in the socio-technical system and their system interrelationships, which leads to a visualisation of the key dynamics of each pathway in a causal loop diagram (CLD; see Annex 1). Each CLD in the Annex summarises the interplay between key sequences of events that constitute a pathway. As these diagrams are complex in showing interrelated sequences of event, Table 1 provides individual event sequences in their formal shape and as a concise narrative.

[INSERT TABLE 1 ABOUT HERE]

The table reveals theorised transition pathways have considerable overlap in their event sequences. Consequently, a simple listing of the presence/absence of sequences is insufficient to determine what transition pathway actually occurs. Additional interpretive steps are required.

Step (2) event sequences that result from a pandemic critical event

To understand the pandemic as an endogenous part of the system we represent Covid-19 and its effects as a set of additional event sequences. The way in which these sequences interact systemically is summarized in Figure 1. Table 2 below describes the additional sequences of events, in three categories:

Responses to minimize health impacts of the pandemic – Sequences S16-S17 are causal loops showing how the number of infections induces a response including the enactment of new practices. New practices can be ones that already were present in niches before the critical event took place or be newly emergent practices consequential from the event.

Economic impacts on regimes and niches – Sequences S18 and S19, in combination with the previously defined sequence S14, specify causal loops where the critical event changes the balance of regime and niche practices which affects the profits reaped from the enactment of regime practices.

General economic impacts – Sequences S20-S22 capture the general economic consequences of the pandemic.

These sequences include variables that also occur in the sequences which make up the transition pathways (Table 2). These shared variables indicate where the pandemic influences transition pathways. The complete set of event sequences (S1-S22) and their interrelations

provides our conceptualisation of the pandemic as endogenic to sociotechnical transitions. Figure 1 combines the separate CLDs in the Annex; individual transition pathways can be identified as combinations of coloured arrows (for instance, the transformation pathway is constituted by the variables connected by solid blue, and solid green arrows). The sequences related to Covid-19 (S16-S22) are indicated by red arrows.

[INSERT FIGURE 1 ABOUT HERE]

Figure 1 is used to assess the effect of Covid-19 on ongoing transitions in food and automobility provision in UK. In general, we expect the overall impact of Covid-19, within a specific domain, on S1-S15 to constitute one of the following:

- A. **Accelerating a transition pathway:** the ongoing transition pathway speeds up, as negative loops are counteracted, and positive loops are strengthened and/or added.
- B. **Retarding a transition pathway:** the ongoing transition pathway slows down, as negative loops are added and /or strengthened that counteract positive loops.
- C. **Shifting a transition pathway:** the type of pathway that characterises the domain changes, as loops are added creating a different basic dynamic. For instance, Technological substitution and de- and re-alignment differ in the presence/absence of S1 and S2. If Covid-19 acts to add or subtract those loops, then the type of pathway changes.

[INSERT TABLE 2 ABOUT HERE]

3. A Methodology for analysing disruption of transition pathways

Building on the above representation of transition pathways and Covid-19 sequences our empirical approach consists of the following steps:

1. Delineate the focal systems of provision based on the purpose of analysis. Vayda's (1983) method of progressive contextualisation was a main guide, choosing an initial phenomenon of interest, around which a first boundary is drawn based on prior knowledge and preliminary investigation. Through iteratively collecting and analysing data, events outside the initial boundary are included until satisfactory understanding has been achieved.
2. Collect data on the systems and their dynamics. Extensive empirical data was obtained through so-called longitudinal field immersion (Wells and Nieuwenhuis 2017). Active immersion in a system of provision has allowed us to identify, access and interpret historical data in both empirical domains. Data for the impacts of the Covid-19 pandemic was collected during the first wave (February – June 2020). Data triangulation data was used where possible to increase validity (Jick, 1979; Johnson et al., 2017). We focused on: (1) data showing how *individual variables* in the model perform over time, using reliable and accepted sources (ONS, OECD, IGD etc.), and (2) data on *links between variables*. Such links represent an underlying structure and can be evidenced by academic literature.

- 209 3. Identify for each system of provision sequences of events from the CLDs, and construct a
210 narrative of sequences and their intersections.
- 211 4. Interpreting the set of sequences for each system, identify current transition pathways
212 using the template CLDs.
- 213 5. Analyse how transition pathways were disrupted. This requires indicators of the impact of
214 the critical event. For socio-technical transitions an indicator should provide reveal the
215 speed and comprehensiveness with which an existing socio-technical regime is being
216 displaced. In our conceptual framework this displacement is defined as the increased
217 enactment of new practices, combined with decreased enactment of regime practices.
218 Proxies for these include the increased sales of artefacts needed for enactment of new
219 practices, and the establishment of infrastructure for such enactment.

220 In the case of 'guided' transitions, such as transitions with specific sustainability
221 objectives, additional indicators can provide insight into the attainment level of
222 objectives. While important, their relevance relies on the realism of assumptions about
223 how the substitution of new practices for regime practices leads to attaining sustainability
224 objectives. If these assumptions are unrealistic, or when unintended consequences occur
225 (for instance because of rebound effects which lead users of energy saving lamps to leave
226 them on longer than normal lamps), then additional indicators are not useful.

227
228 With guided transitions, the additional indicators are thus dependent on the objective
229 envisioned with displacing a given socio-technical regime. We adopted the following:

- 230 • indicators for the acceleration or slowing down of a given transition are based on the
231 objectives that these transitions are perceived to serve.
- 232 • if new objectives emerge as a result of the critical event, this needs to be reflected in
233 the assessment of the changes that occur in the system of provision that is studied.

234
235 Change in both generic and sustainability indicators need to be interpreted with caution.
236 Observed changes in indicators in themselves are not evidence that the change is the result of
237 the critical event. For that we need evidence for a compelling causal narrative, i.e. sequences
238 of events that link the critical event to the observed change. In this paper these are the
239 sequences presented in Table 2.

240 241 **4. Covid-19 and its implications for the transition of UK food and mobility provision**

242
243 We present the results on UK food and automobility provision in sections 4.1. and 4.2. using
244 the same structure to present the impact of the Covid-19 pandemic on ongoing transitions.
245 We chose these empirical domains as they show evidence of ongoing transitions, and have
246 evidently been affected by the pandemic.

247 248 ***4.1. Mobility provision (focused on automobility)***

249 250 ***(1) Statement of system boundary***

We delineate the system as the duality of personal automobility and the automotive industry in the UK, along with other modes including virtual mobility and immobility, and to the UK automotive sector within global systems of production and consumption.

(2) Ongoing transitions in mobility provision: electrification, sharing, autonomy, and digitalisation

Previously, automobility was strongly embedded as the core regime practice. There is long-run evidence of preference for the car (DfT, 2020a), car ownership and licence holding in households (DfT, 2020 b;c). Road transport dominated public infrastructure investment, while the industry enjoyed strong new car sales (albeit cyclical, see DfT, 2020d), and R&D support. The SMMT estimated that the UK automotive sector was worth £202bn GVA to the economy (in 2017). The stock of cars (DfT, 2020e) grew in GB from 2.01 million (1951) to 30.49 million (2019). [S1; S2]. The regime enjoyed strong legitimacy. [S3].

Prior to the pandemic several event sequences indicated a transition. In addition to contestation over e.g. air quality concerns and the emergence of new mobility providers such as UBER [S9], ownership of electric cars was growing slightly [S5] (see DfT, 2020f). Initial investments had been made in public charging points, and incentives were available for both cars and domestic / workplace charge points [S6; S7]. As of 1 April 2020, there were 17,947 public electric vehicle charging devices available in the UK. Since 2015, the number of public charging devices has grown by 402%, (see DfT, 2020g;h). Average distances travelled had reduced over time, and total trip numbers per annum were static (DfT, 2020i). In 2018 a joint R&D fund of £1bn was announced for low carbon vehicles, and £246m for battery electric vehicles R&D along with £250m for connected and autonomous vehicles. [S4-S9 evident to a modest degree].

Transitional change was largely being managed by the automotive industry through institutions such as the Automotive Council, the LCVP, and the SMMT. The government policy document of 2018 (The road to zero) established ‘ambitions’ rather than binding targets, for the share of zero emission vehicles in new car sales by 2030 (Rhodes, 2019).

(3) articulations of possible scenarios of system actors post Covid-19 Statements by system actors, people with a view on possible futures

The automotive industry in the EU and in the UK sought support for new car sales as part of emerging economic stimulus packages. Alternatively, there was stronger support for ‘green growth’ packages, with variable inclusion of support for electric cars across the EU. In the UK and elsewhere there was support for ‘active travel’ solutions (McKinsey, 2020) and reducing the demand for mobility in general (e.g. via remote working). This is evidenced by articulations from industry representatives:

292 *“A strong new car market supports a healthy economy and as Britain starts to plan for*
293 *recovery, we need car retail to be in the vanguard...Safely restarting this most critical sector*
294 *and revitalising what will, inevitably, be subdued demand will be key to unlocking*
295 *manufacturing and accelerating the UK’s economic regeneration.”* (SMMT Chief Executive,
296 Mike Hawes, 05/05/20 [UK])

297
298 Policy makers should:

299 *“Firstly, to take concrete measures to avoid irreversible and fundamental damage to the*
300 *sector with a permanent loss of jobs, capacity, innovation and research capability. Secondly,*
301 *Europe should prepare to stimulate the recovery of our sector, which will be a key*
302 *contributor to the accelerated recovery of the European economy at large.”* (Eric-Mark
303 Huitema, ACEA Director General, 20/03/20 [EU])

304
305 Industry was not unanimous:

306
307 *“I believe that after coronavirus it would be naive to expect everything to return to normal –*
308 *to think that consumers will come back into showrooms asking for petrol or diesel cars.”*
309 Volvo Cars CEO, Håkan Samuelsson, 15/05/20.

310
311 Many critics argued against relaxing carbon emissions reductions rules:

312
313 *“Governments must ensure workers throughout car supply chains remain employed, but this*
314 *is not the time to roll back Europe’s cornerstone emissions rules, such as the CO₂ targets for*
315 *cars, vans and trucks.”* Julia Poliscanova, director of clean vehicles and emobility at T&E,
316 22/04/20.

317
318 While high-level political support for active travel showed a new direction in mobility
319 thinking:

320
321 *“From helping people get fit and healthy and lowering their risk of illness, to improving air*
322 *quality and cutting congestion, cycling and walking have a huge role to play in tackling some*
323 *of the biggest health and environmental challenges that we face. [...] That’s why now is the*
324 *time to shift gears and press ahead with our biggest and boldest plans yet to boost active*
325 *travel – so that everyone can feel the transformative benefits of cycling.”* (Boris Johnson,
326 Prime Minister, 28/07/20).

327
328 *(4) identification of relevant sequences of events (1) operating historically, and (2) seen to be*
329 *emerging as a result of Covid-19*

330
331 Mobility was key to the spread of Covid-19 and for strategies of containment thereafter
332 [S10]. The UK automotive / automobility industry attempted without success to place cars at
333 the core of the recovery process [S21]. The ensuing ‘lockdown’ period and subsequent

austerity in the face of the need for economic recovery packages resulted in a re-ordering of priorities [S21].

The industry suffered a large reduction in new car sales, while many established travel patterns collapsed. New car sales fell by 97.3% in April 2020 compared with April 2019. Data from EVvolumes.com showed electric vehicle sales to the end of 2019 were up 24% compared with 2018 (PHEVs and BEVs) to reach a 3.2% market share. During the first half of 2020 the market share of electric vehicles grew rapidly. As of May, year-to-date 2020 EV sales accounted for a 7.2% share, and more than doubled in absolute volumes as the market overall was at 51% of the equivalent period in 2019 (SMMT, 2020). In the first three months of 2020, 1,436 more BEV charge point devices were available in total, increasing by 9%. Rapid devices also increased by 283, up 10% on the previous quarter. The number of battery electric cars registered for the first time in 2020 Q1 more than tripled (+203%) compared to 2019 Q1 [S21]. Investments in public charge points were brought forward for BEVs [S13].

Google Analytics data shows that compared with the baseline trips fell to retail and recreation (-78%); pharmacies and grocery (-37%); parks (-10%); transit points (-64%); and workplaces (-48%), see Google (2020). Significant behavioural changes regarding mobility followed with the lockdown, some of which are expected to be either enduring for a long time, or effectively permanent [S11; S21]. These changes, underpinned by fear of infection, have acted to support government legitimacy on the lockdown policies [S16] to include remote working, curtailed public events, festivals, and gatherings, and reduced international travel, notably flying. Thus, there was a much stronger challenge to the enactment of regime practices and to the legitimacy of the regime, undermining profitability for incumbents and stimulating the search for new practices [S7].

London Cycling Campaign has advocated a series of steps from short-term response to long-term strategy (LCC, 2020). Cities such as Oakland (US), Bogota, Berlin and Vancouver have allocated lanes on multi-lane roads for pedestrian and cycle use (McKinsey, 2020). Often these measures are ‘temporary’, but they may become permanent [S19]. Pressure groups such as Clean Air for London have argued that the opportunity to retain clean air should not be lost, and traffic levels should be permanently lower [S19]. A Yougov survey across Europe showed strong support for car-free city centres, more bicycle lanes, and a greater emphasis on active travel (Dornier, 2020). The UK government introduced new measures such as monitoring and fines for motorists that park in cycle lanes, improved cycle lane design standards, and funding to support bicycle repairs.¹

In February 2020 it was announced that £5 billion would be available for bus and cycle links, but the emphasis was on buses. In May 2020, the emphasis changed to £2 billion on a ‘new

¹ Also note that the ‘People’s Assembly’ advocated much stronger anti-car measures than the government has so far adopted.

era of cycling and walking'. Emergency bike lanes were established; trials on electric scooters brought forward [S12; S013].

The experienced benefits of reduced automobility, both in the UK and more widely, has resulted in reduced legitimacy for the regime [S10] (see He et al., 2020; Holder, 2020). While profitability for incumbents has collapsed in the short term, those of niche actors (Tesla) have been growing [S12; S13].

While some countries adopted an approach of strongly accelerating the transition to the electrification of automobility, that has not been the case in the UK. Rather, the emphasis has been on active travel, and reducing the 'need' to travel [S17]. However, the pandemic also resulted in an erosion of trust in public transport and shared transport, and in this respect the space available for automobility was not closed [S18]. A survey report in April 2020 by Auto Trader claimed that 48% of existing public transport users would be less likely to do so once the pandemic had passed, and 68% of young people (16-24 years old) thought so (Auto Trader, 2020). In addition, over half (56%) of individuals that had a driving licence but did not have a car thought that Covid19 would now make them consider owning a car [S18].²

The economic consequences of the pandemic are expected to have significant repercussions on mobility and the legitimacy of the prevailing regime [S20]. The Bank of England estimates that the effect of the recession will be equivalent to each household losing £9,000 per annum. Consumer confidence indices (e.g. CEIC, 2020) show that March and April 2020 had large reductions. Unemployment is expected to double to 8% by 2021 while reduced job security will constrain the demand for large credit-financed purchases. Overall, there expected to be a reduction in demand for new cars, but short-term reductions in car use may be offset to some extent by changes in travel mode away from public transport [S18; S20].

(5) Analysis and assessment

Table 3 summarizes the event sequences that were observed in the UK mobility system.

[INSERT TABLE 3 HERE]

Table 3. Event sequences identified in the UK automobility system

Looking first at the system before the critical event the set of event sequences is consistent with the **transformation pathway**. Since Covid-19 pathway changes have taken three forms:

- Acceleration of the transformation pathway** – as noted above, petrol and diesel car sales declined while the absolute number and share of electric cars increased. Use of public transport also declined, while virtual mobility increased;

² Lacking data on impact on car sharing, hire, etc.

- b. *De-stabilisation of the reproduction pathway* – rapid sales declines and the use of factory closures caused stress throughout the existing incumbent regime including retail, petrol stations, and maintenance;
- c. *Parallel emergence of a new (different) transformation pathway* – a new transformation pathway centred on active travel by bicycle and walking, along with micro-mobility in the form of electric bikes and electric scooters (including sharing schemes).

An *assessment* of the transition in terms of the generic indicator of displacement of regime practices is complicated. The moves towards electrification, autonomous driving, and vehicle sharing potentially offers sustainability benefits, but they also have actual or potential disbenefits (Axsen and Sovacool, 2019). In addition, before Covid-19 emerged, automobility was being influenced by other factors, notably micro-mobility and virtual mobility. The balance between substitutional effects and those that are complementary or additional is highly variable depending upon multiple factors. Prior to Covid-19 at least some substitutional effect was anticipated to reduce total automobility (VMT or vehicle miles travelled). In terms of indicators, the following were expected without consideration of Covid-19:

Ahead of Covid-19 the focus of policy for sustainable mobility was on electric powertrain to reduce carbon emissions, but with a long-term perspective that did not envisage full electrification of cars until 2050, and with insubstantial support for active travel. However, in mid-2020 the UK Government published a new policy proposal (DfT, 2020) that identified six priority areas:

- Accelerating a shift towards public and active transport
- Decarbonising road vehicles
- Decarbonising how our goods and services reach us
- Solutions for emissions reductions based on specific locations
- The UK as a hub for green technology and innovation
- Reducing carbon in a global economy

This stance was mirrored by mainstream lobby groups such as The Campaign for Better Transport (CfBT, 2020) which argued for:

- A world-leading public transport network with improved connectivity
- 100 per cent zero-emission road transport and railway
- Permanent improvements to sustain greater levels of walking and cycling
- Changes to the way transport is paid for, including new means to raise revenue.

In both cases, sustainability mobility is defined with a clear focus on decarbonisation and on greater emphasis on both public transport and active travel. Hence policy for sustainable mobility will seek to reverse the losses (of users and revenues) in public transport. The removal of private ownership is under discussion (Lawhon and McCreary, 2020), for example in Wales as are measures such as the Universal Basic Income as an approach to diffusing the ‘jobs versus environment’ dichotomy. Leading academic research suggests that

actual sustainable mobility outcomes will be contested and diverse (Sovacool et al., 2019), but are also likely to include shared and automated electric mobility (Manders et al., 2020). These activities are likely to create new markets and new business opportunities, countering the economic decline of ‘old’ mobility practices (Deloitte, 2019).

4.2. Food provision

(1) Statement of system boundary

The system under consideration is the UK-based food supply from production to consumption. The UK imports almost half of its food with thirty percent coming from the EU and ten to fifteen percent from developing economies; this employs complex supply chains that are vulnerable to disruptions (Lee and Rammohan, 2017). Some UK supply chains are also reliant on EU seasonal labour with UK agriculture employing approximately 70,000 seasonal workers (Defra, 2018).

(2) Description of ongoing transitions: Brexit, healthy diet, eating out

Before Covid-19 food supply by both grocery retail and the non-domestic food sector (hospitality, food to go) was strongly embedded as core regime practices [S1; S2]. Food is the largest manufacturing sector in the UK with 6.3% of GVA worth £120 billion employing 3.98m people (Defra, 2020). The UK’s grocery food retail sector is one of the world’s most concentrated with four leading supermarkets (Tesco’s, Sainsbury’s, Asda and Morrison’s) accounting for 70% of total grocery sales (Garnett et al., 2020). According to Hasnain et al. (2020), grocery retailing is worth £30.3 billion to the UK economy with out-of-home catering worth £36.4 billion. Also, online sales via grocery retailers was static at 7% of total sales (Mintel, 2020).

There was sizeable contestation regarding the legitimacy of food supply related to problems of human and planetary health [S3-S6, S10, 014]. Poor diet in the UK leads to 1 in 7 deaths in Britain every year (Bhunno and Poppy, 2019), accounting for £6.1 billion of annual NHS spend (around 9% of budget). 46% of food and drink advertising spend goes on confectionery, sweet, savory snacks and soft drinks, only 2.5% on fruit and vegetables (Houses of Lords, 2020) [S11]. Almost 23% of children are overweight or obese when they start primary school (NHS, 2019a). Obesity-related hospital admissions increased by 86% in 4 years (NHS, 2019b). Many voluntary initiatives were introduced across the food industry, but were still falling short in meeting dietary recommendations. UK citizens eat the most processed food in Europe (Euromonitor, 2018).

Poor dietary health is compounded by increasing UK food poverty. Between April 2018 and March 2019, the Trussell Trust’s network of food banks distributed 1.6 million food parcels, a 26-fold increase on 2010 (Power et al., 2020; Trussell Trust, 2019a). The Food and Agriculture Organization of the UN estimated in 2018 that around 2.2 million people in the UK are severely food insecure (i.e. with limited access to food, due to a lack of money or other resources) (S10, S14, S15). In addition, the UK food system is responsible for problems with environmental degradation. GHG emissions from UK agriculture were estimated to cost

the UK £3.1 billion per annum (Defra, 2020). Soil degradation costs an estimated £0.9bn - £1.4bn per year (Defra, 2020). Furthermore, regarding UK biodiversity 41% of species in the UK are declining (S10, S11).

There was some evidence of industry voluntary transition with retailers responding to the fourfold increase in the number of UK vegans (Twine, 2018) by launching new vegan food ranges [S5-S8]. Furthermore, several retailers launched sustainability initiatives in partnership with NGOs e.g. Tesco-WWF partnership to halve the environmental impact of food shopping (WWF, 2020) (S4-S9). The National Farmers Union made a public commitment to net zero GHG emissions by 2040 (Waters, 2020). There was also the emergence of food hubs to aggregate and localise food supply, plus the growth of urban indoor vertical farming enterprises (Edmondson et al. 2020; Guzman and Reynolds 2019) [S12-S15]. These efforts were complemented by £46.5 million UKRI and UK Government research funding in the Transform the Food Systems Programme, recognizing the failure of business as usual [S4, S12]. However, according to the House of Lords, the food industry and the UK Government have failed to take the necessary action (House of Lords, 2020). Many Government proposals to impose restrictions on the marketing, advertising and price promotion of less healthy foods have so far failed to progress beyond consultation stage [S002].

A final transition was posed by EU Exit at the end of December 2020, leading actors across the food supply chain to assess their dependency on EU suppliers and markets for products. Grocery retailers had been making contingency for a no-deal Brexit by working on contingency plans including diversifying supply from new sources. (Glotz, 2019).

(3) Articulations of possible scenarios of system actors post Covid-19 Statements by system actors, people with a view on possible futures (Wake-up Call).

Those suffering from obesity are twice as likely to die from Covid-19 (Tan et al. 2020). According to the House of Lords select committee (2020) chaired by Lord Krebs,

“The Covid-19 crisis should serve as an urgent wake up call to the Government. People should be able to access not only enough food, but also the food that they need to stay healthy. [...] We hope one of the outcomes of Covid-19 and the rise in home cooking is move away from our reliance on processed food”.

Dave Lewis outgoing CEO of Tesco said recently,

“...the problems facing the UK food system cannot be left to the market. We need not simple incremental change, but heavy-duty food systems transformational change. The sort of change that means we all have to bring our expertise together and work in a very different way”.

Andrew Opie of the British Retail consortium said,

“It’s thanks to the food industry that the UK has remained resilient during the Covid-19 pandemic. We have shown what is possible in labelling, reformulation, removal of trans fats and healthier promotions. We just need universal application of those and support from government in the Covid-19 recovery period”.

These narratives demonstrate an appetite for a shift in transition towards rule changes for a healthier diet. In addition, they appear to call for strong government.

(4) Identification of relevant sequences of events (1) operating historically, and (2) seen to be emerging as a result of Covid-19

Home cooking has been boosted by lockdown and shutdown of the eating-out sector [S42, more in-home leisure and work time, and the positive connotations these activities enjoy with both economising and healthiness. The UK grocery sector has experienced unprecedented sales growth (Kantar World Panel, 2020) with double digit growth every week [S1-S2]. To support grocery retailers during the pandemic the UK government also provided business rate relief enhancing their profits further [S1, S2] (Fresh Talk Daily, 2020). 45% of adults reported doing more home cooking [S5-S6], within which scratch cooking has been the main focus (Kantar World Panel, 2020). The sector saw a 25% in fresh fruit and vegetable sales and increases in organic category sales of fresh produce (S17). There has also been an increase in alternative business models that take fresh produce direct from farmer to consumer [S13, S14] leading to a 111% increase in demand for UK fruit and vegetable box schemes (Wheeler, 2020).

With fears of Covid-19 there is an increasing interest in healthy diet, exercise and home cooking to boost immune systems [S17, S18-S22]. To support this the UK Government in July 2020 announced a new Obesity Strategy ‘Better Health’ to lose weight and beat Covid-19 (DoHSC, 2020) which involved rule changes to advertising unhealthy food and drink before the 9pm children’s watershed (S9-S11, S16, S17, S19, S20). This appears to signal a shift in transition with stronger government intervention with new rules for the food industry. The Covid-19 outbreak also sparked a rapid increase in usage of online purchasing thanks to the dramatic shift among consumers from in-store to online in response to the lockdown mandate and aversion to busy public spaces (S19). A sizeable 34% of adults said that they had increased the amount of online shopping they were doing as of April 23 2020 (Kantar World Panel, 2020). While some of the demand prompted by the outbreak will ebb, some will bring lasting growth for online sales (S3-S4) (Kantar World Panel, 2020) and scale-up by the grocery sector e.g. Tesco online sales nearly 50% up [S7]; Waitrose opening third fulfilment centre.

Increase in Inequalities

A YouGov survey commissioned in partnership with the Food, Farming and Countryside Commission (FFCC), showed 1.5 million reporting that they'd gone a whole day without eating since the lockdown came into effect, and 7.1 million say they've had to reduce or skip meals. Rising unemployment is predicted in 2020/2021 with 1 in 3 people actually better off during Covid-19 period, thereby increasing disparity (S18).

Shopping Local

After the Covid-19 outbreak 28% of adults report shopping more from local businesses, which is corroborated by Kantar data (Lee, 2020) [S19]. This reflected necessity, with supermarkets struggled to meet demand early on, as well as a desire to support small local businesses, with an invigorated community spirit during the crisis. The solidarity and appreciation for small, local businesses may prove to be a lasting legacy (S11-S15). This Localism trend comprises niche adaptations such as increased orders for indoor vertical farming equipment (at scale), app-based provision and Local Food Hubs direct supplying to consumers.

(5) Analysis and assessment

Table 4 summarizes the event sequences that were observed in the UK mobility system.

[INSERT TABLE 4 HERE]

Table 3. Event sequences identified in the UK food system

The event sequences observed prior to the pandemic are consistent with the **reconfiguration pathway**. The critical event of Covid-19 and the sequences of events it has given rise to have had the following effect:

- a. **Strengthening of the sequences associated with reproduction of the regime** – despite initial disruption to supply chains the grocery retail regime has been strengthened by the pandemic. This has enabled significant investments in online infrastructure, indoor vertical farming and in store safety. Several niches have emerged focused on adaptation of the out of home sector such as vegetable box schemes.
- b. **Acceleration of a desire to see healthy diets** – increase because of poor UK dietary health being exposed by the pandemic. More cooking from scratch with fresh produce and also government intervention with the new Obesity Strategy launched in July 2020. This provided new legislation to curb the advertising of unhealthy products to young people.
- c. **Emergence of a new reconfiguration pathway** - the shift to local retailers and food providers can be seen as a new pathway.
- d. **Destabilisation of the non-residential food sector** which had grown significantly in the past 10-years to be larger than grocery retail.

An **assessment** of the transition due to Covid-19 shows a strengthening of the grocery supermarket regime giving them the resources from increased profits to invest in scaling up

infrastructure to meet the growing demand for online retailing (Cummins et al., 2020). However, the non-residential sector has experienced significant decline showing the largest fall in pay of any sector with 8.8 million employees being furloughed under the UK Coronavirus job retention scheme (ONS, 2020). It is clear the shock of the Covid-19 pandemic has revealed the wicked problems in the prevailing food system of declining sustainability (human and planetary health). Shanks et al. (2020) voice their public health concerns regarding potential disruptions to food supplies due to ‘no-deal’ EU Exit. Obesity, driven by a food system that encourages consumption of cheap energy-dense food quickly emerged as a leading risk factor in Covid-19 mortality. The new UK government obesity strategy, and the increased fruit and vegetable consumption combined with increases in local supply demand demonstrate that Covid-19 could provide a trajectory towards a more sustainable food system.

We are now in the worst recession since the 1930s, in a second wave of Coronavirus and about to exit the EU with many parts of the food sector warning of inflationary pressure on the price of food (Choi et al., 2020). The new National Food Strategy launched its interim report in July 2020 recommending:

- A food security strategy for the UKs growing number of disadvantaged families to shore-up the diets of the most vulnerable children with healthy start vouchers to gain access to free fruit and vegetables
- Legislative restrictions on advertising unhealthy foods and associated fiscal measures
- Improved public sector recruitment of food and drink to promote healthy sustainable approaches
- Incentivise food sector disruptions that reduce the amount of foods that are high in fat, sugar and salt (HFSS).
- Empower consumers with honest nutritional labelling on all foods in retailing and non-residential catering.
- Incentivise farmers to increase soil health, biodiversity and reduce greenhouse gas emissions

5. Comparing systems of provision

Based on the insight provided in the individual systems of provision we can now compare them to see how the pandemic, as a critical event, led to sequences of events that affected ongoing transitions. Table 5 summarizes the main findings.

[INSERT TABLE 5 ABOUT HERE]

Regarding the *pre-Covid transition pathway* we find a difference, with mobility following a transformative pathway while the food system displays evidence of a reconfiguration pathway. This difference lies not in so much in the presence or absence of sequences of events, but rather in the strength of (1) the sequences responsible for reproduction (S1-S3),

which are weaker in the mobility system than in the food system, and (2) the extent to which alternatives to regime practices constitute a viable alternative to the regime, or are too weak to play that role. In automobility, there are indications in 2020 Q1 data (just pre-Covid-19) that the adoption of BEVs was accelerating. For that period there was no clear evidence of a change in the distribution of transport modes. In the food system, although problems of poor diet and obesity had been recognised before Covid-19, there was no evidence of an accelerating pace of change towards alternative systems such as organic products or regional food supply chains. These were stable, but a small proportion of the market.

Looking at the *effect of Covid-19 on pathways*, both systems show effects in different directions: some ongoing transitions are accelerated while others slow down, and in both systems new transition pathways emerge, as summarized in Table 5.

Regarding the generic outcome indicator for a transition (displacement of regime practices) the two systems are radically different: while reproduction sequences are weakened in mobility, they are strengthened in food, leading to a differential effect on regime stability.

In automobility, the immediate effect is to destabilize both the automobility regime and the public transport systems (rail and bus). What is uncertain is the extent to which increased working from home and reduced household trips for shopping, leisure etc. may be a permanent change in mobility behaviour. There has also been a change in emphasis in government policy to support cycling and walking much more strongly than pre-Covid-19. Furthermore, there has been (so far) no large-scale government support for the automobile regime, either in terms of market support for fossil-fuelled car sales or in terms of support for retail sales or maintenance infrastructure. Support for retail sales and maintenance could be made compatible with BEVs, but the policy so far supports a change in direction of the transition.

In the food system, Covid-19 brought about at least three major changes in behaviour. The change to homeworking increased the amount of home cooking. This was reinforced by the restriction and closure of the eating out sector, leading to increased sales in the regime grocery sector. Simultaneously, homeworking together with restriction and closure of the entertainment sectors led to a major increase in online shopping. A further effect has been an increasing concern in the population for health issues, leading to an increase in sales of fruit and vegetables, organic foods and also locally produced foods. Another impact of Covid-19 has been an increase in food poverty.

There are two themes that are common to the automobility and food systems in the impacts of Covid-19. One is the reduction in personal mobility leading to a sudden major increase in the substitution of physical transport by online retail. The other is a sudden major increase in the importance placed on health, leading to an increase in active transport modes and a change towards 'healthier' and local food. A possible outcome is that in both systems ongoing pathways have been partially re-orientated towards health and, in consequence, there is convergence between the two systems of provision. The encouragement of active travel sought partly to alleviate short-term concerns with virus transmission, but also became part of

a long-term concern to improve social health on the basis that a fitter population is better placed to resist the effects of the virus. In consequence, the reduced use of cars to visit restaurants or to go shopping for food, alongside increased active travel and home cooking, speaks to this convergence of transition pathways around health. In macroeconomic terms, the shutdown of the eating out and leisure sectors may cause a long-term decline in the sector, thus reducing travel to leisure activities and demand for food for eating out.

Several of the new practices are part of the response to the pandemic, such as home cooking and active travel. This means that they are fragile, in the sense that it is not clear how these pathways will continue once the sequences constituting the pandemic will weaken/disappear. Viewing niches as platforms for the development and enrolment into new practices, we can build on insights from Theories of Practice (Warde 2005) to assess conditions under which these practices can be retained.

In automobility, new transition outcomes are constrained by structural dependence upon car use alongside embedded cultural dependency. The alternative outcomes of active travel and virtual mobility have weakened the regime, but distrust in public transport has strengthened the regime.

6. Conclusions

We used a system dynamics approach to qualitatively model transition pathways in the UK food and automobility systems of provision. Our analytical ambition is complicated by our timing: it is impossible to assess whether observed changes are inflection points in trends that in five or ten years can easily be labelled as a transition. We therefore focused the analysis on how Covid-19, as a critical event, has affected ongoing transition pathways. The CLD analysis provided a structure for the collection and interpretation of empirical material. It enabled us to interpret the empirical material to identify changes in transition dynamics in the two socio-technical systems as a result of changes in policy and behaviour arising through the Covid-19 pandemic (research question 2).

The cases of automobility and food provision showcase how an initially exogenous event becomes part of the system dynamics that constitute transition pathways. We can now draw conclusions on three distinct topics: (1) the need to make critical events endogenous to the analysis of socio-technical transitions, (2) insights specific to the ongoing transition in the provision of food and automobility in the UK, and (3) the usefulness of making transition pathways explicit as a causal loop diagram where recognizable sequences of events interact.

Critical events become endogenous

Our exemplary cases clearly show how a critical event generates sequences of events that become part of overall system dynamics that constitute transition pathways (research question 1). This has several possible effects. First, a transition pathway that was ongoing

prior to the event can be accelerated or decelerated. We observe that this type of effect can differ for parts of a transition, i.e. some aspects of a transition are slowed down whereas others are accelerated. A key variable in our cases clearly is the income for incumbents generated because of regime practices being enacted, but other variables are important as well. In more general terms this means that critical events can change the strength of existing sequences of events. A clear example of this is the strengthening of regime reinforcing sequences in food provision, and a decrease of these sequences in the automobility system (see Table 5).

Secondly, new transitions emerge as a result of a critical event. In our cases we see the establishment of new niches which bring back past practices, such as active mobility and home cooking. These practices are an integral part of the response to the pandemic, providing evidence for how the critical event is endogenous to system dynamics.

Insights into our empirical cases

Our cases show evidence of how a critical event results in a variegated effect on existing transition pathways as well as the emergence of new pathways. As to changes in existing pathways, the combination of slowing down and acceleration is a direct result of the different ways in which existing transitions align with the societal response deemed necessary. The need to constrain infection rates ultimately requires reductions in social contact, which leads to changed practices of food and mobility provision. Buying food in local shops and using online platforms to deliver ingredients and meals is consequently accelerated. In contrast with the food system, mobility in general is reduced when social contact is reduced, in part countered by shifting from collective forms of mobility to personal mobility.

While we observed the emergence of new practices, we are careful to interpret these as full-blown transitions. With the pandemic ongoing we cannot definitively conclude which new pathways will persist. Nevertheless, there are indications that conditions for retaining changed practices over a longer period are fulfilled in specific cases such as more hours worked from home.

The case of Covid-19 also makes clear how governmental policy can create conditions for the rapid emergence of new transitions, such as active travel and home cooking. Covid-19 has increased the legitimacy of governmental intervention and the results provide evidence for its efficacy. This deserves further study as it is unclear to what extent such legitimacy can be retained over a longer period.

Methodological advances

The use of CLDs to explicitly define sequences of events enables transparent case descriptions and comparative analyses. Crucially, it facilitates the analysis of critical events as an endogenous phenomenon, showing how a critical event, and the societal response to it, becomes endogenous to systems of provision in transition. Inspecting the causal chains that constitute transition pathways enables an assessment of how a critical event can change the causal loops and therefore change the transition pathway.

In developing the CLDs we have made explicit how transition pathways consist of a limited number of sequences of events; the overlap of sequences across transition pathways indicates that the assessment is not only in identifying the presence or absence of a sequence, but also in the relative strength of sequences.

Our method to the analysis of ongoing (possible) transitions can be extended to other cases; it thus responds to the call for case study methodologies for transitions that enable comparative analysis and can perhaps enable the development of general insights (Smith et al. 2010; Köhler et al. 2019).

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FIGURES AND TABLES

Causal Loop	Causal loop variables	Strengthening +/ weakening -	Concise narrative representing causal loop
	P0: Causal loops in the reproduction pathway		
S1	enactment of regime practices → ⁺ profit to incumbents → ⁺ regime-supportive investment → ⁺ enactment of regime practices	+	<i>The continued enactment of regime practices generates profit for incumbent producers, which they use to invest in a way that supports continued enactment of regime practices</i>
S2	enactment of regime practices → ⁺ profit to incumbents → ⁺ resources for market control → ⁻ change of rules → ⁻ enactment of regime practices	+	<i>The continued enactment of regime practices generates profit for incumbent producers, which can be used as a resource to control markets, including the prevention of rule changes that would lead to a reduced enactment of regime practices</i>
S3	enactment of regime practices → ⁺ legitimacy of regime → ⁻ change of rules → ⁻ enactment of regime practices	+	<i>The enactment of regime practices supports the legitimacy of the regime, which reduces the chance that rules are changed in a way that makes enactment of regime practices more difficult</i>
	P1: Causal loops in the transformation pathway		
S4	enactment of regime practices → ⁻ enactment of new practices → ⁻ enactment of regime practices	+	<i>The enactment of regime practices precludes the enactment of new practices, which would reduce the enactment of regime practices</i>
S5	profit to incumbents → ⁺ niche-supportive investment → ⁺ enactment of new practices → ⁺ profit to incumbents	+	<i>Profit generated by incumbents is used to invest in a way that supports niches controlled by incumbents. This leads to the enactment of new practices which generates profit for incumbents</i>
S6	profit to incumbents → ⁺ niche-supportive investment → ⁺ available infrastructure for enactment of new practices → ⁺ enactment of new practices → ⁺ profit to incumbents	+	<i>Profit generated by incumbents is used to invest in niche infrastructure. This supports the enactment of new practices which generates profit for incumbents</i>
S7	profit to incumbents → ⁺ search for new practices → ⁺ actor enrolment → ⁺ enactment of new practices → ⁺ profit to incumbents	+	<i>Profit generated by incumbents provides resources for the search for new practices. This search induces actors to enrol in new practices, leading to enactment of new practices which generates profit for incumbents</i>
S8	profit to incumbents → ⁺ niche-supportive investment → ⁺ resources for rule change → ⁺ change of rules → ⁻ enactment of regime practices → ⁺ profit to incumbents	+	<i>Profit generated by incumbents is used to support the niche, providing resource for rule changes favourable to the niche. The resulting changes in rules leads to enactment of new practices which generates profit for incumbents</i>
S9	legitimacy of regime → ⁻ emergent need for new practices → ⁺ search for new practices → ⁺ enrolment	+	<i>Reduced regime legitimacy feeds the emergent need for new practices, which instigates a search for new practices.</i>

	→ ⁺ enactment of new niche practices → ⁻ legitimacy of regime		<i>This leads to enrolment in new practices which reduces regime legitimacy</i>
	P2: Causal loops in the de-alignment and re-alignment pathway		
S1-S3	See above	+	
S10	legitimacy of regime → ⁻ emergent need for new practices → ⁺ search for new practices → ⁺ enrolment → ⁺ enactment of new practices → ⁻ enactment of regime practices → ⁺ legitimacy of regime	+	<i>Reduced regime legitimacy feeds the emergent need for new practices, which instigates a search for new practices. This leads to enrolment in and then enactment of new practices. This reduces enactment of regime practices, further reducing regime legitimacy</i>
S11	Actor enrolment → ⁺ enactment of new niche practices → ⁺ actor enrolment	+	<i>Actor enrolment in new practices leads to enactment of new practices, which stimulates further actor enrolment</i>
S12	enactment of new niche practices → ⁺ profit to niche actors → ⁺ niche-supportive investment → ⁺ enactment of new niche practices	+	<i>Enactment of new practices generates profit for niche actors which they invest to further support the niche. This facilitates further enactment of new practices</i>
S13	enactment of new niche practices → ⁺ profit to niche actors → ⁺ niche-supportive investment → ⁺ infrastructure for new practices → ⁺ enactment of new niche practices	+	<i>Enactment of new practices generates profit for niche actors which they invest to further support the niche by creating infrastructure. This facilitates further enactment of new practices</i>
S14	enactment of new niche practices → ⁺ profit to niche actors → ⁺ niche-supportive investment → ⁺ resources for rule change → ⁺ change of rules → ⁺ enactment of new niche practices	+	<i>Enactment of new practices generates profit for niche actors which they use as a resource for rule changes favourable to the niche. These rule changes facilitate further enactment of new practices</i>
S15	enactment of new niche practices → ⁺ profit to niche actors → ⁺ niche-supportive investment → ⁺ resources for rule change → ⁺ change of rules → ⁻ enactment of regime practices → ⁻ enactment of new niche practices	+	<i>Enactment of new practices generates profit for niche actors which they use as a resource for rule changes favourable to the niche. These rule changes reduce the enactment of regime practices which facilitates further enactment of new practices</i>
	P3: Causal loop diagram in the technological substitution pathway		
S1-S4 S10- S15	See above	+	
	See above	+	
	P4: Causal loop diagram in the Reconfiguration pathway		
S1-S15	See above	+	
	P5: Causal loop diagram 'disruptive change', a sequence of transition pathways		
S1-S15	See above	+	

Table 1. Transition pathways specified as sequences of events

Causal Loop	Causal loop variables	Strengthening +/ weakening -	concise narrative representing causal loop
	Responses to minimise health impacts		
S16	Covid-19 impact → ⁺ legitimization of government action for lockdown practices → ⁺ change of rules → ⁺ enactment of new practices → ⁻ Covid-19 infections → ⁺ Covid-19 impact	-	<i>The impact of Covid-19 raises the public fear for infection which increases legitimacy of government-induced lockdown practices. This result in change of rules which affects the enrolment in new practices that lowers the number of C19 infections</i>
S17	enactment of new niche practices → ⁻ public fear of infection → ⁺ enactment of new niche practices	-	<i>Enactment of new practices reduces the public fear of infection, which leads to reduced enactment of new practices</i>
	Economic impacts on regimes and niches		
S18	Covid-19 impact → ⁺ legitimization of government action for lockdown practices → ⁺ change of rules → ⁺ enactment of new niche practices → ⁻ profit to incumbents → ⁺ regime supportive investment → ⁺ enactment of regime practices	(not a loop)	<i>The impact of Covid-19 increases the legitimacy of government action to induce lockdown practices. This leads to changes of rules which lead to the enactment of new practices which reduces profits to incumbents. These have less resources for regime supportive investment, leading to reduces enactment of regime practices</i>
S19	Covid-19 impact → ⁺ enactment of new niche practices → ⁻ profit to incumbents → ⁺ resources for market control → ⁺ change of rules	(not a loop)	<i>The impact of Covid-19 leads to the enactment of new practices which reduces profit to incumbents, who then have less resources for market control which leads to a change of rules</i>
S14	See previous table		
	General economic impacts		
S20	enactment of new niche practices → ⁻ regime economic activity → ⁺ profit to incumbents → ⁺ regime supportive investment → ⁺ enactment of regime practices → ⁻ enactment of regime practices	+	<i>Enactment of new practices reduces regime economic activity which reduces the profit to incumbents. This reduces resources available for regime supportive investment which reduces enactment of regime practices. This advances the enactment of new practices</i>
S21	enactment of new niche practices → ⁺ profit to niche actors → ⁺ niche supportive investment → ⁺ enactment of new niche practices	+	<i>Enactment of new practices increases the profit to niche actors. This increases resources available for niche supportive investment which advances the enactment of new practices</i>

S22	enactment of new niche practices → ⁻ regime economic activity → ⁺ profit to incumbents → ⁻ bailouts to preserve employment and boost economic activity → ⁺ enactment of regime practices	-	<i>Enactment of new practices reduces regime economic activity which reduces the profit to incumbents. This invites bailouts to incumbents to support regime activity, i.e. enactment of regime practices</i>
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Table 2. The impact of Covid-19 on transition pathways specified as sequences of events

Sequence #	Ongoing transition	Covid-19 impact
1	Strongly embedded regime practices, normal profits, and regime-supportive investments.	Significant decrease in regime practices resulted in significant decrease in regime profitability. Reduced investment (e.g. in new models; new dealerships, etc.) will result in reduced enactment of regime practices
2	Strong enactment of regime practices, normal profits, alternative modes excluded by (not changing) rules.	Significant decrease in regime practices resulted in significant decrease in regime profitability resources for market control, hence allowing more scope for a (negative to regime) change of rules and reduced enactment of regime practices.
3	Enactment of regime practices gave strong regime legitimacy, low incentive to change rules or regime practices quickly hence ongoing (slow) transition to electrification.	Significant reduction in enactment of regime practices leads to decreased legitimacy of the regime. As the legitimacy falls so the scope for a change of rules increases (e.g. with allowing micro-mobility) and hence a reduction in the enactment of regime practices. Parallel reduction in public transport modes.
4	Enactment of regime practices gave little scope for new practices and reinforced existing regime practices.	Falling enactment of regime practices has resulted in growing enactment of new practices (active travel; remote working), and hence a reduction in the enactment of regime practices.
5	Normal profitability allowed some experimentation in niche supportive investment and enactment of new practices.	Falling profit to incumbents has stimulated niche-supportive investment and the enactment of new practices. This has not (yet) led to profit to incumbents.
6	Normal profitability allowed some experimentation in niche supportive investment and new infrastructure, thence enactment of new practices,	Falling profit to incumbents has been neutral on niche-supportive investment (no extra incentives for BEVs) including the available infrastructure for enactment of new practices (steady policy on charge points) resulting in the enactment of new practices but not profit to incumbents.
7	Normal profitability allowed some experimentation in enactment of new practices and enrolment, thence enactment of new practices.	Falling profit to incumbents has led to the search for new practices and enrolment in those practices, resulting in the growth in enactment of new practices but not profit to incumbents.
8	Normal profitability influenced by Brexit. Experimentation in niche supportive investment but the substantive rule change was reduced political support for automotive industry interests, while enactment of regime practices had stagnated and profits to incumbents had started falling.	Falling profit to incumbents has resulted in niche-supportive investment for other modes (e-scooters and e-bikes), and resources for rule change (making e-scooters legal on the road, creating new bike lanes). These developments have undermined the enactment of regime practices, which in turn will result in lower profit to incumbents (including e.g. car dealerships).
9	Legitimacy of the regime challenged by e.g. air quality and CO ₂ emissions and had resulted in emergent need for new practices and enactment of new practices that generally were supportive of the regime.	Significant challenge to the legitimacy of the regime during the 'lockdown' period, but also significant impacts on competing modes (trains, buses) or complementary demand modes (air travel, ship cruises). Therefore, the experienced need for new practices has stimulated a search for new practices, and some enrolment and enactment of new

		practices, with continued negative consequences for the legitimacy of the automobility regime.
10	Legitimacy of the regime challenged by e.g. air quality and CO ₂ emissions and had resulted in emergent need for new practices, enrolment, and enactment of new practices that had slightly reduced the enactment of regime practices, while were generally were supportive of the regime.	The falling legitimacy of regime drove an emergent need for new practices, and a search for new practices, increased enrolment (more people using active travel, remote working, and EVs) and the enactment of new practices with declining enactment of regime practices driving declining legitimacy of the regime. However, public transport also suffered from falling legitimacy, while informal surveys suggested an increased appetite for automobility.
11	There was modest evidence that enrolment resulted in enactment of new practices (EVs; car sharing; micro-mobility) and hence to greater enrolment.	There was a much stronger enrolment that supported the enactment of new practices that in turn assisted in further enrolment.
12	There was modest evidence that enactment of new practices increased profits to new entrants (Tesla; UBER; micro mobility), which in turn stimulated more niche-supportive investment and the enactment of new practices.	It is too early to be sure that the enactment of new practices has increased profit to niche actors, thereby driving niche-supportive investment and the further enactment of new practices. Some niche practices such as car sharing and ride hailing have declined significantly. Tesla has maintained (modest) profitability and gained market share. Niche micro-mobility suppliers have not yet reported.
13	There was modest evidence that enactment of new practices increased profits to new entrants (Tesla; UBER; micro-mobility), which in turn stimulated more niche-supportive investment and available infrastructure for new practices to increase enactment of new practices.	The impact on new infrastructure has mostly been in the form of (temporary) cycle lane provision, and some acceleration in charge point provision for EVs. There is clear evidence of greater use of active travel, but this might be seasonal and / or temporary.
14	There was modest evidence that enactment of new practices increased profits to new entrants (Tesla; UBER; micro-mobility), which in turn supported resources for rule changes (car-free and zero emissions zones) leading to increased enactment of new practices.	There is stronger evidence for the enactment of new practices, at least in terms of a change of rules reinforcing the enactment of new practices. This does not appear directly related to improved niche profitability but is a political / policy initiative at the highest level to link increased active travel with improved health outcomes and hence better resilience to the pandemic.
15	There was modest evidence that enactment of new practices increased profits to new entrants (Tesla; UBER; micro-mobility), which in turn supported resources for rule changes (car-free and zero emissions zones). Changes in the rules had not notably impacted on the regime except in so far as Brexit altered production and market conditions.	The evidence for this loop is not strong. The enactment of new practices from Covid-19 has not yet been shown to profit niche actors, and niche-supportive investment has not been in automobility. The resources for rule change and the change of rules might reduce the enactment of regime practices if they remain intact, leading to the enactment of new practices.
16	Not present	The emergence of Covid-19 infections has increased public fear of infection (i.e. emergent need for new practices) and provided legitimization of government action for lockdown practices that have severely curtailed automobility but also many forms of public transport.

17	Not present	The enactment of new practices has reduced the public fear of infection and therefore increased the enactment of new practices. This is often captured in the phrase 'new normal'. New practices have been shown to reduce the rates of infection, hence allowing such practices to become more embedded.
18	Not present	The emergence of Covid 19 infections has increased legitimization of government action for lockdown practices, hence driving a change of rules and the enactment of new practices. The profitability of incumbents does not appear to be a consideration per se, hence there is a negative implication for regime supportive investment and the enactment of regime practices. Cut-off date for pure ICE new car registrations brought forward from 2024 to 2030.
19	Not present	As with S020 but with regards to resources for market control and a change of rules. Hence, there is a negative implication for regime supportive investment and the enactment of regime practices.
20	There is modest evidence that economic conditions following Brexit decision had resulted in the enactment of new (trading) practices, some breakdown of regime firms (e.g. closure of Honda assembly plant)	The enactment of new practices has been accompanied by decline in economic activity. Falling GDP will accelerate the breakdown of regime firms (or change in profit to incumbents). This (growing) breakdown will in turn reduce regime supportive investment and the enactment of regime practices.
21	There is no evidence that enactment of new practices in the context of reduced economic activity resulted in the breakdown of niche firms or increased niche supportive investment or the increase of enactment of niche practices.	The enactment of new practices has been accompanied by decline in economic activity and partial breakdown of niche firms (e.g. UBER). Still, there is growth in niche supportive investment leading to further enactment of niche practices.
22	There is no evidence that enactment of new practices in the context of reduced economic activity resulted in the breakdown of regime firms (or change in profit to incumbents) or reduced bailouts to preserve employment and boost economic activity resulting in increased enactment of regime practices.	The enactment of new practices has been accompanied by decline in economic activity. Falling GDP will accelerate the breakdown of regime firms (or change in profit to incumbents). There is not strong evidence for bailouts to preserve employment and boost economic activity and therefore the enactment of regime practices. Cut-off date for pure ICE new car registrations brought forward from 2024 to 2030.

Table 3. Sequences identified in the (auto)mobility system

Sequence	Ongoing transition	Covid-19 impact
1	Strongly embedded regime practices, normal profits, and regime-supportive investments.	<p>Significant growth in grocery supermarket regime practices. In fact, UK grocery sector has experienced unprecedented sales growth during the Covid-19 pandemic (Kantar World Panel, 2020). 45% of adults reported to have done more home cooking as a result of the outbreak, which has resulted in significant increase in regime profitability.</p> <p>This has not been the case in the Out of Home sector (hospitality and food service sectors), which had to lockdown, resulting in store closures, bankruptcy, furlough of millions of workers in the out of home sector.</p>
2	Strong enactment of regime practices, normal profits, alternative modes excluded by (not changing) rules.	This has led to increased investment in online supply infrastructure and provision combined with increased donations to food aid providers (IGD, 2020).
3	Enactment of regime practices gave strong regime legitimacy, low incentive to change rules or regime practices.	<p>Various House of Commons select committees have commended the role played by the Grocery sector during the pandemic increasing this sectors legitimacy (House of Commons, 2020).</p> <p>However, impact of Covid-19 on those people suffering from dietary ill-health has led to rule changes (see S021). In addition, some frustration as House of Lords Report (Hungry for Change) criticised the government for a lack of action on the negative health impacts of our food system.</p>
4	Enactment of regime practices gave little scope for new practices and reinforced existing regime practices.	<p>Some enactment of new practices has resulted increase in home cooking due to remote working. Grocery sector report increase in organic category sales of fresh produce (S0019) .With fears of Covid-19 there is an increasing interest in healthy diet, exercise and home cooking to boost immune systems. McKinsey are calling this homebody trend. Also, increase in online shopping due to fear of infections in busy supermarket environments. Regime responded with increased on-line provision but also redesign of store footfall, new queuing and cashless systems.</p> <p>Out of home has responded by changing to table service only, closely monitored numbers, takeaway provision and screen partitions and cashless systems.</p>
5	Prior to Covid-19 there was some evidence of industry voluntary transition to niche	Falling profits in out of home sector has resulted in new B2C localised supply of food produce and

	supportive investment and new practices e.g. mainstream retailers responding to the fourfold increase in the number of UK vegans (Twine, 2018) launching new vegan food ranges .Furthermore, a range of UK grocery retailers launched sustainability initiatives in partnership with NGOs e.g. Coop Future of Food and Tesco-WWF partnership to half the environmental impact of their shopping basket (WWF 2020). The National Farmers Union making a public commitment to net zero GHG emissions by 2040 (Waters 2020).	investment in new collaborations and donations to alleviate rising food poverty due to the pandemic.
6	Increased profitability to incumbents has allowed some experimentation in niche supportive investment and new infrastructure, thence enactment of new practices, but this was not always profitable for incumbents e.g. food donations to charities.	Some significant donations from grocery retail incumbents to tackle food poverty and employment drives to recruit workers made redundant in hospitality sector by supermarkets to maintain staffing levels due to increased demand due to home working and cooking.
7	Normal profitability has allowed some experimentation in enactment of new practices and enrolment. EU Exit and fears of no deal have meant grocery sector has been implementing new practices by diversifying supply supply e.g. Coop 'Better Strawberries' group in Morocco, changing product specifications, forward contracting, extra warehousing etc. (The Grocer, 2020). In addition, grocery retailers have been forward buying currency due to no deal fears to try and maintain their profits.	Increasing costs to incumbents (hygiene, less footfall) has led to the search for new practices e.g. online and enrolment in those practices, resulting in the growth in enactment of new practices to maximise profits. Hospitality sector has been adapting to new take out practices, using partnerships with deliveroo, taxi companies etc. to keep operating but lower levels of profit. EU single market has been crucial in maintaining food supplies in the pandemic due to undisrupted supply. Any problems associated with port delays would be a problem during a second wave. Particularly if this was in the winter when our food imports from the EU are at a higher level in terms of volume (ONS 2019).
8	A range of UK grocery retailers launched sustainability initiatives in partnership with NGOs e.g. Coop Future of Food and Tesco-WWF partnership to half the environmental impact of their shopping basket (WWF 2020) (S004-S009). The National Farmers Union making a public commitment to net zero GHG emissions by 2040 (Waters 2020). There was also the Emergence of food hubs to aggregate and localise food supply plus the growth of urban indoor vertical farming enterprises but still niche (Edmondson et al. 2020; Guzman and Reynolds 2019) (S0012-S0015). However, a lack of progress in tackling childhood obesity has reduced political support for the food industry. In addition, downward pressure from grocery discounters	As of June 2020, a sizeable 28% of adults said that they were shopping more from local businesses since the start of the Covid-19 outbreak. The Kantar World panel have termed this trend <i>Localism</i> . This solidarity and appreciation for small, local businesses may prove to be a lasting legacy. This has led to a number of niche adaptations such as increase orders for indoor vertical farming equipment (at scale), hydroponics. In addition, some mainstream players eg. Ocado also scaling-up vertical indoor farming around distribution depots. Local Food Hubs have shown resilience in Covid-19 period leading to series of new direct supply chains to consumers.

	has put downward pressure on grocery profit levels.	
9	Legitimacy of the regime challenged need for new practices particularly associated with negative human and planetary health impacts of the food system re obesity and GHG emissions, negative impacts on biodiversity etc.	Some challenge to grocery sector which required investment in new spaced queuing one way systems, screens at check outs etc. plus major investments in new online delivery infrastructure. Now new legislation re better health. Out of home sector has needed changes in going direct to consumers.
10	Legitimacy of the regime challenged by the negative impacts of the food system e.g. CO ₂ emissions and had resulted in emergent need for new practices, enrolment, and enactment of new smart farming practices, alternative proteins etc.	The falling legitimacy of livestock regime has driven the need for new practices. Growing sales of fresh vegetables and fruit. Also fast food outlets have struggled to bounce back so far post lockdown (
11	EU Exit will mean new Environmental Land management Scheme which will pay incentives for sustainable approaches not just yield. Increased number of regenerative farmers (Future Farmers), commitments also by regime to cut GHG emissions (WWF-Tesco partnership).	Concern growing though re EU Exit coupled with the impact of Covid-19 that new trade deals e.g. with US will lower environmental standards.
12	There was modest evidence that enactment of new practices increased profits to new entrants e.g. Quorn Foods, but limited supportive investment	It is too early to be sure that the enactment of new practices has increased profit to niche actors, thereby driving niche-supportive investment and the further enactment of new practices.
13	There was modest evidence that enactment of new practices increased profits to new entrants (e.g. Regenerative Farmers, Food Hubs etc.) ,which in turn stimulated more niche-supportive investment and available infrastructure for new practices to increase enactment of new practices.	The impact of Covid-19 has shown the interest in direct purchasing from farmers e.g. ShopAppy. Demand for shorter supply chains and growing interest in vertical hydroponic approaches e.g. Letusgrow. Increase interest in home cooking.
14	There was modest evidence that enactment of new practices increased profits to new entrants. Some examples of voluntary rule changes such as environmental stewardship incentives ,premiums for organic production etc.	There is stronger evidence for the enactment of new practices, at least in terms of a change of rules reinforcing the enactment of aiming to stimulate better health via advertising legislation on unhealthy produce. The regime still tried to resist though despite evidence.
15	Prior to Covid-19 Outbreak UKRI and UK Government announces research funding of £46.5 million pound to invest in research to improve human and planetary health called the Transform the Food Systems Research Programme. This was a recognition that it could not be business as usual	The enactment of new practices from Covid-19 is clearly an opportunity to pivot our food system. There is early evidence that some niche actors have profited particularly those developing new direct B2C supply chains, fresh produce suppliers etc. However, the grocery regime is certainly strengthened. Plus, it is also best placed to navigate EU Exit.
16	Not present prior to pandemic.	The emergence of Covid19 infections has increased public fear of infection (i.e. emergent need for new shopping practices) and provided legitimization of government action for lockdown practices that

		have severely reduced food to go sector. Grocery sector has absorbed the demand as there has been a huge shift to home working, home cooking and fears of shopping environments hence increases in online approaches e.g. click and pay, click and collect etc.
17	Not present	The enactment of new practices has reduced the public fear of infection and therefore increased the enactment of new practices e.g. online provision, direct purchasing from farmers. This is often captured in the phrase 'new normal'.
18	Not present	The emergence of Covid 19 infections has increased legitimization of government action for lockdown practices, hence driving a change of rules and the enactment of new practices. This could be an opportunity for a new focus on tackling unhealthy diet but too early to tell if rule changes will be strong enough.
19	C19 infections, enactment of new practices, change of profit to incumbents and change of rules	UK Government on 27 th July 2020 announced a new Obesity Strategy 'Better Health Campaign' to lose weight and beat Covid-19 (DoHSC 2020) which involved rule changes to advertising unhealthy food and drink before the 9pm children's watershed.
20	New 25-year Environment plan and associated new Environmental Land Management scheme i.e. public value for public goods was being developed aiming for a Green EU Exit. New Agricultural bill was also preparing the ground for a new approach to UK food production.	The importance of food security has meant the grocery sector has so far benefited from the pandemic. Falling GDP will accelerate the breakdown of some regime firms (or change in profit to incumbents) and a new approach to food poverty will be required to avoid civil unrest and reduced educational attainment.
21	There is no evidence that enactment of new practices in the context of reduced economic activity resulted in the breakdown of niche firms or increased niche supportive investment or the increase of enactment of niche practices.	The enactment of new practices has been accompanied by decline in economic activity but so far not in the grocery sector. Currently still, there is growth in niche supportive investment leading to further enactment of niche practices. The out of home food sector has seen the need for new approaches and new investment in online technology and associated logistics.
22	There is no evidence that enactment of new practices in the context of reduced economic activity resulted in the breakdown of regime firms (or change in profit to incumbents).	The grocery sector continues to experience record sales (increasing proportion online). However, out of home sector is experiencing job losses, firms going bankrupt etc. Falling GDP will accelerate the breakdown of regime firms in the out of home sector.

Table 4. Food System Table of Sequences

		AUTOMOBILITY	FOOD
<i>Analysis of pathways</i>			
pre-covid-19 pathway		transformation	reconfiguration
Effect of Covid-19 on pathways	Accelerate	Transformation towards electrification' Public statement (18/11/20) to reinforce shift to electrification. Ban on new pure ICE cars brought forward ten years to 2030.	Online purchase + home delivery has replaced shopping in physical stores. Nielsen reports a 14% increase in online grocery sales, which equates to an extra 600,000 households shopping for food online for the first time in the UK (Nielsen, 2020).
	Slow down	Observed in the shift back out of public transport towards cars; economic impact has constrained the ability of industry to support the electrification transition	All practices of eating out have been drastically reduced to temporary lockdown closures . Data suggests recovery of this sector will be slow. A quarter of the customers will only feel comfortable to patronize a sit-down restaurant when their communities' ability to test, trace, and isolate Covid-19 cases is significantly improved (Gursoy and Chi, 2020).
	Shift	Emergence of a transition to active mobility, virtual mobility, in terms of enactment of practices and articulation in visions of post-Covid-19 society	Increase in home cooking and decrease in consumption of prepared meals as more people have time to cook. Poor diet identified as one of three top risks of death from Covid-19 and UK Government launches new Obesity Strategy on 27 th July 2020.
<i>Assessment of outcome indicators [change resulting from the pandemic]</i>			
Displacement of regime practices		Regime has been weakened	Grocery regime has been strengthened
Advancement of pre-Covid-19 transition outcomes	Electrification: accelerate sales of electric vehicles		healthy diet increased purchase of fresh fruit and vegetables as more people home cook. obesity levels continue to increase
	Autonomous driving: No specific outcome		EU exit concerns from various quarters about impact on fresh fruit and vegetable supply to the UK regarding port delays, price inflation.
	Carsharing: Reduced car sharing, taxis, etc.		Eating out: UK public concerned about eating out without proper track and trace system in place.
New transition outcomes	Active mobility: Increased cycling and walking		Shopping locally, convenience stores experience market growth
	Reduced user trust in public transport:		Home cooking: reduction in sales of prepared meals and increased consumption of fresh ingredients as more people cook from scratch at home.
	Major Reduction in trips with substitution by Virtual mobility; shopping delivery; home working		Significant increase in digital grocery shopping

Table 5. Summary of key findings in the UK automobility and food systems

ANNEX 1

The annex provides individual causal loop diagrams for each transition pathway, which are combined into figure 1. As part of the article main text. Each CLD contains the sequences as listed in Table 1 (included in main text). For the conventions that we have followed in drawing these CLDs, see Lane DC. 2000. Diagramming conventions in system dynamics. *Journal of the Operational Research Society* 51(2), 241-245, and Sterman (2000 chapter 5).

Path P0. Reproduction process: If there is no external landscape pressure ('regular change' in Suarez and Oliva's typology), then the regime remains dynamically stable and will reproduce itself.

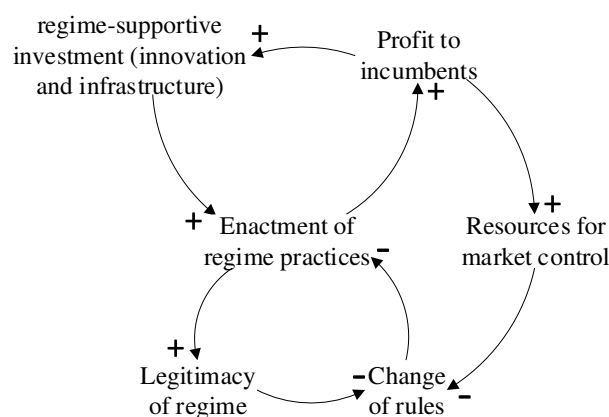


Figure 1 Causal loop diagram of the reproduction pathway

Regime reproduction is the result of the sequences of events S1, S2 and S3.

P1. Transformation path: If there is moderate landscape pressure (‘disruptive change’) at a moment when niche-innovations have not yet been sufficiently developed, then regime actors will respond by modifying the direction of development paths and innovation activities.

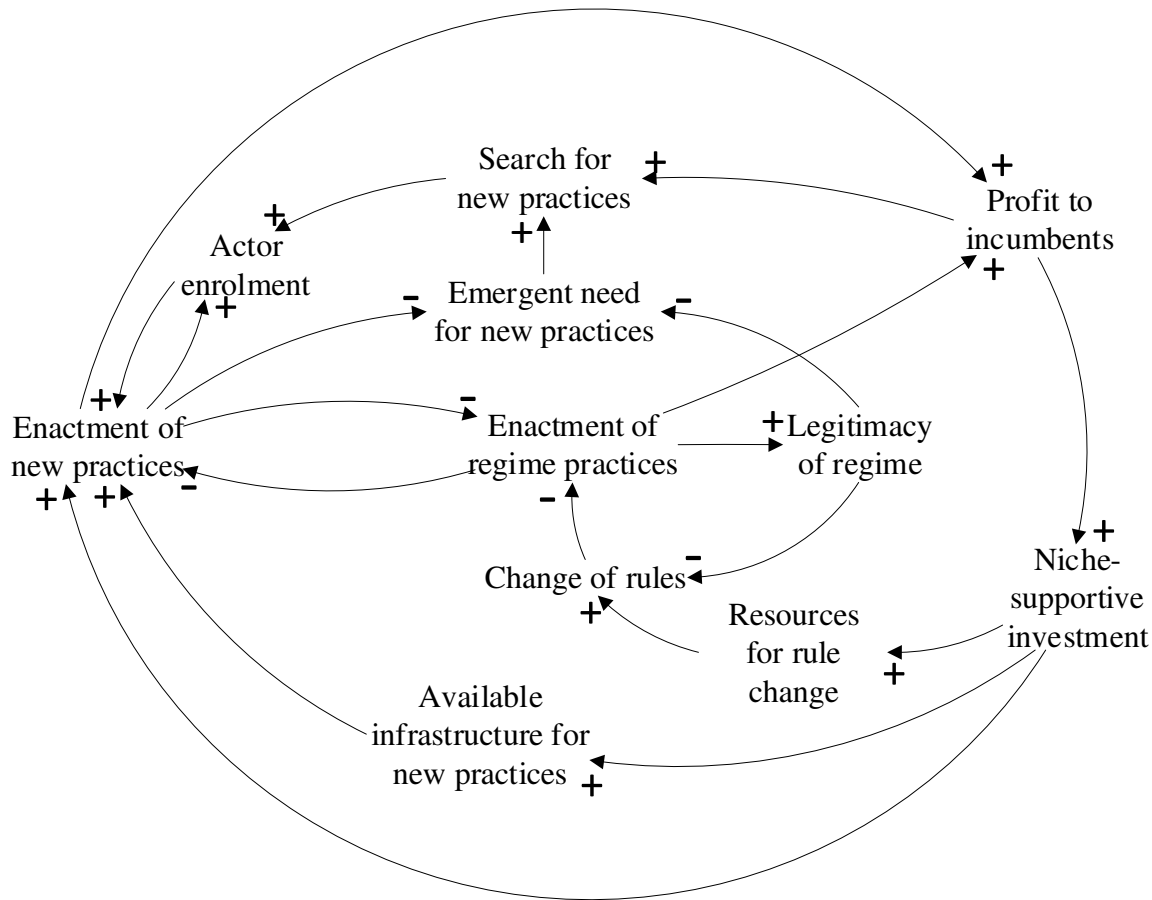


Figure 2 Causal loop diagram of the transformation pathway

In this pathway there is no longer a loop that sustains regime practices. Instead, enactment of regime practices supports investment into the development and infrastructure for new practices.

P2. De-alignment and re-alignment path: If landscape change is divergent, large and sudden (‘avalanche change’), then increasing regime problems may cause regime actors to lose faith. This leads to de-alignment and erosion of the regime. If niche-innovations are not sufficiently developed, then there is no clear substitute. This creates space for the emergence of multiple niche innovations that co-exist and compete for attention and resources. Eventually, one niche-innovation becomes dominant, forming the core for re-alignment of a new regime.



Figure 3 Causal loop diagram of de-alignment and re-alignment pathway

This pathway is marked by the absence of S-001 and S-002, which indicate the fact that incumbents do no longer believe in the viability of the regime. After a delay, sequences kick in which translate the emergent need for new practices into action. Over time, this erodes the enactment of regime practices, as S-003 by itself is not strong enough to reproduce the regime.

P3. Technological substitution: If there is much landscape pressure (‘specific shock’, ‘avalanche change’, ‘disruptive change’) at a moment when niche innovations have developed sufficiently, the latter will break through and replace the existing regime

This pathway is almost identical to de- and re-alignment; the difference is that there may be resistance of regime actors (indicated by the presence of S-001 and S-002).

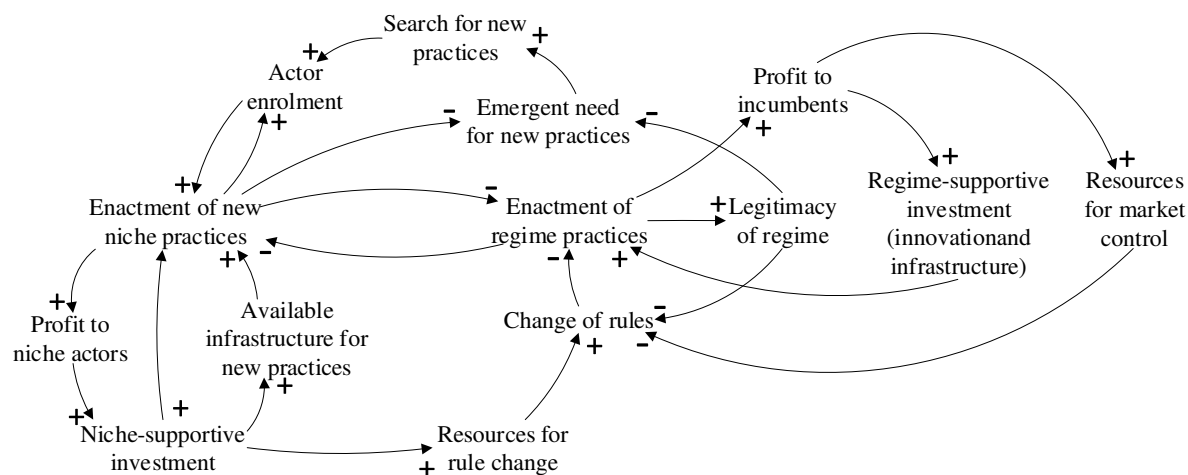


Figure 4 Causal loop diagram of technological substitution pathway

P4. Reconfiguration pathway: Symbiotic innovations, which developed in niches, are initially adopted in the regime to solve local problems. They subsequently trigger further adjustments in the basic architecture of the regime.

The sequences of events bring into play both niche actors and incumbents, both of them involved in shaping, and then profiting from, the enactment new practices. This pathway is constituted by all previous sequences of events.

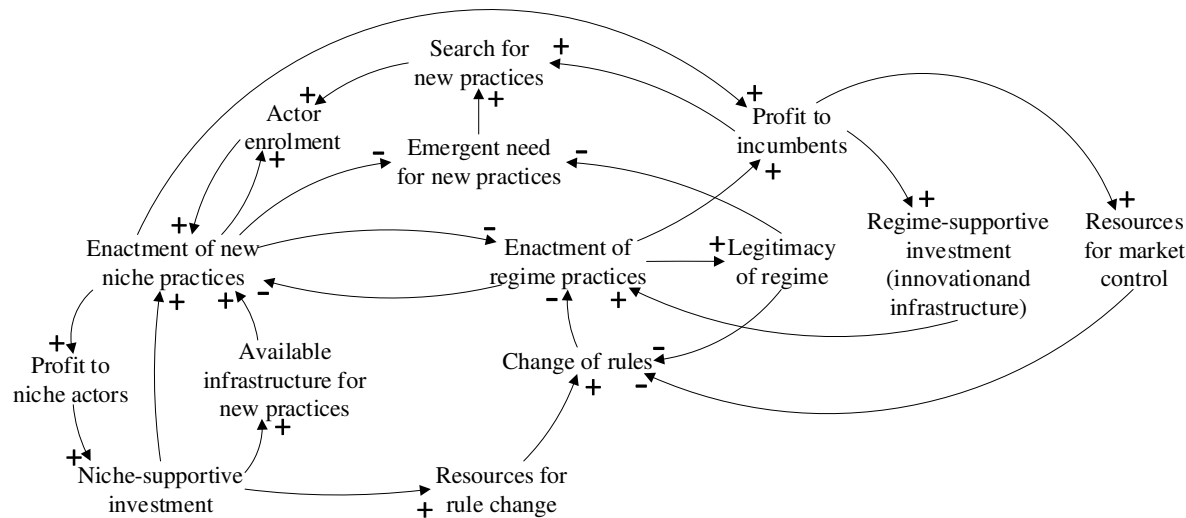


Figure 5 Causal loop diagram of reconfiguration pathway

P5. If landscape pressure takes the form of ‘disruptive change’, a sequence of transition pathways is likely, beginning with transformation, then leading to reconfiguration, and possibly followed by substitution or de-alignment and re-alignment.

As this is a combination of previous pathways, it is constituted by the sequences presented above.