Contact Information

Institution:	University of St Gallen Institute for the Economy and the Environment Tigerbergstrasse 2 9000 St. Gallen
Author:	Gieri Hinnen
Postal Address:	Seefeldstrasse 173 8008 Zürich Switzerland
Email:	gieri.hinnen@unisg.ch
Mobile:	+41 79 681 95 10
Fax:	+41 71 224 27 22

GROWING OUT OF CARBON-LOCK IN?
AIRLINES, BIOFUELS AND PATH CREATION

Carbon lock-in describes the outcome of a path dependent process whereby market, organizational and institutional barriers inhibit the diffusion of low-carbon technologies. Path creation theory predicts that actors engage in 'mindful deviation' to escape such situations of lock-in. With respect to carbon lock-in, researchers have analysed path creation strategies of entrepreneurs, incumbents and investors. This paper adds the new perspective of firms as consumers of energy ('firm-consumers'). The paper investigates how firm-consumers create paths to escape carbon lock-in. It analyses triggers, challenges and instruments of such path creation strategies through a case study of European airlines' biofuel strategies in the period 2008-12. The findings indicate that firm-consumers are aware of the path dependent challenges and that they mindfully use distinct instruments to create contingencies and feedback-loops in order to increase market adoption of renewable energies. The respective instruments are used both in the Market and Socio-Political arena.

Key words: Path Dependency, Path Creation

INTRODUCTION

Aviation suffers from carbon lock-in (Lawson, 2012). The alignment of technological, institutional and organizational factors leads to a lack of disruptive innovation and thus to continuing addiction to fossil fuel (Unruh, 2000, 2002; Unruh & Carrillo-Hermosilla, 2006). However, in recent year cracks have emerged in aviation lock-in. Fuel Prices have tripled in the last decade, putting airlines under enormous pressure (Euromonitor, October 2012). NGO have become increasingly vocal in their criticism of the environmental impact of aviation. Aviation today only represents about 3% of global man-made carbon emissions, but the sector is growing rapidly: Air traffic grew an annualized rate of 4.4% from 1989-2009, carbon emissions grew by a staggering 11% between 2005 and 2010 (ICAO, 2009; TheEconomist, 2012). Regulators have become more rigid. The European Union included aviation in its Emission Trading Scheme EU ETS starting 2012, thus putting a price on carbon (Vespermann & Wittmer, 2011). Against this background various stakeholders have proposed the adoption of sustainable biokerosene as a potential remedy for the fossil fuel dependent industry (ICAO, 2011; WWF, 2011). Several airlines have recently started their own biokerosene projects. British Airways has announced a $500m Joint Venture with biofuels producer Solena, KLM has co-founded the Biofuels Trading House 'SkyNRG' and the Lufthansa Group has set-up its own biofuels department. The National Resource Defence Council today counts 22 major airlines that have started biofuels projects (Hammel, 2013). Airlines, so it seems, are actively engaging in path creation (Garud & Karnøe, 2001; Garud, Kumaraswamy, & Karnøe, 2010) to escape a carbon locked-in system. How are they doing this?

I investigate airlines' biofuel strategies in order to analyse how firms as energy consumers ('firm-consumers') are trying to escape carbon lock-in through path creation. Thus, I build my research on path dependency (Arthur, 1994; Dobusch & Schussler, 2012; Unruh, 2000; Vergne & Durand, 2010) and path creation theory (Garud & Karnøe, 2001; Garud et al., 2010). Taking on a firm perspective, I conduct an embedded case study of the three largest European airlines' biokerosene engagements during the period 2008-2012. Thereby the paper at hand addresses two gaps in current research on path creation. First, I add a new perspective. Previous research largely focused on the roles of entrepreneurs, investors and policy makers, but has so far neglected firm-consumers. Second, I add new empirical evidence to the theory of path creation through an analysis of the airline industry.

The structure of the paper is as follows. First, is discusses path dependency and path creation theory and develops a framework for analysis. The second chapter introduces the research method. The third part analyses airlines' path creation strategies, specifically addressing its triggers, challenges and instruments. The final part discusses the findings and concludes.

THEORERTICAL BACKGROUND

The following three sections will develop the analytical framework used in the case study. The first part discusses path dependence and creation, the subsequent chapter elaborates on carbon lock-in. The last part proposes a framework to cluster path creation strategies.

Path Dependency and Path Creation

Path Dependency, in its broadest definition, describes a suboptimal long-term outcome as a result of self-reinforcing processes that are triggered by contingent events (Arthur, 1989; David, 1985; Dobusch & Schussler, 2012). In essence, it states that 'history matters'. It is applied to the analysis of different systems and has its intellectual roots in the science of complexity (Ashby, 1956; Simon, 1996). Path dependency has been frequently applied to technological and social systems. Examples include the computer keyboard (David, 1985), nuclear energy (Cowan, 1990), regional clusters (Arthur, 1994; Kenney & Burg, 2001) and the development of organizations (Burgelman, 2002; Sydow, Schreyögg, & Koch, 2009).

Vergne and Durand (2010) define path dependency as a "*…property of a stochastic process which obtains under two conditions (contingency and self-reinforcement) and causes lock-in in the absence of exogenous shock"* (p. 737). This highlights the five constituting points of path dependency. First, it describes both a *process and an outcome,* but separates the two (Garud et al., 2010). Second, it states that a process is not path dependent if it is already predetermined by initial factors (Goldstone, 1998). Rather, it is 'contingent' on initial factors, but the effects are random and unpredictable. Third, processes must be to some extend 'self reinforcing'. Dobusch and Schussler (2012) argue that such positive feedback loops are the only necessary condition for path dependency. Fourth, the initial conditions and the positive feedback loops underlying a path dependent process lead to 'lock-in'. This describes a sub-optimal outcome where actors are not able to evolve to a new, optimal state (Garud et al., 2010). However, 'sub-optimality' is often impossible to proof in reality, as this would in essence require to analyse an alternative world with a different development path (Lawson, 2012; Vergne & Durand, 2010). I thus follow Lawson (2012) who implies that an equilibrium conceptualisation of lock-in is impractical. I use lock-in to describe a situation where a switch to an *alternative alignment of elements* seems impossible. Finally, path dependency scholars argue that a 'locked-in' outcome cannot be changed endogenously. Thus, the concept 'decentralises agency' (Dobusch & Schussler, 2012) as the individual actor is unable to endogenously change the system.

The counterargument to path dependency is *path creation* (Garud & Karnøe, 2001; Garud et al., 2010; Kenney & Burg, 2001; Lovio, Mickwitz, & Heiskanen, 2011). Garud and Karnøe (2001) introduce the idea of path creation as a process of 'mindful deviation'. They imply that agency – e.g. the firm – can play a deliberate role in shaping the evolution of specific path. With respect to technology, path creation thus describes the mindful management of the co-evolutionary processes underlying the development of technology, i.e. shaping both social practices and technologies (Lovio et al., 2011). This logic is rooted in two important intellectual concepts. First, path creation draws on Schumpeter's (1934) concept of 'Creative Destruction'. From this point of view, an individual's (e.g. the entrepreneur) deliberate efforts to recombine the factors of production leads to a disruption of an economic equilibrium. Second, Giddens (1984) structuration approach implies that structure (institutions) shape the actions of individuals, but that at the same time individuals shape institutions. Based on its origins, Sydow, Windeler, Möllering, and Schubert (2005) conceptualise path creation as a case of collective institutional entrepreneurship. They introduce a typology of path constitutions, differentiating between emerging (i.e. unintended) and mindful path generation. Garud et al. (2010) contrast the above-introduced constituent elements of path dependency with a theory of path creation. They introduce four assumptions for path creation: (1) Initial conditions are not given but constructed. (2) Contingencies are not exogenous but emergent and serve only as a context for action. (3) Self-reinforcing mechanisms are not given but strategically manipulated by actors. (4) Lock-in is only a provisional stabilizations in a broader structuration process. Path creation thus acknowledges the theoretical foundation of path dependency: Contingent processes are driven towards lock-in through self-reinforcing mechanism. However, the essential difference lies in the role of agents. From this perspective, agents may deliberately and mindfully trigger change.

Carbon lock-in a result of a path dependent process

Unruh (2000) has introduced the notion of 'carbon lock-in' as a specific sub-category of path dependency. Carbon lock-in describes an outcome of a path dependent process that comes into existence *"…through a combination of systematic forces that perpetuate fossil fuel-based infrastructures in spite of their known environmental externalities and the apparent existence of …remedies"* (p. 817). Thus, the focus of analysis lies on for instance electricity or transport systems (Unruh & Carrillo-Hermosilla, 2006). The lock-in is the outcome of the systemic interactions of technologies and institutions. Unruh (2002) thus coined the term *Technological-Institutional Complex (TIC)* to describe the different system components that underlies the path dependent process leading to carbon lock-in.

First, carbon lock-in is the result of a path dependency in technological deployment in the marketplace (*Market Arena*). This draws back on the work of Dosi (1982), Arthur (1989, 1994) and David (1985). Path dependency implies that a technology is initially not chosen because it is inherently better, but because of the positive feedback-loops underlying its deployment. First, technologies usually display *increasing returns of scale*; thus the faster a technology is brought to the market the faster the price will fall, giving it a head start. Second, technologies become more attractive the more they are adopted, thus *network effects occur.* Third, with increasing spread of a technology leads to *learning effects*. Fourth, with wider adoption customers will increasingly take other *customers expectations about other future choices into account* (Arthur, 1989). As specific industries emerge, path dependency is further reinforced through specific supplier-relationships (e.g. through co-specialised assets) and industry standards (Unruh, 2000, 2002). Market-acceptance has been extensively researched, with recent examples being the DVD (Dranove & Gandal, 2003) or mobile technological standards (Koski & Kretschmer, 2005). Unruh argues that carbon-based technologies – e.g. combustion engine – have been deployed so widely due to these processes.

Second, carbon lock-in occurs because of path dependent processes within firms *(Organizational Arena*). Sydow et al. (2009) introduce the notion 'organizational path dependency', describing the self-enforcing mechanisms within an organization. A similar route is taken on by Koch (2011), who looks at the nature of inscribed strategies. Unruh (2000) Vergne and Durand (2010) focus on 'organizational routines' as a force for path-dependency. Organizational routines are excepted to emerge through path dependent organizational learning (Helfat et al., 2007). A firm initially choses a technology and develops its routines around the technology. Specialized labour and organizational silos with specific rules of thumbs emerge (Nelson & Winter, 1982; Unruh, 2000). If routines are leading to a competitive advantage, the underlying positive feedback-loops lead to a further institutionalization. This results in organizational lock-in; the learned, specialised and technology-specific routes become core rigidities (Leonard-Barton, 1992). As firms build their routines around their carbon-intensive the technologies, they struggle to find new ways of doing business.

Third, carbon lock-in is the result of the co-evolutionary development of the *technology* and *social and formal institutions* (*Socio-Political Arena*). *Social institutions* is a term used for a wide range of aspects, such as for instance customer or public expectations and preferences (Unruh, 2002). Also, terminology differs; Vergne and Durand (2010) label these 'stable social patterns', Lawson (2012) 'cultural lock-in'. I use the term 'social institutions' synonym with *attitudes* towards a technology [1]. Attitude is understood as a social evaluation of an object of thought (Augoustinos, Walker, & Donaghue, 2006). As a TIC develops, the public attitudes towards a technology co-evolve with the TIC. The lock-in occurs if such social patterns are becoming stable and widely dispersed values and norms. The strongest manifestation for a social lock-in is if a firm's technology becomes synonym for a certain activity (e.g. 'to Google something'). *Formal institutions* refer to governmental bodies and legal frameworks. A new technology triggers the establishment of legal frameworks governing it. These are able to override market-forces and thus constitute the strongest force for lock-in (Unruh, 2000). Both *social* and *formal* lock-in may be explained by a variety of theories. The most frequent reference is made to the work of Williamson (1985, 2000) and North (1990). Williamson (2000) argues that institutions set the scene for all economic activity. In his view*, social institutions* come into being through evolutionary processes and change only over decades and centuries. They thus are the strongest force of inertia. Similarly, he states that formal governmental institutions can set the 'rules of the game' (e.g. property rights) and thus have a also very strong effect on the economy.

In sum, carbon lock-in (*outcome*) occurs because of path-dependent *processes* on market, firm and institutional level. According to path dependency scholars such an outcome cannot be changed endogenously (Unruh, 2002; Vergne & Durand, 2010). The system requires exogenous shocks to break out of lock-in. Unruh (2002) specifies three shocks that could possibly unlock carbon lock-in: (1) New technological developments, (2) social and institutional changes and (3) crisis.

Escaping carbon lock-in trough path creation

In Unruh's framework only exogenous shocks can help society to overcome path dependency. I take on a different route and argue that an endogenous break-up of carbon lock-in is possible. Two aspects are crucial to analyse carbon break-up: Actors and strategies.

Who are possible path creators when it comes to carbon lock-in? Lovio et al. (2011) propose a framework deducted by Schumpeter's 'Creative Destruction' and the findings of Smith, Stirling, and Berkhout (2005) on governance structure. They propose four categories for path creation in energy systems: Start-Up companies, incumbent companies, civic activity and policy interventions. Classic innovation research, such as Schumpeter (1934), Christensen (1997) or Utterback (1994) focus largely on start-up companies and large incumbent firms. An important sub-stream of this line of research is the role of financial actors as path creators (cf. Grichnik and Koropp, 2011). Recently, researchers have also analysed the interaction between start-up companies and incumbents in transitions to more sustainable modes of business (Hockerts & Wüstenhagen, 2010). Finally, the role of policy makers has been extensively researched. Of course, one may also conceptualise policy makers as exogenous, however, I argue that these actors are very much part of the system itself, thus must be viewed as endogenous. The strongest examples of such policy-oriented research is Unruh's (2002) paper on 'escaping carbon-lock-in', in which he provides an overview of specific policy recommendations to escape a situation of path dependency. Another example is Bento (2010), who analyses different actor strategies to unlock carbon-lock in through hydrogen technologies. Drawing on North's ideas on the interdependence of actors and institutions his conclusion focuses on government policies to 'reduce the uncertainties and open the market' (p. 7198). A final illustration is the work of Wüstenhagen and Menichetti (2012), which analyzes the implications of path dependence on policy maker's choice for stipulating investments in renewable energy. Finally, the role of the civil society, consumers and political movements has been extensively researched by political scientists, sociologists and marketing scholars. However, what we miss is an analysis of a firm acting as a consumer in energy markets. I

[1] I am aware that the underlying sociological constructs of 'social institutions' are more complex than attitudes. However, I will focus here on attitudes for parsimonies' sake

term such actors *firm-consumers.* I argue that large companies as energy consumers play an crucial role in a carbon locked-in system due to their sheer size of their energy bill. Consider for instance the Lufthansa Group: It's annual fuel bill amounts to approximately 7bn Euros - or roughly the fuel imports of Finland. Thus, this paper addresses this research gap and focuses on path creation strategies of firm-consumers.

Secondly what strategies do actors employ to create paths? Strobel and Duschek (2007) introduce the term 'Path Management' to describe the active management of both the old and the new ways of doing business (path exploitation and path exploration). Focusing on energy producers, they conceptualize a path creation strategy as a quest for increasing returns regarding a new technology, thus focusing on regulation, financing and coalition building in their analysis of Shell's activities in sustainable fuels. In a similar tradition, Sydow et al. (2005) analyse the role of research consortia in path creation. Focusing on the firm as an energy consumer, Lovio et al. (2011) give some indication on possible strategies for path creation. They mention demonstration projects, network collaboration or coalition building as examples for path creating strategies. However, we miss a framework that allows for a structured analysis of the various path creation strategies that researchers have discovered so far. Thus, I propose a 2*2 matrix in order to cluster path creation strategies (Figure 1). The matrix divides path creation strategies into the two dimensions of *Strategic Arena* and *Strategic Approach*.

Strategic Arena

Strategic Approach		Market Arena	Socio-Political Arena
	Shaping conditions and contingencies	*Manipulate historical and emerging conditions to shape investor, consumer and firm behaviour towards a new technology*	*Manipulate historical and emerging conditions to shape institutional framework and public attitudes towards a new technology*
	Initiating and reinforcing feedback-loops	*Manipulate feedback-loops to shape investor, consumer and firm behaviour towards a new technology*	*Manipulate feedback-loops to shape institutional framework and public attitudes towards a new technology*

Figure 1: Path Creation Strategies Matrix

The *Strategic Arena* refers to the above discussed levels of Path Dependence. To overcome carbon lock-in, actors must overcome path dependent forces in the *market, organizational and institutional arena*. In the paper at hand I treat the firm as a single actor, thus Figure 1 does not enfold the *organizational arena*. The *Market Arena* relates to the above-discussed challenges of technology adoption by firms, consumers and investors. Such challenges include taking on technologies that enjoy inter alia vast economies of scale, far-ranging network effects or far-fetching user know-how. The *Socio-Political Arena* relates to the institutional challenges that a new technology faces. Thus, this refers to fighting resentments towards a new technology (i.e. changing attitudes) or challenging unfeasible regulation that is based on an incumbent technology.

The *Strategic Approach* refers to the instruments discussed by Path Creation scholars. This thus refers to the instruments that can be employed to overcome lock-in in both the Market and the Socio-Political Arena. Following the framework of Garund et al (2010), I argue that the *Strategic Approach* enfolds instruments to (i) shape the (initial) conditions and (subsequent) contingencies and (ii) to induce and reinforce positive feedback-loops. The first row (i) covers the strategic manipulation of two related aspects. 'Initial conditions' relates the historical conditions that already exist when the new technology is introduced to the market place. With respect to such historical contexts Garund et al (2010) argue that "actors […] mobilize specific sets of events from the past in pursuit of their initiatives (p. 769). Such 'past events' may be existing standards of technology systems, long-established subsidy schemes, investment distribution of institutional investors or consumer behavior. Thus, the question is which instruments firm may use to alter such historical conditions in their favor, i.e. to create a path for the new technology. 'Subsequent contingencies' in contrast relates to new market, social and institutional aspects that emerge with a new technology. This could for instance be new new stock markets (e.g. Nasdaq for the new economy), new start-up clusters (e.g. high tech solar in Bavaria), new consumer groups or new regulations. Again, firms may use distinct instruments to establish contingencies, which lead favour certain (chosen) development paths. The second row (ii) enfolds instruments that are used to establish and reinforce positive feedback-loops, both in the institutional and in the market realm. One may divide these into economic feedback-loops (e.g. economics of scale) and social feedback loops (e.g. endorsement by key actor leads to endorsement by other related actors). This can enfold network effects of infrastructure or economies of scale of production, but also political action plans or public advocacy groups. Figure 3 illustrates this logic: Actors reduce the number of possible pathways by strategically manipulating conditions/contingencies and feedback loops.

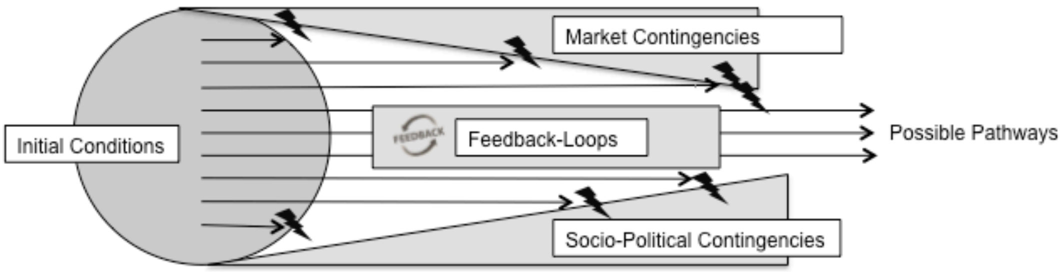

Figure 2: Strategic Manipulation of initial Conditions, contingencies and feedback-loops

METHODOLOGY

I investigated airlines' biofuel strategies through an *embedded case study* in the period 2008-2012. This method has two distinct features: (1) a case study logic and (2) an embedded data collection.

The rational for this choice of method is twofold. First following Garud et al. (2010) the focal point of path creation analysis must be the *process*. Pettigrew (1992) argues that processes are embedded in their respective context and must be understood as such. He thus suggests the *Case Study* as the method of choice for strategy process research. His comments can be transferred to path creation processes[2]. Furthermore, a case study is appropriate in cases of theory building, i.e. in cases where a research gap exists and the phenomena is complex in nature (Eisenhardt, 1989). As we have seen above, airlines strategies to counter lock-in in the aviation sector fulfill these two criteria. Second, Garud et al. (2010) imply that to fully understand path creation processes, researchers shall try to understand processes as if they were taking part themselves in the process. Again, this matches Pettigrew's (1992) guiding principle of 'embeddedness' for process research. I interpret 'embeddedness' along the lines of what Mintzberg (1979) calls 'measuring in real organizational terms': getting out into the field, inside organizations, to understand how firm-consumers try to shape their environment. Only such 'embeddedness' allows for a deeper understanding of the thinking behind integrated strategies, but also for the role of coincidence and the possible conflicts that may arise in strategy making. The *embedded case study* is thus characterised by a *case study approach* and an *embedded data collection*.

A *multiple case study* approach is used as proposed by Eisenhardt (1989) and Eisenhardt and Graebner (2007). The central idea is to use cases to inductively develop theory (Siggelkow, 2007). Three cases were selected using theoretical sampling. The cases were selected to allow for replication logic and generalization (Yin, 2003). In addition, cases were also selected based on the richness of available data. The research process, data collection and data presentation was structured along the lines of Eisenhardt (1989).

The data collection within the case studies was driven by the principle of *embeddedness.* This refers to the fact the author is simultaneously employed as a researcher at the University of St. Gallen and as employee in the environmental strategy department of a medium-sized airline. This allowed me to observe path creation processes first hand, as it enabled access to relevant documents, decisions makers, meetings and industry conferences. However, this raises undoubtedly the question if 'objective' research is possible under such circumstances. I haven taken three steps to mitigate biased perception. First, I have regularly mirrored and discussed my findings with research colleagues outside the airline industry, allowing me to reflect on my implicit assumptions. Second, I have used multiple data sources (e.g. observation, text documents, media analysis) to ensure a high variance. Finally and most importantly, I have conducted additional interviews with involved individuals to complement my subjective observations. As proposed by Eisenhardt and Graebner (2007) I have used a number of 'knowledgeable informants' who view the phenomena from diverse perspectives. As shown below, this does not only include airline personnel, but also NGOS, associations and investors. In order to understand the issue from the individuals freely expressed perspectives, the interviews were conducted in a semi-structured format (Kvale, 2008; Patton, 1990). The interview guideline was developed based on informal conversations during the course of 2011-12 and tested beforehand with two subjects. Afterwards the interview guidelines were iteratively developed and were tailored to the respective interviewee. The interviews were transcripted and stored in a database. A simple coding system was developed in order to analyze interview data and enable pattern matching (LeCompte, 2000; Weston et al., 2001). A widely discussed issue is the appropriate number of interviews. I follow the arguments of

[2] It is however important to note that the research subject differs in nature. Strategy process research focuses on the emergence of strategy within organizations (inside perspective); path creation process research analyses how an organization shapes its environment (outside perspective)

Guest, Bunce, and Johnson (2006) and state that in the average research situation saturation should occur after 6-12 interviews. I thus conducted 9 interviews.

The analysis focuses exclusively on the European Aviation system (air carriers regulated by EU aviation law). The sample consists of the three largest air carriers in the European Union: British Airways, AirFrance-KLM and the Lufthansa Group. As argued above, the cases were selected through theoretical sampling. I selected the airlines because they have started real biofuels projects (relevance) and they have each chosen a different pathway (variance). Data sources included personal observation (meetings, conferences, industry calls), publicly available data (media, company reports, press releases) and a series of interviews. Interviews were conducted with firm representatives as well as with other system stakeholders. The goal of the interviews was to include a range of different perspectives in order to gain a holistic picture of lock-in and path creation processes. Table 3 provides an overview of the interviews. These interviews were complemented by informal, non-documented conversations with other system players.

Institution	Title	Role of Institution
British Airlines	Head of Environment	Air Carrier that actively engages in Path Creation
KLM / SkyNRG	Managing Director SkyNRG	KLM Start-up that specialises on sustainable aviation fuels
AirFrance	Environmental Affairs Manager	Air Carrier that actively engages in Path Creation
International Air Transport Association	Assistant Director Environmental Technology	Industry association that aims to facilitate the scale-up of sustainable alternative aviation fuels
Roundtable on Sustainable Biofuel	RSB Acting Executive Secretary	University spin-off that specialises on the development of sustainability standards for biofuels
World Wildlife Fund	Bioenergy Coordinator	Association that critically observes the sustainability of aviation biofuels
Boeing	Director of Sustainable Aviation Fuels	Aircraft manufacturer which has far-fetching activities in biofuels project
Green Air Online	Editor & Publisher	Specialised journalistic institution that critically observes the effects of aviation on the environment
Sustainable Asset Management (SAM)	Senior Equity Analyst Sustainability Data Analyst	Investment firm that invests in sustainability business and develops an asset sustainability index

Table 1: Interview Partners

CARBON LOCK-IN AND PATH CREATION IN THE AVIATION INDUSTRY

In order to understand airlines' path creation strategies three questions must be addressed: (1) Why do airlines engage in path creation? (2) What challenges must airlines overcome? (3) What instruments do airlines employ to overcome these challenges? I address these three questions in the following paragraphs. The analysis is based on the findings of the case studies and existing research.

Why do airlines engage in path creation?

Lawson (2012) argues that 'aviation lock-in' prevents the aviation industry from escaping its addiction to fossil fuel. On technology level, aviation seems to be locked-in to the jet aircraft and thus kerosene as its main source of energy. Despite the enormous gains in efficiency, the underlying technology and energy source have to a large extend remained the same (Kivits, Charles, & Ryan, 2010). Although alternative technologies exist in a laboratory setting (Airbus, 2012; Donaldson-Balan, 2013; Gologan, 2008; Sehra & Shin, 2003), they lack rapid commercialisation. The reason for this is the extreme high capital intensity of aircraft technology research and existing network effects with regards to airport and air traffic infrastructure. These market forces are further reinforced through rigid formal institutions. Aviation is one of the most rigorously regulated industries, focusing primarily on passenger safety. Doganis (2010) states: 'The need to ensure passengers safety (…) have all created pressure for the introduction of more wide-ranging external controls and regulations than are found in most industries' (p. 27). Finally, the underlying social institutions further foster aviation lock-in. The increasing affordability of travel has been recognized as an important element of cultures of industrialized countries. For instance, Urry (2002) implies that the idea that an individual is entitled to travel is deeply embedded in US culture. The notion of 'entitlement to air travel' has become a dominant attitude in the US and in the EU, as flying has moved from a luxury good to a reality of everyday life (cf. Lawson, 2012). The result is little room for high-tech innovation, as flying as moved from a luxury to a commodity good. Lawson (2012) provides a good summary of the state of lock-in: '*The overall picture that emerges from these accounts is then one in which large-scale transformations are unlikely to occur. Technological interdependencies in aviation are characterised by the dominance of safety issues, the massive amounts of resources required to realise innovations and huge problems of coordination*' *(p. 1232).*

However, in Europe, three exogenous forces have been disrupting aviation lock-in recent years: A fuel price spike, the introduction of emission trading (ETS) and the advent of 2nd generation biofuels. These three forces equal Unruh's (2002) conceptualisation of exogenous shocks that disrupt a carbon locked-in system: Policy (e.g. ETS,), crisis (e.g. rising fuel prices) and the emergence of a new technology (2nd generation biofuels). First, fuel prices have almost tripled over the last decade (Yergin, 2011). In 2013, fuel cost represent on average 31% of operation expense of air carriers, up from 14% a decade ago (IATA, 2013). This rise in fuel prices has not been reflected in prices: On intra-European routes real yields have declined by 44% in the last decade. In the same period, inflation was 22.6% and jet fuel prices increased by 336% (Seabury, 2012). Not only have fuel prices risen, they have also become increasingly volatile (Euromonitor, October 2012). Thus, energy cost has become a key issue for airlines. Second, the social institutions are gradually changing: Environmental regulation has been on top of the EU's agenda in the years preceding the financial crisis. In 2007, the EU announced that starting in 2012 it will include aviation in its European Emission Trading Scheme EU ETS (EuropeanParliament, 2007). This puts a price on carbon emissions, again increasing energy cost for airlines. For example, Vespermann and Wittmer (2011) estimate that the EU ETS leads to average annual cost of MEUR 299.4 in the period 2012-2020 for the Lufthansa Group alone[3]. Although the EU

[3] I shall be noted that the EU has changed the scope of its EU ETS to intra-EU flights only for 2012, following fierce international opposition against the extraterritorial nature if the system. Within Europe, the system is however still in place.

ETS is often criticised as dysfunctional (TheEconomist, 2013), its significance should be expected to increase in the future. Other regions and countries, such a California, South Korea or some provinces in China, are already replicating the system (Brown, Hanafi, & Petsonk, 2012). Thirdly, with the advent of 2nd generation biofuels for the first time aviation has, at least in theory, a low carbon alternative to kerosene. As we will see later on, such 2nd generation biofuels provide airlines with an exit route to carbon lock-in, as the path dependent challenges for adoption are less severe compared to aircraft technology. These three trends have been mentioned by all carriers in the sample as a key driver behind their biofuel engagements.

Hence, the reason for airlines' path creation strategies must be found in exogenous forces. This relates to Gidden's (1984) idea of structuration: They system shapes actor's actions (exogenous forces drive path creation), but actors also actively shape system properties (through the induced path creation).

Which path dependent challenges must be overcome?

All three airlines in the sample have chosen to become engaged in biofuels. Thus it is necessary to understand why this path has been chosen and what path dependent challenges must be overcome.

According to Gardner and Tyner (2007) biofuels are 'energy sources derived from recently living organic material' (p. 1). In theory, such fuels extract the same amount of carbon from the air when they grow (through photosynthesis) as is emitted when they are burnt. In reality, their carbon reduction potential is dependent on the production process, leading to a high variance in reduction potential. The International Energy Agency estimates the Green House Gas emissions of biofuels to range in between 60-120% of fossil fuels (Eisentraut, 2010). Biofuels are an old technology, specifically Ethanol. For instance, in the early day of the combustion engine in the late 19th century, is was heavily debated weather ethanol or gasoline should be preferred to power the combustion engine (Dimitri & Effland, 2007). Throughout the course of the 20th century biofuels occasionally got a boost, such as for instance during the great depression (initiated by a drop in commodity prices) or during the oil crisis of the 1970ies (Yergin, 2011). In addition, in some regions, such as for instance in Brazil, a considerable amount of biofuels is used to fuel road transport. However, biofuels never became a large-scale alternative to fossil fuel. More importantly, traditional biofuels have never been used for commercial aviation. They lack the performance requirements – high energy density and temperature resistance. Only with the advent of so-called 2nd generation biofuels in the late 2000 aviation was able to use biofuels in existing commercial airplanes. In contrast to 1st generation biofuels, 2nd generation biofuels allow a transformation of almost all organic materials into energy (Zah et al., 2010). For aviation, such fuels are labelled 'drop-in biofuels' and can be used with all current aircraft types. The first blend of biofuel and fossil-fuel based kerosene was officially approved for the use in commercial airplanes in 2009, another blend in 2011 (Faaij & van Dijk 2012). A large number of 2nd generation biofuels, based on different underlying organic material and different conversion processes, are today technically ready for the use for aviation[4]. So-called 3rd generation biofuels, most prominently fuels made out of algae, are currently only feasible in a laboratory setting. I will not further discuss the technical details of biofuels in the paper at hand. I assume that from a purely technical point of view, biofuels could provide a low-carbon alternative for aviation. A wide range of stakeholders has acknowledged the potential of low-carbon aviation biofuels. The aviation industry itself frequently states that aviation biofuels are "one of the biggest opportunities (…) in low-carbon, sustainable aviation fuels" (ATAG, 2011, p. 1,). This view is shared by the World Economic Forum, which calls biofuels "a potential game changer for the aviation industry". Most notably, the same observation is made by selected NGOs. The World Wildlife Fund stipulates that for the moment, the only realistic renewable energy source for aviation is in bioenergy (WWF, 2011). Others, such as for instance the National Resource Defense Council

[4] For an overview please see Faaij & van Dijk (2012)

(Hammel, 2013), take a similar view. However, most observers agree that biofuels are not a sliver bullet and will not come to substitute a majority of fuels needed for aviation. Optimistic estimates range from 18-40% biokerosene used in 2050 (Reals, 2013) . The reason for this optimism lies in parts in the above described aviation lock-in: Drop-in biofuels may be used in existing airplanes, thus overcoming some of the above described barriers to disruptive innovation in aircraft technology.

If airlines want to use biofuels as a large-scale alternative to fossil fuels, they must overcome three distinct path dependent challenges (Figure 3).

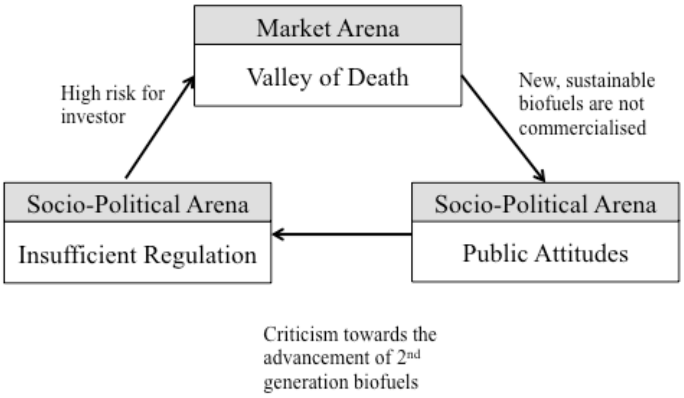

Figure 3: Path dependent barriers to biofuels adoption

The Market Arena refers to challenges of technology adoption. Assuming that biofuels are technically a substitute for fossil fuels, why are they not commercialised? To begin with, the so-called 'Valley of Death' (VoD) plays a crucial role. The VoD describes a funding gap for high-risk and capital-intensive technologies that occurs between the emergence of a technology in the lab and its commercialisation in the market (Ghosh & Nanda, 2010). As Ghosh and Nanda (2010) imply, this is also true for advanced biofuels. This relates to a path dependent challenge: Economies of Scale. It is widely excepted that the price of biofuels falls when production is increased, as it is the case for other forms of renewable energy (ATAG, 2011). However, at current price there is no demand for sustainable biokerosene, as its prices widely exceeds the price of the dominant technology: Kerosene. As fuel is a commodity, airlines are not willing to pay more for biofuels unless the carbon reduction is reflected in the price. Thus investors are reluctant to invest in biokerosene projects, as they see no demand. As one observer puts it:

> The challenge now is commercialisation and getting first plants build so that we can proof that we can produce the products in commercial volumes at prices that are cost-competitive with fossil-based fuels.

However, in comparison to aircraft technology, network effects do not play an important role as an inhibiting factor. All interviewees agreed that infrastructure does not constitute an obstacle: Drop-in biofuels can be operated with existing airplanes and airports. In addition, customers (airlines) are not locked-in on the basis of learning effects or adaptive expectations, as biofuels are an almost perfect substitute for fossil fuels.

Moreover, two decisive challenges occur regarding socio-political acceptance of a technology. First, the *social institutions* inhibit a large-scale adoption of aviation biofuels. Public attitudes in Europe towards the use biofuels remain sceptical, as their sustainability benefits are increasingly doubted (Upham, Tomei, & Dendler, 2011) . One observer for instance notes:

> There is a, especially in the UK, a lot of scepticism, around biofuels, there is a view that they are not really sustainable

First, it is severely debated if they really reduce carbon emission when analysed from a lifecycle point of view. Secondly, as 1st generation biofuels are made out of edible material, the fuel-versus-food issue is fiercely discussed. Thirdly, even for 2nd generation biofuels, issues such as indirect land-use change or resource availability are oftentimes cited as a reason not to opt for biofuels. For a summary of these arguments, see for instance Zah (2010) or Kampman, van Grinsven, and Croezen (2012). These technical challenges undoubtedly exist; however, observers note that these sustainability challenges can be overcome with prudent agricultural management and the new process and resources underlying 2nd and 3rd generation biofuels. However, despite the theoretical technical feasibility, the public remains very critical of the use of biofuels. The public antipathy towards biofuels is rooted in the historically unsustainable mode of production of first generation biofuels such as ethanol or biodiesel. These resentments are deeply embedded in the European Public. For example, the German expression 'Teller im Tank' ('Plate in the Tank') is commonly used slogan to criticise the use of food resources for the production of biofuels. As path dependency theory predicts, the negative attributes towards biofuels lead to negative feedback effect on investments, thus inhibiting the financing in new, possibly more sustainable ways of producing biofuels. One investor notes:

> (…) because intrinsically biofuels is a controversial subject, probably as controversial as GMO, Genetically Modified Organisms, biofuels are clearly linked, very quickly, to food scarcity – because of the first generation ethanol production in the US (…). So some people in the investment community might even see biofuels as risk increasing.

These social institutions are reflected in the *formal institutions,* i.e. regulation. The problem here is twofold. First, the regulatory set-up is to a large extent aimed at first generation biofuels produced for road transport. This leads to an unequal playing field and distorted incentives. As the use of resources and production facilities for road transport biofuels competes with the use for aviation biofuels, this has a direct effect on the speed of commercialisation. One interviewee notes:

> The biofuels, which the aviation sector should be using, are more expensive than traditional fuel. And the road transport for example receives quite a lot of incentives that the aviation sector does not.

Second, no harmonized standards to assess the sustainability of biofuels exists. Again, the logic of path dependency applies. The underlying standards and policies have been developed for 1st generation biofuels and for road transport. Again, this regulatory uncertainty is directly reflected in investment behaviour. As this regulatory gap increases risk, the Valley of Death is prolonged.

As Figure 1 indicates, these three path dependence challenges are linked through a feedback-loop. The result is a lock-in to the use of fossil fuel and a lack of adaption of sustainable biofuels. However, in contrast to the above-described aviation lock-in, the challenges are less daunting. The scope of challenges, e.g. the lack of network effects relating to the dominant technology, enables airlines to become engaged in path creating strategies.

How do airlines engage in path creation?

Lufthansa, British Airways and AirFrance-KLM have all engaged in path creating strategies to overcome the above laid out challenges in the adoption of biofuels. I categorize their strategic instrumentts in the matrix as introduced above (Figure 4).

Strategic Arena

Strategic Approach		Market Arena	Socio-Political Arena
	Shaping conditions and contingencies	– *Commercial Proof of Concept* – *Supply Chain Incubator*	– *Technical Proof of Concept* – *Voluntary Sustainability Standards* – *Lobbying*
	Initiating and rein-forcing feedback-loops	– *Corporate Venturing* – *Off-Take Agreements* – *Customer Inclusion*	– *Private-Public Action Groups* – *Alliances*

Figure 4: Classification of Path Creation Strategies

Shaping Initial Conditions and Contingencies in the Socio-Political Arena. All airlines in the sample have tried to shape condition and contingencies in the socio-political realm. All airlines in the sample have provided a *technical proof of concept* to alter the historical perception that biofuels are not safe to use in aviation. The particular instrument was to conduct test-flights with biofuels. Such single initiatives were frequently used in early days of aviation biofuels (2008-09). AirFrance-KLM's initial measure was to conduct a first test flight in 2009, with industry and government representatives on board. British Airways initiated a scientific test programme in collaboration with Rolls Royce in July 2008 to investigate the viability of alternative fuels for the aviation. Lufthansa started biokerosene testing only in 2012, but provided a more in depth analysis. The German carrier conducted a six months biokerosene trial in one engine of an Airbus A321 operating commercially between Frankfurt and Hamburg. The test involved inter alia an analysis of engine performance, storage and carbon reduction potential. These initiatives were driven to a large extend by the above-introduced safety-focus of aviation. Regulators and the public had first to be actively convinced that this new energy source has no negative implications for the safety of passengers: With new technology, biofuels work safely in existing aircrafts. As one airline representative notes:

> I think the main resistance that we met […] was the technical feasibility, there was a degree of scepticism […] that Biofuels could actually be made to work […] but we sort of worked very hard with our engineering function and our flight ops people, we have now overcome that. Everybody is now convinced that technically these fuels will work within the aviation environment.

Secondly, all airlines in the sample addressed the historically negative sustainability reputation of biokerosene through early commitment to *voluntary sustainability standards.* All carriers stated publicly that they will only use 'sustainable biokerosene' through becomimg a member of the Sustainable Aviation Fuel Users Group (SAFUG). The group sets forth a list of sustainability criteria, which must be fulfilled if biofuels were to be used. AirFrance-KLM signed this charter as early as 2008. Later on, all carriers have begun to engage (directly or indirectly) in the Roundtable on Sustainable Biofuels (RSB). This initiative aims at developing a certification system for sustainable biofuels, taking into account NGO, consumer and producers needs. In the absence of globally harmonized sustainability standards this is essential to gain credibility and to convince the public that the mistakes of the 1st generation biofuels will not be replicated. As a airline representatives puts it:

> We had the feeling at the very beginning that we wanted to avoid absolutely what has happened in car transportation development of biofuels, and we wanted to avoid deforestation or any kind of negative impact due to biofuel development. So we decided to become part of the RSB.

Through commitment to sustainability criteria airlines alter historically conditions for technology adoption as well as the contingencies for further research.[5]

As third instrument is direct lobbying. Again, the lobbying efforts were both used to alter historical conditions, such as existing regulations for road transport biofuels, as well as to create new contingencies, such a new regulations. All airlines in the sample lobbied European institutions and member states to implement stringent and harmonized biofuels regulations. Thereby the focus on two issues: Harmonized and applicable sustainability criteria and equal incentives to road transport. One airline representative describes this as follows:

> We have a work stream look at how make sure that is appropriate policy influence to incentives biofuels. (On National Level) a primary focus is to level the playing field to make sure that we get equal incentives for the use of biojet. In the EU again its starts with the same issues, basically with biodiesel, so this is primarily focused on the Renewable Energy Directive. But in addition it's making sure that within the EU Emission Trading Scheme there is appropriate incentives and crediting for the use of biofuels.

Shaping Initial Conditions and Contingencies in the Marketplace. As shown above, the aviation biofuels market is its still infancy. To push the market forward, airlines have employed distinct instruments to foster market-formation. First, airlines have established a *Commercial Proof of Concept.* This provides evidence that the initial technology and infrastructure conditions theoretically allow for market adoption of new technology; that the technology is ready for commercialisation. Historical evidence with 1st generation biofuels is often used to deny full-scale commercial feasibility of the technology. Airlines aim to alter this historical perception. British Airways has initiated research collaboration with Canfield University, which aims at proofing the scalability of biofuels production from algae ('SURF consortium'). Similarly, Lufthansa collaborates with Leuphana University and INCONAS GmbH in order to develop application-oriented concepts of sustainable biofuels production. One project for instance analyses how biofuel resources could be integrated in existing large-scale agricultural plantations. It thus is aimed at providing evidence that initial conditions, e.g. state of technology and existing historical infrastructure, would allows for a commercial production of biokerosene

Secondly, some airlines engage as *Supply Chain Incubators.* The aviation biofuels market remains highly fragmented; demand does not find supply. Start-ups miss out on investments, as they are unable to overcoming problems of distribution (e.g. access to refineries, airport processes). In a similar sense, farmers have no access to investors or customers. One work stream of the AirFrance-KLM venture SkyNRG (cf. below) thus focuses on building local supply chain, focusing on bringing partners together. For instance, they implemented a fully functional supply chains for biofuels at Amsterdam Schiphol airport. SkyNRG has initiated the formation of several local supply chains across the globe, the latest being in Brisbane, Australia. To a smaller extent, Lufthansa has also set up a local supply chain in its long-term biofuels test; it has teamed up with refiner Nesteoil and has altered the necessary tanking and fuelling capacity at Hamburg Airport. This collaboration is still in place today.

These strategies focus to large extend on overcoming problems of coordination, thereby mitigating barriers to commercialisation for biofuels producers and laying the foundation for future investments. Airlines take on a decisive role as market markets as they are large energy consumers in various parts of the worlds and because their local marketplaces are very confinable (i.e. airports). They have the capacity to 'make the market'. As Managing Director of SkyNRG and the former Head of Innovation of KLM notes:

> We are a demand aggregator for sustainable jet fuel and market maker. We know how to sell premium fuel, we know how make markets […]

[5] However, it should be noted that a recent study by the National Resource Defense Council (Hammel, 2013) has found that airlines' commitments to "sustainable biofuels" is relatively weak, often more an intention than a promise.

As market-making instruments, these measures alter the initial conditions and set the conditions for further market formation.

Initiating Feedback-Loops in the Market Arena. Airlines have consciously created and manipulated feedback-loops in the market place. Frist, airlines have become entrepreneurial in order to create the necessary feedback-loops (*Corporate Venturing).* AirFrance-KLM is a forerunner in this respect. As a spin-off of its innovation department, KLM founded its own biofuels venture SkyNRG in 2009. Driven by KLM, it was set up together with commodity service provider North Sea Group and the strategy-consulting firm Spring Associates. SkyNRG offers a 'feedstock-to-flight' service, managing the entire supply chain ranging from project development, sustainability certification to distribution logistics. It offers its services to all potential clients, not only AirFrance-KLM. It thus acts as a demand aggregator. Other carriers have not founded a new firm, but are commercially engaging with partners companies. AirFrance has announced in 2013 that it will take on an equity stake in the pilot firm Syndièse, an outcome of its cooperation with the government funded research organization CEA. Another prominent example is British Airways' Joint Venture with biofuels producer Solena ('GreenSky London'). The JV aims at building a plant that converts municipal waste into biokerosene, converting 500,000 tonnes of waste into 16m gallons of biofuel each year by 2015. The plant shall fuel all BA flights from London City Airport. Furthermore, the project also aims at proofing that large volumes of biokerosene can be produced economically and sustainably. Thus, BA states that if successful, the project shall be replicated across England. BA has taken an equity stake in the company and has committed to buy all biokerosene form the plant, estimated to be worth $500m. BA notes that the reason for this is to reduce risk:

> To get investor confidence, we need to take an equity stake. We believed this was a good enough proposal to take the risk.

Second, airlines commit to *off-take agreements*. All airlines in the sample have done so. Air France has committed to take 3000t of biokerosene the CEA-led pilot project, BA has agreed on a 10year contract to buy all fuel from its Solena JV (cf. above). According to Press reports, Lufthansa has reached an agreement with Biofuel producer AlgaeTec, committing to a long-term off take agreement of 50% of the crude oil production. From an investor's perspective, such contracts substantially reduce the risks involved:

> If we (are) talking about biofuels suppliers (…) the prime example is a take-off contract, a take-off agreement is obviously a strong plus on a biofuels supplier.

Thirdly, airlines try to further create positive feedback loops by including the end customer. AirFrance-KLM, which has been one of the front-runners in this area, has begun to do so through its venture SkyNRG. First of all, SkyNRG claims to follow a premium branding strategy. Through its cooperation with WWF and various research institutions, SkyNRG aims to sell "premium fuel". The relatively higher-priced fuel relative to kerosene has thus contains the 'luxurious' property of substantially lower GHG emissions:

> We believe in a fuel that is more expensive than fossil fuel. A commodity oil player thinks that will never work. I will not even start in the market if that is the case. At the same time that is the secret of our success, because no one else is doing it.

Biokerosene is branded as a sustainable, low carbon innovation, not a mere commodity. However, such branding efforts remain fruitless, if such commodity differentiation is not acknowledged by the end-customer. To reach the end customer, SkyNRG has this started a *Customer Inclusion* initiative. Similar to carbon offsetting schemes, SkyNRG in collaboration with KLM offers corporate customers to fly their staff (virtually) on sustainable biofuels. Companies such as Nike, Accenture and Heineken have signed up to the program. Until 2013, 15 companies have joined the program. Companies use such programs to fulfill their carbon targets as stated in their Corporate Social Responsibility strategies. The other two airlines in the sample have not yet started to use such market strategies, however, they might do so at a later stage.

All of these instruments aim to create distinct feedback-loops. First, they aim at creating *Economies of Scale*. The increased production is a result of increased investments through direct funding as well as trough lowered risk for the investors through off-take contracts. This reason has been explicitly board forward by airlines. Similarly, if (corporate) customers a willing to pay a premium for sustainable fuel, this will allow the scale up of current production, leading to lower cost in the future. In addition, through actively collaborating with producers and investors, *learning effects* should be expected with regards to biofuels technologies. Finally, such initiatives alter the *investor and customer expectations about other future choices.* If investments seem to become less risky, others might feels they should follow (herding). These strategies explicitly aim to bridge the above-introduced notion of the 'Valley of Death'. One airline representative argues:

> You may have heard of the concept of the valley of death (…) so there is period where we need to go through (…) to proof the commercialisation of these projects and it will involve (…) users sharing some of the risk.

Initiating Feedback-Loops in the Socio-Political Area. All airlines have actively engaged with governmental bodies and NGOs to create ' momentum' for further development of biofuels. First, they have engage in *Public-Private Action Groups*. For instance, all airlines in the sample are involved in the EU's Advanced Biofuel Flight Path, an initiative that aims to establish a yearly production of 2m tonnes of sustainable biokerosene for aviation by 2020. Air France engages in a similar initiative on national level, whereby it collaborates with the French Aviation Authorities. Lufthansa too has sought public involvement. Its long-term biofuel test in 2012 was undertaken with support of the Germany's Federal Ministry for Economics and Technology. The EU Commission has mandated the German Carrier to analyse blending properties of such fuels in 2013/14.

To reach not only institutional actors but also the general public, airlines have become engaged in *Alliances and Stakeholder Dialogue.* KLM has had a partnership with WWF as early as 2008. The KLM venture SkyNRG later on actively sought to integrate NGOs in its decision process. It has a sustainability board consisting of NGOs and academia. The board must approve all projects, thus proving a strong signal to the public that sustainability is on top of the agenda. Notably, the Word Wildlife Federation is part of this board. The Lufthansa Group has formed the 'Aviation Initiative for Renewable Energy in Germany' (AIREG), bringing together different actors of the aviation value chain as well as research institutions, consultancies and biofuel ventures. Due to the wide range of included stakeholders, this initiative shapes attributes through different mediators (private companies, NGO, regulators and academia).

Both activities aim at creating feedback-loops in the Socio-Political Area. Including formal institutions and seeking governmental endorsement for a technology is expected to trigger respective changes in regulation and public action plans (e.g. public climate change strategies). The inclusion of NGO and media is aimed at seeking public support for a technology. If organizations such as the WWF can be convinced to support a certain technology, this affects the attitudes of its (vast) membership as well as of other NGO.

DISCUSSION

The results of the case study indicate that airlines as energy consumers seem to use a distinct set of instruments to overcome the path dependent challenges inhibiting the further development of sustainable biofuels. These practical instruments can be matched with the theoretical framework developed by path creation scholars. It provides evidence that actors indeed try to ‘mindfully deviate’ if they find themselves on a locked-in path. However, five issues must be addressed to fully grasp the implications of these results.

First, the results do not indicate if airlines’ path creation strategies are successful in escaping carbon lock-in. As energy systems are complex systems, it is nearly impossible to ex post understand the influence of a single player on system-level. To allow an analysis of the success of path creation strategies future research may include methods used by complexity scholars (Simon, 1996). This would possibly allow a deeper understanding of why a system reaches a tipping point. It remains to be seen if airlines efforts make a difference on system level.

Second, the paper at hand purposefully omits organizational lock-in. However, the case studies provided evidence that considerable efforts were undertaken to overcome path dependent challenges within airlines, such as scepticism towards biofuels or a lack of capabilities. The results indicate that these organizational challenges are no less daunting then the system challenges. These challenges undoubtedly influence both the adoption of new low-carbon technologies by firm-consumers as well as the effectiveness of path creation strategies.

Third, the results of the case study point to the importance of conflicting aims in path creation. A high carbon price would undoubtedly be the best incentive for the rapid deployment of biokerosene. However, the airlines in the sample opposed regional carbon pricing schemes such as the EU ETS, as this would hurt their competiveness and already fragile financial state in comparison to their competitors. A global regime, which the industry lobbies for, is unlikely to materialize soon. Thus existing industry dynamics (e.g. high competition, low margins) inhibit radical path creation strategies by energy consumers. I term this “second-order path dependence”, describing the conundrum that even path creation strategies are path dependent. This leads to the danger of ‘green-washing’: Firms may put efforts into escape carbon lock-in while still be stuck in the corset of the old lock-in. Such second order path-dependence undermines the effectiveness of path creation strategies. Future research should thus investigate how firms deal with such contradicting aims.

Fourth, it is important to emphasise that the technology itself has a decisive influence on path creation strategies. For instance, if it turns out that the current generation of biokerosene simply cannot be sustainably produced in large volumes, path creation strategies must be adopted accordingly. The airlines in the sample seem to have done so over the course of 2008-12. The co-evolution of path creation strategies and technology is another area where more research is needed.

Finally and most importantly, how generically is the proposed framework applicable to other industries and technologies? First, most forms of renewable energy face similar constraints than biofuels. However, challenges are dependent on the development stage of the respective technology. For instance, wind energy may face less challenges in the Market Area (e.g. already enjoys economies of scale), however still faces problems of social-political acceptance due to its visibility (Jobert, Laborgne, & Mimler, 2007). For other technologies, which are even in an earlier stage than 2nd generation biofuels, such as for instance Carbon Capturing and Storage, shaping the initial condition in the Socio-Political Arena is even more urgent than setting up market environments (Huijts, Midden, & Meijnders, 2007). Another example is Electric Mobility, a technology were network effects play a considerable role as a barrier to adoption (Steinhilber, Wells, & Thankappan, 2013). Second, do besides airlines other firm-consumers engage in similar strategies? The answer is yes, although by different degrees. Prominent examples include Google and Volkswagen’s investments in Wind Parks (FinancialTimesDeutschland, 12.05.2011, 19.04.2011) or railway provider Deutsch Bahn’s commitment to Green Energy (Handelsblatt, 2012). Another example are the efforts of Holcim, a cement manufacturing company, to create a renewable energy supply. Thus, other actors seem to engage in path creation as well. However, more research is needed to understand the scope and drivers of firm-consumers' strategies across industries, regions and energy sources. Also, research should analyse the interaction of path creation strategies employed by consumer, entrepreneurs, investors and policy makers.

CONCLUSION

This paper investigated how firms as energy consumers ('firm-consumers') are trying to escape carbon lock-in, drawing on both path dependency and path creation theory. I conducted an embedded case study of the three largest European Airlines' biokerosene engagements in the period 2008-2012. The findings indicate that firm-consumers are aware of the path dependent challenges and that they follow path creation strategies in order to overcome these challenges. Such strategies include distinct instruments to create contingencies and feedback-loops in order to allow for an more rapid market adoption of renewable energy. Moreover, these instruments are both employed in the Market as well as in the Socio-Political Arena.

The paper contributes to path dependency and creation research in two distinct ways. First, it adds a new perspective by analysing strategies of firm-consumers. Past research has largely focused on entrepreneurs, incumbents, investors and policy makers. Secondly it proposes a new analytical framework of analysis, which may also be used for future empirical research in other industries.

However, the paper has three important caveats. First, I purposefully omitted questions of organizational lock-in. Second, questions of second-order path dependence, i.e. the path dependence of path creation strategies, have not been analysed in depth. Finally, the success of airlines' biofuels strategies remains unclear. Future research should address these three issues in order to gain a more thorough understanding of path creation strategies.

Finally it remains to be emphasised that the analysis underlines the importance of more research on path dependency and path creation. Escaping carbon lock-in is one of the key challenges of the 21st century. Unruh (2002) makes that case that external shocks (crisis, disruptive technologies, policy interventions) are crucial to overcome the path dependent challenges. I do not reject that, but I argue that endogenous actions by agents will play an equally crucial role. Only if we understand the importance and interaction of both endogenous as well as exogenous shocks to locked-in systems we will be able to give relevant advice to policy makers and market players alike.

REFERENCES

Airbus. 2012. ***The Future of Flight***. Retrieved 28.3.2013 from www.airbus.com

Arthur, W. B. 1989. Competing Technologies, Increasing Returns, and Lock-In by Historical Events. ***The Economic Journal***, 99(394): 116-131.

Arthur, W. B. 1994. ***Increasing Returns and Path Dependence in the Economy***. Ann Arbor: University of Michigan Press.

Ashby, R. 1956. ***An Introduction to Cybernetics***. London: Chapman and Hall.

ATAG. 2011. ***Powering the future of flight.*** Retrieved 25.4.2013 from www.atag.org

Augoustinos, M., Walker, I., & Donaghue, N. 2006. ***Social cognition: An integrated introduction (2n Ed.)***. London: Sage.

Bento, N. 2010. Is carbon lock-in blocking investments in the hydrogen economy? A survey of actors' strategies. ***Energy Policy***, 38(11): 7189-7199.

Brown, L. M., Hanafi, A., & Petsonk, A. 2012. The EU Emission Trading Scheme: Results and Lessons learned. ***EDF Study.*** Retrieved 25.9.2013 from www.edf.org

Burgelman, R. A. 2002. Strategy as Vector and the Inertia of Coevolutionary Lock-in. ***Administrative Science Quarterly***, 47(2): 325-357.

Christensen, C. M. 1997. ***The Innovator's Dilemma***. Boston: Harvard Business School Press.

Cowan, R. 1990. Nuclear Power Reactors: A Study in Technological Lock-in. ***The Journal of Economic History***, 50(3): 541-567.

David, P. A. 1985. Clio and the Economics of QWERTY. ***The American Economic Review***, 75(2): 332-337.

Dimitri, C., & Effland, A. 2007. Fueling the Automobile: An Economic Exploration of Early Adoption of Gasoline over Ethanol. ***Journal of Agricultural & Food Industrial Organization***, 5(2).

Dobusch, L., & Schussler, E. 2012. Theorizing path dependence: a review of positive feedback mechanisms in technology markets, regional clusters, and organizations. ***Industrial and Corporate Change***, 22(3): 617-647.

Doganis, R. 2010. ***Flying off course: Airline economics and marketing (4th Ed.)***. New York: Routledge.

Donaldson-Balan, E. 2013. Blended wing body design shows environmental promise as NASA completes flight testing of Boeing prototype, ***Green Air Online***. Retrieved 30.4.2013 from www.greenaironline.com

Dosi, G. 1982. Technological paradigms and technological trajectories. ***Research Policy***, 11: 147-162.

Dranove, D., & Gandal, N. 2003. The Dvd-vs.-Divx Standard War: Empirical Evidence of Network Effects and Preannouncement Effects. ***Journal of Economics & Management Strategy***, 12(3): 363-386.

Eisenhardt, K. M. 1989. Theories from Case Study Research. ***The Academy of Management Review***, 14(4): 532-550.

Eisenhardt, K. M., & Graebner, M. E. 2007. Theory Building From Cases: Opportunities And Challenges. ***Academy of Management Journal***, 50(1): 25-32.

Eisentraut, A. 2010. Sustainable Production of Second-Generation Biofuels. In I. E. Agency (Ed.), ***Information Paper***. Paris: International Energy Agency.

Euromonitor. October 2012. Key Threats and Opportunities Facing Global Airlines. ***Briefing.*** Retrieved 30.7.2013 from www.euromonitor.com

EuropeanParliament. 2007. Clear Skys ahead: MEPs vote to curb airline emissions by including them in European trading scheme. ***Press Release.*** Retrieved 24.7.2013 from www.europa.eu

Faaij , A., & van Dijk , M. 2012. ***White Paper on Sustainable Jet Fuel.*** Retrieved 23.5.2013 from www.skynrg.com

FinancialTimesDeutschland. 12.05.2011. Erneuerbare Energien: Volkswagen plant Einstieg in Offshore-Windparks ***Financial Times Deutschland***.

FinancialTimesDeutschland. 19.04.2011. Erneuerbare Energien: Google investiert in weltgrößten Windpark. ***Financial Times Deutschland***.

Gardner, B., & Tyner, W. 2007. Explorations in Biofuels Economics, Policy, and History: Introduction to the Special Issue. ***Journal of Agricultural & Food Industrial Organization***, 5(2).

Garud, R., & Karnøe, P. E. 2001. ***Path creation as a process of mindful deviation. In In Path d Eependency and creation,***: Lawrence Earlbaum Associates.

Garud, R., Kumaraswamy, A., & Karnøe, P. 2010. Path Dependence or Path Creation? ***Journal of Management Studies***, 47(4): 760-774.

Ghosh, S., & Nanda, R. 2010. Venture Capital Investment in the Clean Energy Sector. In H. B. School (Ed.), ***Working Paper 11-020***.

Giddens, A. 1984. ***The constitution of society: Outline of the theory of structuration.*** . Cambridge: Polity Press.

Goldstone, J. A. 1998. Initial Conditions, General Laws, Path Dependence, and Explanation in Historical Sociology. ***American Journal of Sociology***, 104(3): 829-845.

Gologan, C. 2008. Conceptual Design of a Strol Regional-Jet with a Hybrid Propulsion System. In B. L. e.V. (Ed.), ***26th International Congress of the Aeronautical Sciences***.

Grichnik, D., & Koropp, C. 2011. ***Business angels and energy investing: insights from a German panel study***. Cheltenham, UK: Edward Elgar Publishing.

Guest, G., Bunce, A., & Johnson, L. 2006. How Many Interviews Are Enough? An Experiment with Data Saturation and Variability. ***Field Methods***, 18(1): 59-82.

Hammel, D. 2013. Aviation Biofuel Sustainability Survey, ***NRDC Issue Brief***: National Resources Defence Council.

Handelsblatt. 2012. Bahn kauft von Eon großes Ökostrompaket. *Handelsblatt*

Helfat, C. E., Finkelstein, S., Mitchell, W., Peteraf, M., Singh, H., & Teece, D. J. 2007. ***Dynamic Capabilities: Understanding Strategic Change in Organizations***. Oxforf: Blackwell.

Hockerts, K., & Wüstenhagen, R. 2010. Greening Goliaths versus emerging Davids — Theorizing about the role of incumbents and new entrants in sustainable entrepreneurship. ***Journal of Business Venturing***, 25(5): 481-492.

Huijts, N. M. A., Midden, C. J. H., & Meijnders, A. L. 2007. Social acceptance of carbon dioxide storage. ***Energy Policy***, 35(5): 2780-2789.

IATA. 2013. Fact Sheet: Fuel. Retrieved 23.9.2013 from www.iatat.org

ICAO. 2009. ICAO Environmental Report. Montreal: ICAO. Retrieved 27.5.2013 from www.icao.int

ICAO. 2011. ICAO Review: Sustainable Biofuels for Aviation. Retrieved 13.8.2013 from www.icao.int

Jobert, A., Laborgne, P., & Mimler, S. 2007. Local acceptance of wind energy: Factors of success identified in French and German case studies. ***Energy Policy***, 35(5): 2751-2760.

Kampman, B., van Grinsven, A., & Croezen, H. 2012. Sustainable alternatives for land-based biofuels in the European Union. ***CE Delft Study***. Retrieved 13.9.2013 from from www.cedelft.eu

Kenney, M., & Burg, U. 2001. ***Paths and regions: the creation and growth of silicon valley***. Mahwah, NJ: Lawrence Erlbaum Associates.

Kivits, R., Charles, M. B., & Ryan, N. 2010. A post-carbon aviation future: Airports and the transition to a cleaner aviation sector. ***Futures***, 42(3): 199-211.

Koch, J. 2011. Inscribed Strategies: Exploring the Organizational Nature of Strategic Lock-in. ***Organization Studies***, 32(3): 337-363.

Koski, H., & Kretschmer, T. 2005. Entry, Standards and Competition: Firm Strategies and the Diffusion of Mobile Telephony. ***Review of Industrial Organization***, 26(1): 89-113.

Kvale, S. 2008. ***Doing interviews***: New York. Sage.

Lawson, C. 2012. Aviation lock-in and emissions trading. ***Cambridge Journal of Economics***, 36(5): 1221-1243.

LeCompte, M. D. 2000. Analyzing qualitative data. ***Theory into practice***, 39(3): 146-154.

Leonard-Barton, D. 1992. Core capabilities and core rigidities: A paradox in managing new product development. ***Strategic Management Journal***, 13(S1): 111-125.

Lovio, R., Mickwitz, P., & Heiskanen, E. 2011. ***Path dependence, path creation and creative destruction in the evolution of energy systems***. Cheltenham, UK: Edward Elgar Publishing.

Mintzberg, H. 1979. An Emerging Strategy of "Direct" Research. ***Administrative Science Quarterly***, 24(4): 582-589.

Nelson, R. R., & Winter, S. G. 1982. ***An evolutionary theory of economic change***. Cambridge: Belknap.

North, D. C. 1990. ***Institutions, institutional change and economic performance.*** Cambridge: Cambridge University Press.

Patton, M. Q. 1990. ***Qualitative evaluation and research methods (2nd ed.)***. Thousand Oaks, CA: Sage.

Pettigrew, A. M. 1992. The character and significance of strategy process research. ***Strategic Management Journal***, 13(S2): 5-16.

Reals, K. 2013. Fueling the Future, ***Airline Business***: 44-45.

Schumpeter, J. A. 1934. ***The Theory of Economic Development.*** New York: Oxford University Press.

Seabury. 2012. Sustainable European Aviation. ***European Association of Airlines Study***. Retrieved 30.8.2013 from www.ea.be

Sehra, A. K., & Shin, J. 2003. Revolutionary Propulsion Systems for the 21st Century Aviation, ***International Gas Turbine Congress 2003***. Tokyo: NASA / Glenn Research Center.

Siggelkow, N. 2007. Persuasion With Case Studies. ***Academy of Management Journal***, 50(1): 20-24.

Simon, H. A. 1996. ***The Sciences of the Artificial*** (3rd ed. ed.). Cambridge, MA.: MIT Press.

Smith, A., Stirling, A., & Berkhout, F. 2005. The governance of sustainable socio-technical transitions. ***Research Policy***, 34(10): 1491-1510.

Steinhilber, S., Wells, P., & Thankappan, S. 2013. Socio-technical inertia: Understanding the barriers to electric vehicles. ***Energy Policy***, 60: 531-539.

Strobel, J. C., & Duschek, S. 2007. Beyond Path Dependency: Why and How Mineral Oil Companies Support the Development of Sustainable Fuels - Workshop Presentation. ***International Workshop on Innovations, Institutions and Path Dependency***, Zurich.

Sydow, J., Schreyögg, G., & Koch, J. 2009. Organizational Path Dependence: Opening the Black Box. ***Academy of Management Review***, 34(4): 689-709.

Sydow, J., Windeler, A., Möllering, G., & Schubert, C. 2005. Path-Creating Networks: the role of consortia in the process of path extension and path creation, ***21 EGOS Colloquium***. Berlin.

TheEconomist. 2012. Not Free to Fly, ***The Economist***.

TheEconomist. 2013. Carbon trading: ETS, RIP?, ***The Economist***.

Unruh, G. C. 2000. Understanding carbon lock-in. ***Energy Policy***, 28: 817-830.

Unruh, G. C. 2002. Escaping carbon lock-in. ***Energy Policy***, 30: 317-325.

Unruh, G. C., & Carrillo-Hermosilla, J. 2006. Globalizing carbon lock-in. ***Energy Policy***, 34(10): 1185-1197.

Upham, P., Tomei, J., & Dendler, L. 2011. Governance and legitimacy aspects of the UK biofuel carbon and sustainability reporting system. ***Energy Policy***, 39(5): 2669-2678.

Urry, J. 2002. Mobility and proximity. ***Sociology***, 36(2): 255-274.

Utterback, J. M. 1994. ***Mastering the Dynamics of Innovation***. Boston: Harvard Business School Press.

Vergne, J.-P., & Durand, R. 2010. The Missing Link Between the Theory and Empirics of Path Dependence: Conceptual Clarification, Testability Issue, and Methodological Implications. ***Journal of Management Studies***, 47(4): 736-759.

Vespermann, J., & Wittmer, A. 2011. Financial, ecological and managerial impacts of emission trading schemes: the case of Lufthansa. ***Business Strategy and the Environment***, 20(3): 174-191.

Weston, C., Gandell, T., Beauchamp, J., McAlpine, L., Wiseman, C., & Beauchamp, C. 2001. Analyzing Interview Data: The Development and Evolution of a Coding System. ***Qualitative Sociology***, 24(3): 381-400.

Williamson, O. E. 1985. ***The Economic Institutions of Capitalism: Firms, Markets, Relational Contracting***. New York: The Free Press.

Williamson, O. E. 2000. The New Institutional Economics: Taking Stock, Looking Ahead. ***Journal of Economic Literature***, 38(3): 595-613.

Wüstenhagen, R., & Menichetti, E. 2012. Strategic choices for renewable energy investment: Conceptual framework and opportunities for further research. ***Energy Policy***, 40: 1-10.

WWF. 2011. The Energy Report: 100% Renewable Enegerby by 2050. ***WWF Briefing.*** Retrieved 30.7.2013 from www.wwf.org

Yergin, D. 2011. ***The Quest: Energy, Security and the Remaking og the Modern World***. New York: The Penguin Press.

Yin, R. K. 2003. ***Case study research: Design and methods***. Newbury Park, CA: Sage.

Zah, R., Binder, C., Bringezu, S., Reinhard, J., Schmid, A., & Schütz, H. 2010. ***Future Perspectives of 2nd Generation Biofuels***. Zürich: Hochschulverlag AG an der ETH Zürich.