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Low-carbon sustainable transitions in the motorsport industry
the case of FIA Formula E

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Low-carbon sustainable transitions in the motorsport industry: the case of FIA Formula E

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List of Abbreviations

ASN	National Sporting Authority
ANT	Actor-Network Theory
BEVs	Battery Electric Vehicles
CBiS	Centre for Business in Society
CEO	Chief Executive Officer
CMO	Chief Marketing Officer
CO_2	Carbon Dioxide
COO	Chief Operating Officer
CTA	Constructive Technology Assessment
CWG	Commercial Working Group
ENEC	Electric and New Energy Commission
Eprix	Electric Prix
ERS	Energy Recovery System
EV	Electric Vehicle
F1	Formula One
FEH	Formula E Holding
FEO	Formula E Operation
FETA	Formula E Team Association
FEV	Fully Electric Vehicle
FIA	Federation International del 'Automobile
FETA	Formula E Team Association
FOTA	Formula One Team Association
GIMS	Global Institute for Motorsport and Safety
GT	Gran Turismo
HR	Human Resources
HV	Hybrid Vehicles
KERS	Kinetic Energy Recovery System
LMP1	Le Mans Prototype Category 1
MAT	McLaren Applied Technologies
MD	Managing Director
MLP	Multi-Level Perspective approach
MRT	Middle Range Theory

NDA	Non-Disclosure Agreement
OEM	Original Equipment Manufacturer
PEV	Pure Electric Vehicles
R&D	Research and Development
S0	Season 0 (August 2012 – August 2014)
S1	Season 1 (September 2014 – August 2015)
S2	Season 2 (September 2015 – August 2016)
S3	Season 3 (September 2016 – August 2017)
SCOT	Social Construction of Technology
SNM	Strategic Niche Management
SRT	Spark Racing Technologies
STS	Socio-Technical System theory
SWG	Sporting Working Group
TDI	Tribeca Disruptive Innovation award
TEP	Techno-Economic Paradigm
TIS	Technological Innovation System theory
TM	Transition Management
TSC	Temporal-Spatial Cluster
TT	Technological Trajectory
TTP	Technology Trajectory Paradigm
TTX	Zero carbon TT motorcycle
TWG	Technical Working Group
USA	United States of America
V8	An eight cylinder V configuration engine
WAE	Williams Advanced Engineering
WEC	World Endurance Championship
WRC	World Rally Championship
WTCC	World Touring Car Championship

Abstract

This research explores low-carbon sustainable socio-technical transitions. It does so through application of the Multi-level Perspective (MLP) approach to the example of FIA Formula E in motorsport. FIA Formula E is a new fully electric motorsport championship, which has rapidly grown and globalised in response to the low-carbon agenda within transport and mobility.

Developing a temporal understanding of the dynamics of low-carbon transition, this thesis contributes to the socio-technical transition literature, including the process of operationalisation of regimes, delineating the composition and agency of the socio-technical landscape level, the identification of alternative transition pathways, and the influence of interrelated systems on the overall dynamics of transitions. The concept of disruptive innovation within low-carbon shifts is considered.

Empirically, the thesis undertakes a two-phase approach to the investigation of FIA Formula E. The initial scoping phase is based on extensive analysis of documentary data and expert interviews. The main phase includes twenty-six semi-structured interviews with senior actors involved directly with FIA Formula E in the period of time considered for this study (from August 2012 until August 2017).

Examining micro-changes in actors and relations, between levels and amongst regimes, from season zero to season three of FIA Formula E, this research leads to three outcomes: first, it uncovers a regime-led transition pathway where the socio-economic landscape level, the patchwork of regimes level and the influence of adjacent interrelated systems play a role in triggering, shaping and enacting this low-carbon sustainable shift. Second, it argues that by acknowledging further the temporal system dynamics in transition processes, several factors are illuminated aside from technology (such as societal belief, power relations and vested interests of a wide range of stakeholders), which are central for strategy-building towards low-carbon transitions. Finally, by mobilising the theory of disruptive innovation within the MLP approach, this study answers the call for further exploration of novel transition pathways within low-carbon socio-technical shifts.

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This work would not have been possible without the support of all my friends, former colleagues and personnel from the motorsport Industry. In 2015, when I announced leaving my senior manager role, they thought I was retiring from the industry. Now they understand that I wanted to build a legacy, making sure that our hard work towards low-carbon sustainable motorsport was recognised and that other sectors could benefit from this story. In particular, it is to two of them whom I dedicate this work: to Pierluigi Corbari, who taught me that, with determination and passion, my hobby could be turned successfully into my job, and to my former colleague, friend and mentor Charlie Whiting. With sadness, they will not be able to see my mission accomplished.

Lastly, I would like to thank Prof K., a mathematician from my former undergraduate University, for suggesting that it is never too late to be a researcher.

To Pierluigi

(1947-2018)

To our friend Charlie

(1952-2019)

1. Introduction: Socio-technical transitions and the rise of FIA FE

1.1 Transitions to sustainability

There is a great interest from policy and academia in developing an in-depth understanding of transitions to low-carbon sustainable systems as a way to implement interventions which deliver tangible impact for issues addressed as The Grand Challenge[1] (European Commission 2012).

Scholars have suggested that for these transitions to succeed, specific attention should be directed not only to developing low-carbon technological innovations, but also to understanding the broader context of these systems' transformations whether in the mobility, food, water or energy sector (Geels 2012; Kivimaa and Martiskainen 2018; Raven and Walrave 2018; Schot and Kanger 2018). Low-carbon transitions are, in fact, "goal-oriented or purposive in the sense of addressing the problem of climate change" (Geels et al. 2017: 464), and involve systems that "consist of an interdependent and co-evolving mix of technologies, supply chains, infrastructures, markets, regulations, user practices, and cultural meanings" (Geels et al. 2017: 464). Though, it has been argued that the MLP framework has focused mainly on radical technical innovation for triggering socio-technical transitions allowing a deterministic view of technology to permeate most of the work using this approach (Van Driel and Schot 2005; Genus and Coles 2008), and explaining changes as triggered by the winning technology in its socio-technical regime, undermining the complexity of recent sustainable transition studies where policy, society and cultural regimes seem to constrain or enable such changes.

1.2 Socio-technical transitions in the mobility sector and the motorsport industry

One of the most prominent examples of the use of the MLP approach is found in studies concerning the transition to a low-carbon transport system in mobility (Berkeley et al. 2017; Dijk, Orsato and Kemp 2013; Geels et al. 2017; Geels 2012; Ghosh and Schot 2019; Marletto 2014; Moradi and Vagnoni 2018; Truffer, Schippl

[1] 'Grand challenge' is the label with which the Europe 2020 strategy addresses high priority problems such as climate changes, food security, energy security, etc. (Geels 2014).

and Fleischer 2017) which uses empirical examples from the UK, Germany, Italy and the Netherlands. In those large scale transport studies, scholars have defined these systems as the whole (national) automobility system. In those researches, system transitions occur when one of the radical technological innovations, at niche level, reaches the dominant design status, and diffuses into the market, destabilising and replacing existing regimes.

In 2006, in line with the automobility industry and its shift from the Internal Combustion Engine (ICE) to Hybrid (HV) and Electric Vehicles (EV), the motorsport industry and, specifically, the Federation Internationale de l'Automobile[2] (FIA) recognised the need to reflect broader political and environmental concerns which had an impact on global transport and energy ecosystem issues, and began discussions about a low-carbon transition of motor racing. These discussions culminated with the introduction of a set of technical regulations for the early deployment of a Kinetic Energy Recovery System (KERS) in Formula One in 2009, which was then mandated in 2011. This technological shift soon spread to include the broader system of motorsport. For example, in 2012, Audi Sport announced that a KERS system would be used in the Diesel-Hybrid R18 e-tron Quattro cars competing in the 24 hours of Le Mans[3], as did Toyota. In 2014 KERS become compulsory in the World Endurance Championship Le Mans Prototype 1 class (WEC LMP1), and manufacturers such as Audi, Toyota and Porsche started to invest in the development of hybrid systems.

This low-carbon transition to sustainability, culminated in August 2012 with the FIA unveiling the first all-electric racing cars championship, FIA Formula E, which began racing for the first time in September 2014 in Beijing (Huber 2012; Skeete 2019).

[2] "The Federation Internationale de l'Automobile (FIA) is the governing body of the world motor sport and the federation of the world's leading motoring organisation. Founded in 1904, with headquarters in Paris, the Fédération Internationale de l'Automobile (FIA) is a non-profit making association. It brings together 245 national motoring and sporting organisations from 143 countries on five continents. Its member clubs represent millions of motorists and their families" (www.fia.com).

[3] The 24 hours of Le Mans is a 24-hour race that is run in France every year. The race is not regulated by the FIA but by the ACO. In 2012 Audi voluntarily adopted the flywheel and won the race at its first attempt, placing all three cars on the podium, showing this technology's superiority.

Todt, president of the FIA, explained the FIA's vision in endorsing a Full Electric Vehicle (FEV) championship:

> "I thought it was important to have a vision for new technology for the development of the motoring industry and that's why we changed the regulations in Formula 1, that's why we supported new regulations in the World Endurance Championship. And then came the idea of making a specific flagship championship with electric technology. A lot of people were enthusiastic about this idea. For me, the electric car is really the future of motoring in the cities. And that's why we begin with hosting races in world cities. It's a new approach; it's a new product." (Todt 2012 cited in Formula E Holdings 2012)

FIA Formula E has since rapidly grown, responding to the low carbon agenda and the role of motorsport as automotive R&D, and attracted many car manufacturers and technology companies (Citroen, Renault, Mahindra, Audi, BMW, Mercedes-Benz and Faraday Future amongst others). Sponsors and teams have migrated, in time, from more established motorsport championships to Formula E, highlighting how policy, global and societal issues have contributed, together with technology, to the dynamics and the temporal dynamics of this system transformation. It comes as no surprise that FIA Formula E has been frequently associated with the term disruptive innovation[4] from journalist and writers (Leggett 2012; Formula E Holdings 2012; Sylt 2015b), winning the Tribeca Disruptive Innovation award (TDI), in 2015, presented by Tribeca co-founder Hatkoff, in collaboration with Professor Christensen[5].

It is the fast pace of this low-carbon shift in the motorsport industry, its connection with other sectors (Skeete 2019), and being addressed as driven by the need to help fulfil part of The Global Challenge (Robeers and Van Den Bulk 2018; Robeers

[4] "Formula E is disruptive in motorsport, redefining the very boundaries of what a sport can be through the unique fusion of entertainment, sustainability, technology and innovation. We are fighting climate change by offering electric vehicles as a solution to air pollution in city centres and breaking down the barriers to the electric vehicle market: Technology, Perception and Infrastructure" (Agag 2014 cited in Formula E Holdings 2012; Leggett 2012).

[5] "The awards focus on breakthroughs occurring at the intersection of technology and culture where frequent clashes and resistance to change impede social progress and solutions for some of the world's most vexing problems" (Disruptor award 2018).

2019) that makes the motorsport industry a suitable context for investigating the dynamic of low-carbon sustainable socio-technical transitions.

In this study, the definition of system differs from the one often used in recent automobility research (For example, Berkeley et al. 2017; Dijk, Orsato and Kemp 2013; Geels et al. 2017). Motorsport is a global industry (Henry et al. 2007) and has a well-established set of rules and a shared value proposition (see chapter 3). The range of sporting championships and business models that comprise the motorsport industry can be argued to share the same socio-economic landscape level, similar technological trajectories and part of the niche level (tier 1 and tier 2 suppliers). However, individually, the well-established and shared rules and value propositions which are contained within each championship, makes it difficult to place a championship at niche level alone. Each championship displays a high level of structuration that is embedded in a patchwork at regime level. Hence, in this thesis, a championship is not positioned at niche level – where, for MLP scholars, the locus of innovation resides (unstructured agglomeration of companies producing innovations that have no common vision or rules) – but, necessarily, at regime level.

Thus this study considers FIA Formula E a system 'per se' which includes, in the language of the MLP: a patchwork of regimes level where all different stakeholders of FIA Formula E sits, which is well-structured and has shared norms and rules within regimes; a landscape level that acknowledges the broader international and national policy and one-time events, which also influences all the other championships; and a niche level, where single companies and suppliers belong. This way of looking at the system has been used in research where transitions are not triggered by radical innovation at niches level (Papachristos, Sofianos and Adamides 2013, Dijk, Wells and Kempt 2016; Moradi and Vagnoni 2018, Skeete 2019).

1.3 Low-carbon socio-technical transition

This thesis applies the MLP approach to FIA Formula E in the motorsport industry, to explore the system dynamics of low-carbon sustainable socio-technical transitions. Hence, this research develops an overarching research question:

How do actors and institutions successfully facilitate, shape, drive and enact the dynamics of a disruption-led, low-carbon socio-technical transition?

The question has been then split into four objectives, set out in Table 1-A.

Table 1-A Research objectives

RO1	Understand the temporal dynamics of FIA Formula E, defining key moments, events and activities.
RO2	Identify the main factors, events and activities that drive changes in this innovatory system.
RO3	Identify actors and institutions, through the lens of the multi-level perspective to understand how these and their relations facilitate, shape and enact this disruptive-led low-carbon socio-technical transition in the motorsport industry, over time.
RO4	Consider implications for policy and management for informing strategy-building towards coherent low-carbon transformations in other sectors than motorsport

To answer these research objectives and to conduct the empirical analysis of this transition process, a research design was developed. It comprises of two phases: the scoping phase and the main phase (right-hand side of Figure 1).

The thesis structure is outlined in Figure 1.

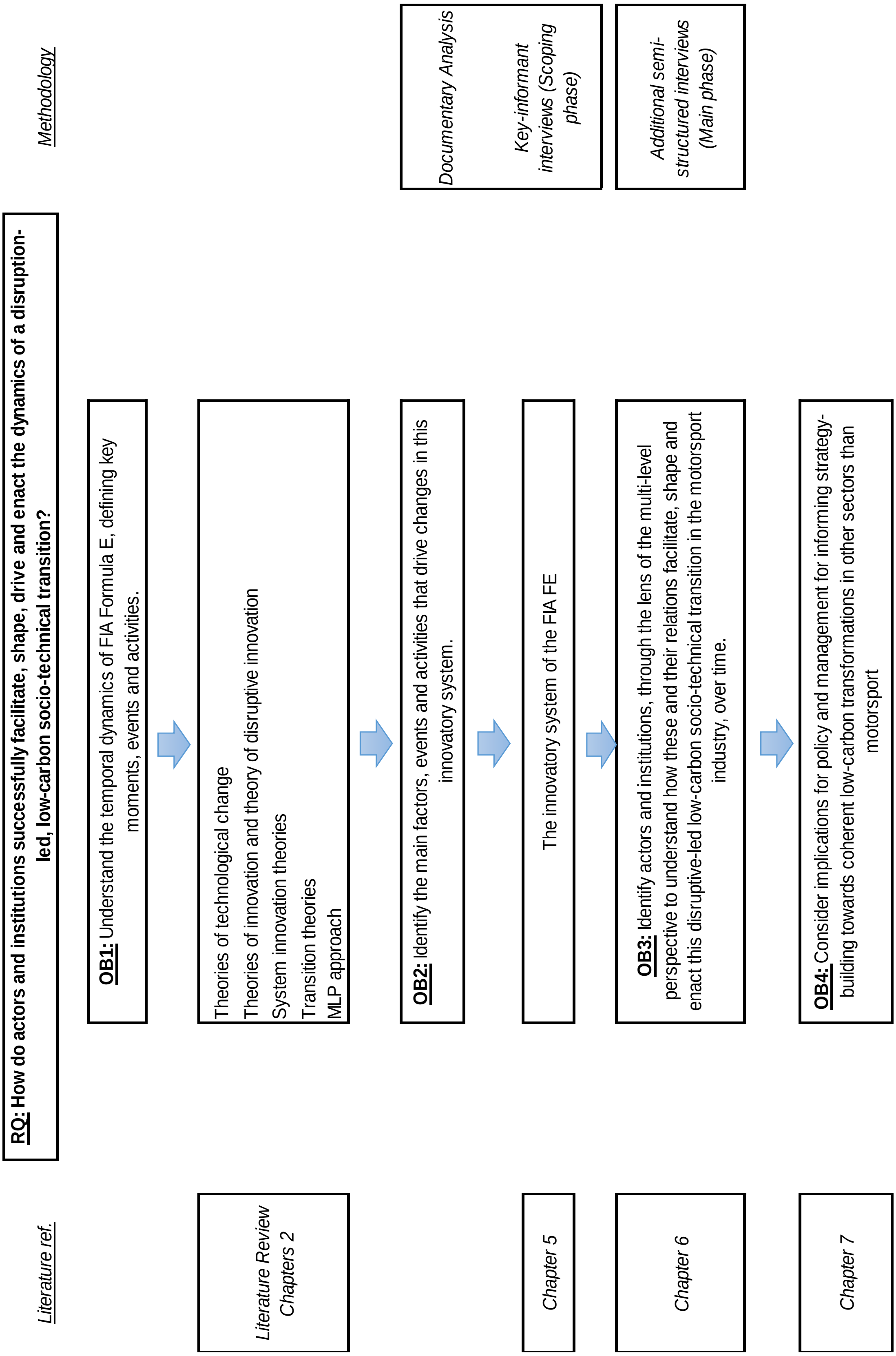

Figure 1 Relationship between the literature, methodology, the research question and objectives (author's compilation)

Following this introduction (chapter 1), *chapter 2* will cover the theoretical background used to develop an understanding of the temporal system dynamics of disruptive innovation-led low-carbon socio-technical transitions. Specifically, this section covers some main broad areas reviewing concepts which are useful for this study: technological change, innovation, disruptive innovation, system innovation theories, the current state of research for socio-technical transition theory and the MLP approach. The end of this chapter will discuss current research gaps and intended improvements.

Chapter 3 will present the context of this research, the motorsport industry, explicitly focusing on its value for understanding low-carbon sustainable socio-technical transitions, its value chain and the innovatory system of this industry, providing insights into how innovation percolates through this system, and how the system has dealt with disruptive innovations in the past. This chapter will conclude by presenting a summary of FIA Formula E story.

Chapter 4 will set out the research methodology for investigating the research question and objectives. It will outline the philosophy of this research, critical realism, and my positionality. This chapter will detail the research design and the research methods that this PhD will use to gather and analyse the data in both the scoping and main phase of this research.

Through the analysis of nine hundred and twenty documents and five expert's interviews from the scoping phase of this research, *chapter 5* will present the innovatory system of FIA Formula E, identifying activities and events from the initial announcement in 2012 until the end of season three, in August 2017. Using strategies for processing data (Langley 1999), this chapter will reorganise these events in a visual map, where season will be the unit of time used in the analysis of the temporal dynamics of this system (X-axis), and technological, business and regulatory factors will be the themes amongst which events and activities are classified (Y-axis).

With the help of twenty-six additional semi-structured interviews, *Chapter 6* will reinterpret the innovatory system of FIA Formula E with the lens of the MLP approach, presenting the findings of this research which will be discussed in depth in chapter 7 to comprehensively answer the research question and objectives of this study.

Finally, *Chapter 8* will conclude this thesis. A summary of the thesis will be provided, including contributions to knowledge, specifically to theory, methodology, motorsport and practice. This chapter will also discuss limitations of this work, further research topics and a brief reflection on my PhD.

1.4 Contribution to knowledge

This thesis aims to contribute to the debate on low-carbon socio-technical transitions towards sustainability. This is accomplished by mobilising business theories, management theories and methods to process data within the MLP approach (Foster 1986; Christensen and Raynor 2013; Langley 1999; Langley et al. 2013). Additionally, through a deeper understanding of micro-changes of actors and relations of the transitioning system, this research aims to shed lights on the following literature gaps which have emerged from the MLP framework:

1. Opening the "garbage can" (Geels 2011: 36) of the socio-economic landscape level, providing a clarification of the composition of this level and its interaction and agency with other levels (Schot, Kanger and Verbong 2016).
2. "Mobilising insights" (Geels 2011: 30) other theories in order to improve the understanding of the mechanism throughout which various levels and dimensions interact. In particular, by mobilising business and management theories, several findings on the influence of adjacent interrelated systems within which this system transition has emerged.
3. To advance the discussion around alternative transition pathways, where system changes are not triggered by niche innovations gaining momentum, but from other levels and actors in the system. Specifically, this study wants to respond to the recent call from Ghosh and Schot (2019) to find other empirical examples of alternative transitions pathways in Western culture.
4. To contribute to the debate about disruption and MLP approach (Geels 2018; Kramer 2018; Wilson and Tyfield 2018), mobilising the theory of disruptive innovation within the MLP approach for exploring system

dynamics and system reconfiguration in low-carbon sustainable transition triggered from the patchwork of regimes level.

Since the thesis is an empirical study, it is also willing to make a methodological contribution. Responding to calls for robustness in operationalising the regimes and levels within the MLP approach (Genus and Coles 2008; Markard and Truffer 2008; Smith, Voβ and Grin 2010; Fisher and Newig 2016), this research wants to offer a way to do so by applying methods to process data used in business, change management and engineering disciplines. Specifically, by applying strategies from process theories to bracketing time and identifying events and activities using flow charts and institutional mapping techniques, this study wants to offer a reliable way to place actors and groups of actors within regimes and levels to prevent biases and increase the replicability of this research.

Concerning the motorsport literature, this thesis wants to contribute to the limited existing literature between motorsport and low-carbon sustainable transitions using FIA Formula E as a suitable example (Huber 2012; Skeete 2019; Robeers 2019). Through this empirical example, this thesis aims to shed light on the process of change and the role and agency of institutional actors. Contrary to many studies that have considered any changes in the motorsport industry driven solely by institutional actors, such as the FIA (Huber 2012; Papachristos 2014), this research wants to unveil also how teams, manufacturers and scientists, together with the socio-economic context and international policies play, in time and combination, an active part in driving and enacting changes, in all the FIA regulated championships. This finding might bear implications on the understanding of the innovatory system of motorsport.

Finally, the originality of this study is to use the motorsport industry as a context for studying low-carbon sustainable socio-technical transitions using the MLP approach, introducing a cross-disciplinary interpretation of novel transition pathways, which has emerged by mobilising the theory of disruptive innovation (Christensen and Raynor 2013) within the MLP approach.

The motorsport industry is well known to be fast-paced innovation and at the forefront of technology development. Hence, changes happen in shorter time scales than other industries, which will help to explore the dynamics of this low-carbon shift. Being able to study this phenomenon while the system is transitioning facilitates a much better and in-depth observation of the phenomenon.

2. Understanding low-carbon socio-technical transitions

2.1 Introduction

Acknowledging that innovation, technological change and system theories constitute the conceptual basis of ‘transition studies’, this chapter begins with a critical review of these theories (2.2).

Given the substantial literature (see Twomey and Gaziulusoy 2014 for a review), this section covers only key concepts particularly relevant to the area of socio-technical change. As transitions are purpose driven changes which focus on system shifts, theories of technological change (2.2.1) are reviewed to illuminate factors which enabled these shifts. Whilst these shifts are mainly thought to be triggered by technological development, socio-economic and political factors are identified equally as important factors for explaining systemic change. Thus, the chapter moves beyond theories of technological determinism to explain technology shifts, including situation in their historical context whether through Foster S-Curves, Dosi’s (1982) technological trajectories and the theories around Social Construction of Technology.

Yet (socio) technological change has been identified historically to be triggered by innovation, thus the literature review moves on to discuss theories of innovation. However, recognising that socio-technical transitions especially are usually initiated by a drastic event (Geels and Schot 2010), the focus is understanding that form of innovation that engenders major change, including engagement with the business and management literature on disruptive innovation (Christenson and Raynor 2013) The section culminates with a brief discussion of systems innovation theories (2.2.3) to emphasise the interlinkage between elements of a system when changes occur, and in accordance with understandings of socio-technical transition.

Given the review of key underpinning concepts in understanding systemic shifts in technologically-rich economic systems, Section 2.3 moves on to discuss the current state of research of socio-technical transition theory, defining key terms and different frameworks that have been considered useful in exploring system changes (Markard, Raven and Truffer 2012). As this study considers FIA Formula E as a system, Transition Niche Management (TNM) and Strategic Niche

Management (SNM) are only briefly addressed whilst alternative frameworks such as the socio-ecological transformation approach (Meadows 2007) are considered out of scope given this approach comes from and is more suited for ecology (rather than evolutionary economics.

The thesis specifically engages with one of the most prominent frameworks in transition studies, the Multi-Level Perspective approach (Geels and Schot 2010; Geels 2012; Geels et al. 2017), which, in the past decade, has been extensively used for exploring low-carbon sustainable socio-technical transition in a number of sectors (Berkeley et al. 2017; Fuenfschilling and Truffer 2016; Geels 2012; Geels et al. 2016; Geels 2012; Moradi and Vagnoni 2018; Rogge, Pfluger and Geels 2018; Verbong and Geels 2007). Section 2.4 presents the theoretical foundation of MLP and discusses its articulation of proposed transition pathways. In particular, the section addresses the use of this approach to study low-carbon sustainable socio-technical shifts, including 'disruption in transition' literature and the limitations of the MLP approach.

Section 2.5 concludes the chapter by presenting the knowledge and empirical gaps that this study seeks to fill.

2.2 Understanding socio-technical transitions through innovation, technological change and system innovation theories

Socio-technological transitions involve "innovations that are directed to redesigning entire systems of practice and provisions, instead of individual products or processes" (Sterrenberg et al. 2010: 9). Hence, the first sub-section reviews theories of technological changes. This sub-section includes the Techno-Economic Paradigm (TEP) and Socio Construction of Technology (SCOT) theories, underlining how it is not just technology that changes systems, rather a complex mix of factors. These theories constitute the foundation of the MLP approach, which is the conceptual framework of this thesis.

Although the focus of this research is on system changes, there is acknowledgement that these shifts are usually triggered by innovation (Geels and Verhees 2011; Schot 2005; Twomey and Gaziulusoy 2014), which dictates the need to understand innovation at a micro level. Hence sub-section 2.2.2 touches on theories of innovation presenting a categorisation of innovations. This sub-section concludes by discussing the theory of disruptive innovation (Christensen and Raynor 2013). This theory offers a different proposition to that of other innovation theories, where the novelty of innovation is in its value-proposition and has lately been at the centre of the debate of the value of the disruption theory in low-carbon transitions (Geels 2018; Kramer 2018; Wilson and Tyfield 2018).

2.2.1 Technological change theories

The literature around technological change is populated with a number of theories that explain these shifts in different ways, depending on the philosophical orientation of the scholars (Clark and Staunton 1989). Amongst these philosophical orientations, technological determinism regards technology as the key mover in the history of economic and social changes. This reductionist theory was founded by the Austrian sociologist Veblen in 1899 during a period of intensive technological progress, such as the first and second industrial revolution. It identifies technology as the sole cause of changes in society, resulting in humans being a “mere pawn” of the system (Clark and Staunton 1989). Technological determinism supports the idea that human behaviour is caused by forces and conditions that exist independently from the actors themselves, dismissing the notion of “free will” and equating technology only with the equipment, neglecting the role of the socio-political environment in defining or determining what technology is (Clark and Staunton 1989). Although reductive, this notion of technology has been influential in the introduction of extensive, quantitative, cross-sectional studies during the period 1960-1980, producing a number of theories and empirical studies based on after changes and before changes, to explain technological transitions (Abernathy and Utterback 1978; Ellul et al. 1954; Maclaurin 1953; Rosenberg 1974; Utterback and Abernathy 1975).

In contrast with Veblen’s hard technological determinism, a soft technological determinism was introduced by Finnegan (1987) and White (1978), claiming that technology is only an enabling or facilitating factor that creates an array of possibilities which might be pursued by society, depending on other issues such as, for example, time in history, maturity and societal needs. De Sola Pool (1983) explains that in the soft technological determinism theories “technology shapes the structure of the battle but not every outcome” (Finnegan et al. 1987: 32). The first elaboration of this theory in a socio-economic context can be dated back to the theories of Marx (Marx 1967), who observed that changes in technology and, specifically, in production are the primary source of influence for social relationships and organisational structure. Specifically, both society and institutions adapt to accommodate further technological changes.

Following the World Wars, within the reconstruction years, new philosophies argued that a mixture of variables is responsible for technological changes. In these years, Fielding and Duncan introduce the idea that technology is mainly driven by social changes, otherwise known as idealistic determinism (Ogburn and Duncan 1964). This theory argues that ideas and beliefs shape actions and outcomes associated with the introduction of technologies. Hence, changes in technology are only one of the factors amongst many others which trigger these transitions (MacKenzie and Wajcman 1999).

This fundamental characteristic of how technology, society and market induce changes sits at the core of different theories of technological change and system innovation. Amongst these theories, the most relevant for understanding low-carbon sustainable transition are 1) the ones considering technological changes as dynamic processes and 2) the ones considering socio-technical change triggering systems' shifts. Specifically, amongst the theory considering the technological changes as dynamic models (1), for the purpose of this thesis the Utterback and Abernathy model (U-A model) (1975, 1978) and the S Curve model (Foster, 1986) will be discussed. The U-A model offers a dynamic approach to technological changes, considering the rate of innovation (Y-axis) over time (X-axis) as the main factor influencing these changes. Defining Schumpeter's (1939) creative disruption as the trigger for technological shifts, Abernathy and Utterback (1975) investigate the longitudinal patterning of innovation over the lifetime of a sector. Their studies show that radical innovation is solely responsible for the start of a new technological cycle. Hence they define radical or discontinuous innovation as an innovation that creates major disruptive changes, "change that sweeps away much of a firm's existing investment in technical skills and knowledge, design, production technique and equipment" (Utterback, 1996: 200). Considering the time dimension fundamental in technological changes, and acknowledging that process and product development need to be considered complimentary as both causes of innovation, the U-A model identifies a life-cycle with three phases for both process and product development: the fluid phase, the transitional phase and the specific phases. Each of these phases is characterised by a different rate of product and process innovation, and different capabilities and degree of flexibilities of a company. These factors change over time and follow predictable patterns.

In contrast with the U-A model, Foster (1986) considers technological changes unpredictable and unlikely to happen at a certain pace. Drawing from the understanding that technology lifecycles can be represented by a curve shaped like an S, he suggests a model in which technological changes trigger the start of a new S-curve that will, at a certain point, displace the old one. Foster's model argues that time and technological performance are variables over which a technology curve is plotted, and are the main factors of influence for technological changes. The scholar highlights that a key element for the replacement of the old technology with a new one is the phenomena of maturation of each technology (already known in the U-A model). He observes that, at the early stage of a technology, the infancy phase, the rate of progress in performance, defined as performance over time, is relatively slow. As the technology reaches its mature phase, becoming more known to users, "the rate of technological improvement increases" (Sahal, 1981 in Christensen 1993: 334). The novelty of this theory is to affirm that the levelling out of technology at the end of each technology life-cycle is mainly due to the technology reaching its physical limit, "the fundamental fact of nature" (Foster, 1986 cited in Christensen, 1993: 337). In foster's S-curve model, a new technology does not typically displace an existing technology until this reaches the physical limit. When this happens, the new technology replaces the existing one, causing what Foster identified as technology substitution.

Despite the empirical examples Foster has offered, some scholars have argued that the technology cycle does not follow precisely the S-curve trajectory (Sahal, 1981; Dosi 1982). Above all, Sahal (1981) proposes a theory of technology maturity where factors such as the scale of the phenomena (the impossibility of getting a device bigger or smaller) and the complexity of the system are at the basis of the decline of existing technologies in modern time. Additionally, Sahal reinforces the idea that space and time are two critical factors to study technological changes as they inform us of how technology diffuses.

Amongst theories considering socio-technical change triggering systems' shifts, Dosi (1982) analyses the nature of technology in the view of technological changes, outlining that previous works have undermined the role of the socio-economic environment in shaping technologies and technological changes. In his theory, Dosi defines technology as:

> "A set of pieces of knowledge, both directly 'practical' (related to concrete problems and devices) and 'theoretical' (but practically applicable although not necessarily already applied), know-how, methods, procedures, experience of successes and failures and also, of course, physical device and equipment. […] Therefore, technology, in this view, includes the 'perception' of a limited set of possible technological alternatives and of notional feature developments." (1982: 152)

Drawing from Kuhn's (1962) scientific paradigms, he explains technological paradigms "as a model and a pattern of a solution of selected technological problems, based on selected principles derived from natural sciences and on selected material technologies" (Dosi 1982: 152). A crucial question in Dosi's work is how a given technological paradigm emerges and what causes its selection amongst other possible technologies.

> "Within a large set of possibilities of directions of development, notionally allowed by science, a first level of selection […] operates on the basis of rather general questions: 'is any practical application conceivable?'; 'Is there any some possibility of the hypothesised application being marketable? […] The economic criteria acting as selectors define more and more precisely the actual paths followed inside a much bigger set of possible ones." (1982: 153)

Dosi (1982) defines technological trajectory as "the movement of multi-dimensional trade-offs amongst the technological variable which the paradigm defines as relevant" (1982: 154) borrowing the definition of momentum and natural trajectory from Nelson and Winter (1982). Once the problem-solving activities and paths have been selected and established, the path shows a momentum of its own, shaped by social and institutional factors, which contribute in defining the direction in which the problem-solving activity moves, the so-called natural trajectory. Hence, the emergence of the technological paradigm and the definition of the problem leads the way for a technological transition.

Dosi's (1982) theories have been beneficial towards furthering the discussion of theories of technological change, bringing together most of the theories of technical change and innovation and helping to soften up the technological determinism that was detected in most of these theories (Nightingale 2008). For this research framework, Dosi's (1982) theory is useful to reinforce that the solution to a technological problem is influenced by many factors such as market dynamics and the socio-economic context in which technology is chosen (choice of technology). As the choice of the technological paradigm is amongst known technologies, defining boundaries to the problem and locating the technological problem within a space and a temporal dimension becomes paramount in Dosi's theory. Once the technological paradigm is chosen, the socio-economic-political context directs and shapes its technological trajectory (Dosi and Winter 2002; Dosi and Nelson 2010).

Similarly, Nelson and Winter define the concept of technological regimes which directs technological changes towards a resolution of a technological problem (Nelson and Winter 1977).

At the bottom of Dosi's and Nelson and Winter's works lies the understanding that technological changes are discontinuous events involving the interaction of technology and society which might lead to transformations of the existing systems. Hence technology is not seen as an antithesis to society, but they are both perceived as connected phenomena in system changes. Developing further those concepts, Freeman (1989), in his Techno-Economic Paradigm (TEP), conceptualises the interaction between technological changes and shifts in economic conditions. For Freeman (1989) a techno-economic paradigm represents a stable cluster of technologies around which economic activities and innovation occur. This cluster of technologies influences the economy and the social environment in which the technology is placed. A new paradigm arises when a major technological change happens, disrupting the current technology and economic life. The displacement of old technology in the new paradigm creates an array of inventions and innovations that are not linked anymore with old technology. The displacement generates a subsequent opportunity for incremental innovation, allowing the new technology to spread, causing shifts in paradigms. The shift does not only affect technology but involves society, institutions and economic issues as the framework that is suitable for the old paradigm might not be appropriate to the new one. Hence the techno-economic paradigm results from the interaction of technological, institutional, social and economic factors.

Reddy (2009) has observed that one of the most important parts of the TEP is to provide a macroeconomic definition of innovation (techno-economic paradigm), built upon two dimensions: time and space. The definition of space is vital to the theory, as the paradigm will affect different regions and different countries in different ways and with a different momentum. The time dimension is crucial, as the process of technological change and its social and economic impact differs over time.

Perez (2010) applies the techno-economic paradigms to a meso and micro-level of analysis of technological changes, treating innovation as the dynamic space for the study of these technological shifts. Perez argues that for each innovation the space of possible technological developments is greater than the space for those which, ultimately, are economically profitable and socially excepted. Perez (2010) concludes that managers have the responsibility to turn invention into innovation and, in order to do so, they need to consider profit as the main target for their choice of technology. Hence, profit, and therefore economic condition, is the main driver for managers' acceptance or rejection of an innovation. Perez continues:

> "Those decision processes are not random. They are shaped by the context, including relative prices, regulatory and other institutional factors and obviously, their perceived market potential. They are also path-dependent, because market potential often depends on what the market has already accepted and because the incorporation of technical change requires the coming together of several pre-existing explicit and tacit knowledge bases and various

> sources of practical experience. Thus, the meaningful space where technical change needs to be studied is that of innovation, at the convergence of technology, the economy and the socio-institutional context. That space is essentially dynamic and, in it, the basic concept is that of a trajectory or paradigm, which represents the rhythm and the direction of change in a given technology." (Perez, 2010: 4).

Drawing from the Utterback-Abernathy (1975) model and specifically from the trajectory of an individual technology, Perez's (2010) study accepts Dosi's technological paradigms as "a collectively shared logic at the convergence of technological potential, relative costs, market acceptance, functional coherence and other factors" (2010: 5). However, for Perez the emergence of an individual innovation does not happen in isolation but is normally a collective process involving all stakeholders. Thus, Perez defines technological revolution "as a set of interrelated radical breakthroughs, forming a major constellation of interdependent technologies; a cluster of clusters or a system of systems." (Perez 2010: 8). Drawing from empirical data, Perez identifies five core technological revolutions between 1770 and 2000, each linked to a techno-economic paradigm. The scholar concludes:

> "No matter how important and dynamic a set of new technologies may be, it only merits the term revolution if it has the power to bring about a transformation across the board. It is the techno-economic paradigm (TEP), evolving as the new technologies diffuse, that multiplies their impact across the economy and eventually also modifies the socio-institutional structures." (Perez 2010: 13).

It is this awareness of innovation as a dynamic and "meaningful space" (Perez 2010: 13) of technical changes, where each actor plays a significant role in enabling and shaping the technological revolution, that this research considers TEP and Perez's theories particularly useful.

In contrast with the techno-economic theory of technological changes, the theory of Social Construction of Technologies (SCOT) does not perceive technological changes as the outcome of market demands or technological opportunities but influenced by social interactions amongst relevant social groups (Olsen and Engen 2007). In response to technological determinism, where technology determines human actions, SCOT argues that human actions shape technology. Hence, technological changes cannot be understood without understanding how technology is embedded in its social context. Thus, technological innovation, the trigger for technological shifts, results in an open process that can produce a different outcome depending on the social circumstances in which it develops (Bijker, Hughes and Pinch 1987). Latour (1990) and Callon (1987) emphasise how social structure plays an essential part in the understanding of innovation, which is generally transferred along a chain of actors. Each actor plays an equally important role in the adoption or rejection of the innovation. Specifically, these scholars' contribution has been in understanding innovation as a social construction process, where all the actors and entities are interconnected, creating a network where the value of the innovation is only relative to the same network where actors, entities and innovation co-exist. A technological change happens when the most influential group of actors accepts one dominant design (Olsen and Engen 2007).

Considering technological determinism a myth, as technological paths are multiple, Bijker (2012) develops a structurally oriented perspective of the SCOT proposing a way to understand technological systems by looking at their technological frames as shared cognitive frames, that define relevant social groups around a technology (Klein and Kleinman 2002). Bijker considers technological frames as dynamic, emerging during the innovation process, in contrast with the more diffuse idea of fixed entities:

> "Within a technological frame not everything is possible anymore (the structure and the tradition aspect), but the remaining possibilities are relatively clearly and readily available to all members of the relevant social groups (the actor and innovation aspect)." (Bijker 1997: 192)

SCOT underlines factors such as social interaction amongst groups, interconnected actors and entities, and networks that create a value-network within which the value of innovation is defined. Within this theory, technical changes are dynamic and relative to the conventional interpretation of a social group (Bijker 1997; Bijker, Hughes and Pinch 2012).

Misa (1994) has argued that TTP and SCOT draw on evidence from different levels of analysis to construct their arguments. At a macro-level "a causal role for the machine is not present" (Misa 1994: 117), and authors have focused on industrial development leading towards technological determinism. These authors (Olsen and Engen 2007) tend to abstract from individual cases and are more concerned about the nature of innovations, technological accumulations and the institutions affecting these processes. Contrarily, at a firm-level, "studies tend to focus solely on case studies, to refute rationality or confute functionality, and to be disorder-respecting, for historians of technology and business this means analysing the institutions intermediate between the firm and the market or between the individual and the state" (Misa 1994: 117-118). Therefore Misa calls for an analysis of the phenomena at a meso-level where institutional actors are introduced:

> "Since these institutions mediate between key actors in society, whether they orchestrate or respond to sociotechnical change, such an analysis would naturally lead us to the historical public debates concerning the costs and benefits of sociotechnical change." (Misa 1994: 119)

In summary, most of the theories reviewed above identify technological changes as processes of qualitative changes that take place in historical time, driven by technology, firms, governments and other organisations with a diverse set of motivations, decisions, rules and capabilities (rather than optimising behaviour and perfect information). Hence, their overall value is to offer conceptual and analytical insight on system transformation as long-term socio-technical processes.

2.2.2 Innovation theories

Section 2.2.1 has dealt with theories of technological change mostly showing how innovation triggers and shapes shifts of existing systems. This leads to the need to review innovation theories at a micro/meso-level.

A multitude of disciplines have studied innovation, and its definition has been subject to a variety of interpretations (Garcia and Calantone 2002). Historically the term innovation was coined by Joseph Schumpeter to describe “creative disruption” (1942: 59) as the act of replacing old innovation with new innovation. Moving away from technological deterministic theories, where technology advancements were the only source of change (Kondratieff 1979; Schatzberg 2006), Schumpeter (1942) defines development as a historical process of structural changes driven by innovation. He identifies a broad range of events as sources of it, including: “the introduction of new commodities, technological change in the production of commodities already in use, the opening up of new markets or of new sources of supply, improved handling of material – in short, any form of ‘doing things differently’ in the realm of economic life” (1942: 59).

In their systematic review of innovation theories, Crossan and Apaydin (2010) suggest that innovation can be seen as the “production or adoption, assimilation, and exploitation of a value-added novelty in economic and social spheres; renewal and enlargement of products, services and markets; development of new methods of production; and establishment of new management systems. It is both a process and an outcome” (Crossan and Apaydin 2010: 1155). This definition emphasises the complexity of the phenomenon that is both a process and an outcome influenced by multiple factors. Technological, economic and social factors are often addressed together with business and management factors to explain this concept. If their systematic review focuses mainly on organisational innovation studies, Garcia and Calantone (2012) have reviewed the literature of innovation with a particular focus on technological innovation. In their study, they found that there are various constructs within the academic literature for categorising innovation, which are mainly based on dichotomies. Those dichotomies are a way to operationalise the concept of new innovation replacing old innovation addressed from Schumpeter (1942). Specifically, to study socio-technical transitions, the dichotomies in table 2A are of particular interest.

Table 2-A Summary of theories of innovation relevant for this research (author's compilation)

Authors	Dates of key articles	Innovation dichotomy
Abernathy and Utterback	1975	Radical vs incremental
Abernathy and Clark	1985	Architectural vs Regular
Clark **Clark and Staunton**	1989 1985	Epochal vs episodic/generic
Tushman and Anderson	1986	Continuous vs discontinuous
Chandy and Tellis	1988	Radical or breakthrough vs incremental
Christensen and Raynor	2003	Disruptive vs Sustaining

Considering innovation as an outcome, Abernathy and Utterback (1975) were the first to distinguish between radical and incremental innovation. They define radical innovation as technology significantly different from the existing ones. In contrast, incremental innovation is available throughout continuous improvements of existing products/processes. Each of these innovations has a different set of characteristics and implications. Defining innovation as the initial introduction into the market of a product or process, Abernathy and Clark (1985) suggest that the significance of innovation depends mainly on two factors: its added value and the impact that the innovation has on the existing technical competencies of incumbent firms. The framework of this model is based on the concept of transilience (Abernathy and Clark 1985), which is the capacity of innovation to influence the traditional system of production and marketing. The scholars suggest the use of these two factors as dimensions of innovation, suggesting the existence of four typologies of innovation: *regular innovation,* which builds on manufacturer technological capabilities and market knowledge; *revolutionary innovation,* which makes technological capabilities obsolete but preserves market knowledge; *niche innovation,* which preserves technological capabilities but makes market knowledge obsolete and *architectural innovation* which arises when both technological and market capabilities become obsolete. Specifically, Abernathy and Clark’s (1985) model defines architectural innovation as a process or product innovation that destroys both market and technical core capabilities of an existing firm.

Moving away from the idea that innovation is “a dramatic event’” (Clark 1989 1: 10), and building on previous theories of innovation (Abernathy, Clark and Kantrow 1983; Utterback and Abernathy 1975), Clark and Staunton (1985) focus on innovation in technology and organisations, recognising the various levels of analysis needed to understand this phenomenon and its dynamic. To reflect this, they define five categories of innovation: *generic innovation* which creates a new techno-economic paradigm (Freeman 1982; Perez 2010) “of clusters of innovation emanating from a new core process (electricity) which cross-cut many sectors and many stages of production (electrification of city)” (Clark 1985: 112); *epochal innovation* defined as a subset of generic innovation, which is confined to a particular sector; *altering innovations* if it introduces an important alteration at a firm or niche-level; *entrenching innovation* if innovation modifies existing methods but proceeds in the same direction; and *incremental innovation* when there are no new inputs but the existing ones are reconfigured to achieve a new output. In this context, epochal innovation assumes the connotation of innovation that “affect the existing capital equipment, labour skills, materials and components, management expertise and organisational capabilities” (Clark 1985: 112) in one sector only, similarly to radical, architectural and revolutionary innovation. Categorising innovation in this way, Clark (1985) seeks to bridge the gap between previously identified variables at a micro-level and factors influencing innovation at a meso-level such as core capabilities, the maturity of a company, capital equipment, technology and market, and remarking how those levels are connected.

Introducing the organisation as one of the dimensions of the analysis of innovation, the micro or firm-level, Tushman and Anderson (1986) create a new model of innovation, which focuses on two different dimensions: the impact of innovation on existing organisational capabilities of firms (competence enhancing vs competence destroying) and technological capabilities (continuous vs discontinuous). This model shows that these discontinuities affect firms in different ways, depending on the competence-enhancing or competence-destroying qualities of technological innovation. From an organisational point of view, competence-enhancing innovations exploit existing skills and knowledge within firms. These innovations serve to consolidate industry leadership in larger companies and hinder the development of new organisational forms. Contrarily, competence-destroying innovations spur the creation of new organisational forms that can quickly acquire and utilise new technologies (Tushman and Anderson 1986).

Chandy and Tellis (1998) propose a model accounting for two different dimensions, the technological novelty dimension and a new dimension based on the fulfilment of the customer, or value network. They propose a new matrix categorising four typologies of innovation: *incremental innovation* if both the newness of technology and the customer needs fulfilment is low; *radical innovation* if the newness of the technology and the fulfilment of the customer needs is high; *market breakthrough* if the newness of technology is low, but the customer fulfilment is high and *technological breakthrough* if the newness of technology is high, and the customer fulfilment is low.

The novelty of their approach has been to give an alternative explanation of why firms succeed in introducing a radical product. In contrast with the theories which assert that the size of a firm or the longevity of the means of an organisation are the main causes of success or failure in introducing a radical product innovation, Chandy and Tellis (1998) define the willingness to cannibalise their current product as the main reason for firms' failure or success. They continue to explain that the willingness to cannibalise their product is a strategy usually well recognised amongst new, agile and small firms, and they conclude that this is the reason why new entrants usually do succeed in the introduction of radical innovation (Chandy and Tellis 1998).

Whilst most of the distinction of the theories above are more inclined to describe changes as a product and in terms either of technological novelty or market, the theory of disruptive innovation (Christensen and Raynor 2013) offers a different proposition to the arena where both the technological and business dimension of innovation come together within a temporal dimension and a dynamic space.

The theory of disruptive innovation is most strongly associated with the work of Christensen (Bower and Christensen 1995; Christensen, Horn and Staker 2013; Christensen and Raynor 2013; Christensen 1997; Christensen 2006; Christensen 1993; Christensen and Overdorf 2000; Christensen, Raynor and

Mcdonald 2015; Raynor and Christensen 2003). It recognises that very rarely technologies are *per se'* disruptive; rather it is the business model which these technologies enable that creates a disruptive impact on the existing business organisations.

> "In other words, it was not a technology problem; it was a business model problem. I made a mistake when I labelled the phenomenon disruptive technology; the disruptive business model in which the technology is deployed paralyses the incumbent leader" (Christensen and Raynor 2013: 43).

This concept originated from the theory of disruptive technologies (Bower and Christensen 1995), which defines disruptive technologies as products, services or technologies with characteristics inferior to existing products, services or technologies already in the market:

> "Generally, disruptive technologies were technologically straightforward, consisting of off-the-shelf components put together in a product architecture that was often simpler than prior approaches. They offered less of what customers in established markets wanted and so could rarely be initially employed there. They offered a different package of attributes valued only in emerging markets remote from, and unimportant to, the mainstream" (Christensen 2000: 15).

Contrarily, sustaining innovation does not involve a new market or a new value network and is defined as an innovation that improves an existing product, either technologically or in terms of price, allowing firms already present in the market to compete with each other within the existing value network.

The concept of relativeness of disruptive innovation, although not new (Rogers 1962), explicitly includes all the main dimensions of innovation (Crossan and Apaydin 2010): (a) technological dimension, which defines the impact of innovation on existing technological standards and its differences with the existing technological trajectory; (b) market dynamics dimension, which considers the effects of innovation on the dynamics of the market, bringing together variables such as changes to customer preferences, channels of distribution, modes of customers' communication and customers' applications (Abernathy and Clark 1985; Schumpeter 1939a; Schumpeter 1939b); and (c) organisational dimension which refers to the impact of innovation on existing organisational competencies (Gatignon et al. 2002; Tushman and Anderson 1986).

Christensen and Raynor (2013) consider disruptive innovation as a relative process, relative to all established players in the market. As such, two main variables are identified that influence the dynamics of disruptive innovation: *market types* and customers' *value network.* These concepts are discussed below.

Market Types

Drawing from the fact that, in the existing market, products compete on performance, Christensen and Raynor (2013) identify two types of mechanisms for market disruption:

a. **New market disruption** refers to those innovations that compete with non-consumption because they are "so much more affordable to own and simpler to use that they enable a whole new population of people to begin owning and using the product, and to do so in a convenient setting". (Christensen and Raynor 2013: 46). Examples of such disruption are the personal computer and Sony's first transistor radio. These were products introduced to entirely new consumers, who had not previously had any access to computing power or radios.
b. **Low-end disruption** refers to those innovations that enter the market as not good enough solutions compared to established products and services. Examples are steel mini-mills and Asian automakers (Christensen and Raynor 2013).

Those two mechanisms for market disruption are represented below in Figure 2.

Figure 2 The third dimension of the disruptive innovation model (Christensen and Raynor 2013: 44)

Specifically, besides time and performance, a third dimension is added, the non-consumption or non-consuming occasions. This dimension represents a new context of consumption and competition, a new value-network.

> "Although new market disruption initially competes against non-consumption in their unique value network, as their performance improves they ultimately become good enough to pull customers out of the original value network into the new one, starting with the least demanding tiers" (Christensen and Raynor 2013: 45).

In this event of new market disruption, both traditional and new markets coexist. Additionally, technological innovation does not invade the mainstream market but gradually pulls customers away from it.

In 2013, Christensen, Horn and Staker (2013) defined and conceptualised hybrid disruption as the combination of low-end and new-market, and identified some examples of such a type of innovation such as the investment management company Charles Schwab. Specifically Charles Schwab "stole some customers from full-service brokers with its discount trading fees, creating at the same time a new market by enabling people who historically were not equity investors - such as students - to begin owning and trading stocks" (Christensen and Raynor, 2013:

47). Recognising that “industry often experiences hybrid stages when they are in the middle of a disruptive transformation” (Christensen, Horn and Staker, 2013: 1), they explain that industries create hybrid disruption when the disruptive technology is not yet convincing compared to the industry leader. In another example, they point out how the automotive industry developed hybrids “along its way to transitioning from gasoline-fuelled engines to engines with alternative power sources” (Christensen, Horn and Staker, 2013: 1).

Value network

The concept of *value network* is well known to the business literature. Chesborough and Rosembloom (2007) define value network as the context around a given firm, including but not limited to suppliers, customers and anything else “required by the firm to create and distribute the offering” (2007: 13). The position that a firm decides to occupy in the value network depends on the relationship that the firm has with the other players in the value network (actors or stakeholders).

Similarly, Christensen and Raynor define value network as “the context within which a firm establishes a cost structure and operating processes and works with suppliers and channel partners in order to respond profitability to the common needs of a class of customers” (Christensen and Raynor 2013: 44). Within Christensen’s theory, the value network influences the firm’s perception of the economic value of a new technology: “within a value network, each firm's competitive strategy, and particularly its past choices of markets, determines its perceptions of the economic value of a new technology” (Christensen and Raynor 2013: 44). Christensen and Raynor (2013) explain how incumbent firms see the value of innovation in pursuing sustaining innovation, sustaining current customer values within the same value network. Therefore, disruptive innovation appears outside the value network of the incumbent firms, and it usually brings lower profits and different technologies and is less appealing for existing customers. Hence, incumbent firms will not allocate resources in developing disruptive innovation but instead will use these resources to improve the performance of existing products.

Christensen’s concept of value network presents similarities with other concepts such as industrial clusters and business ecosystems (Mount 2012). Easton defines industrial clusters as a long-term stable relationship amongst a network of companies, focusing on the fact that all these entities are involved in the process of converting resources into services and goods (Easton et al. 1992; Easton 2010). Gadde et al. (2003) develop this concept further, adding that these business relationships influence the nature and the outcome of the firms’ actions and are potential sources of efficiency and effectiveness. Additionally, Hakansoon and Ford (2002) demonstrate that the interaction between firms can only be fully understood if a wider network is considered and that the wider network, not just the firm’s strategy, defines what the firm can and cannot do. Therefore the network relationships that the company has with other companies in the industrial cluster, in terms of resources and activities, is a strong determinant of a firm’s ability to perform a task effectively and efficiently (Hakansoon and Snehota, 2006 cited in Mount 2012). The similarity observed between the theories of industrial cluster and value network is that both theories agree with the existence of strong interdependences amongst actors playing a role in the economic process. Studies on disruptive innovations and clusters have observed that clusters, defined around the geographical proximity of companies, are a way to inhibit or facilitate the technological trajectory of disruptive innovation (Defilippi and Wikstrom 2014; Gadde, Huemer and Håkansson 2003; Gadde, Huemer and Håkansson 2003; Håkansson and Ford 2002; Wikstrom and Defilippi 2016).

2.2.3 System innovation theories

Many frameworks have been used to explore system innovation. The main focus of these approaches is identifying elements of a system and the interlinkage among those elements to address the functioning of the system. Specifically, Innovation System Theories have been used to understand the success or failure of innovations within the context of the entire system, taking into account actors of this system and their interactions. Three main strands of theories have been extensively used for theoretical and empirical studies: Technological Innovation Systems (TIS) (Hekkert et al. 2007; Markard and Truffer 2008), Socio-Technical System (ST-System) and Actor-Network Theory (ANT) (Latour 2005). The scope of this section is not to provide an extensive overview of these approaches, but to critically present the points for which those approaches are argued to fall short in conceptualising socio-technical transition.

Drawing from the ideas that a system is not made exclusively of individual firms and research institutes but also from the societal structures in which firms and research institutes are embedded, Carlsson and Stankiewicz (1991) define Technological Innovation Systems (TIS) as:

> "Network(s) of agents interacting in a specific economic/industrial area under a particular institutional infrastructure or set of infrastructures and involved in the generation, diffusion, and utilisation of technology. Technological systems are defined in terms of knowledge or competence flows rather than flows of ordinary goods and services. They consist of dynamic knowledge and competence networks" (1991: 111).

TIS has been used as a framework to explore system innovation at an industry level for innovation with a technological core. Its framework is based on four key structural dimensions: actors, institutions, interactions and infrastructures (Hekkert et al. 2007). Those four dimensions serve to understand the rate and the direction of technological changes over time. Although this framework has been applied to a number of studies to understand how the configuration of actors, infrastructures, institutions and interactions change over time, this theory has mostly referred to organisations as actors, disregarding other societal functions such as a the diffusion and the use of technology (Geels 2004; Smith, Voß and Grin 2010).

The ST-System approach tries to fill this gap, examining not only the production function but also diffusion and use of technology, explicitly including knowledge, artefact, capital, people and so on. Drawing from SCOT, this theory includes social groups in the analysis of an innovation system, where a social group is defined as a group of people who share a particular agenda, perceptions, norms and preferences (Coenen and López 2010). Like TIS theory, the ST- System approach considers the system defined by spatial and temporal boundaries and described by its structure and its purpose, using the four structural dimensions which TIS defined.

The Actor-Network Theory (ANT), instead, suggests a new approach to socio-technical innovation, opening the black box of technological innovation and considering networks as the primary actors to study in order to understand the structure of the system. ANT defines network builders as tangible (firms and technologies) and intangible actors of innovatory processes (human and social organisation and the web of relations). Trying to escape any form of deterministic approach, the novelty of ANT is what is known as the principle of generalised symmetry, which defines both human and non-human (artefact, organisation structure) actors of the system, assigning them the same agency within the dynamic process of innovation (Latour 2005). This framework considers society is made of heterogeneous networks, i.e. "seamless webs", a collection of social and technical elements that connect every object in the system. Identifying those actors and networks leads to the explanation of system innovations.

> "We are not primarily concerned with mapping interactions between individuals…we are concerned to map the way in which they [actors] define and distribute roles and mobilize or invent others to play these roles". (Law and Callon 1988: 258)

Geels and Schot (2010) have argued that all system innovation approaches fall short in conceptualising socio-technical transitions as they do not explain adequately structural changes of the system and its dynamics. They address three fundamental limitations of these theories and specifically:

a. These theories have over-emphasised agency as an explanatory factor, neglecting issues of power or structures.
b. These theories have either over-estimated society on technological innovation (or the equation of social and material elements in the case of ANT) or technology over society.
c. STS empirical studies have analysed rather short-term, local projects. Transition studies, however, aim at the analysis of long-term and large-scale processes and are therefore interested in *"patterns and regularities*

at a more aggregate level (e.g. technological trajectories)" (Geels and Schot, 2010: 34).

Therefore, Geels and Schot (2010) suggest that in order to understand the dynamics of socio-technical transition, and to make recommendations on transition pathways, the Multi-Level Perspective (MLP) approach is most suitable.

2.3 Socio-technical Transition Theory: current state of research

Technological changes have been addressed as complex and long-term processes comprising of multiple actors (Anderson and Tushman 1990; Freeman 1989; Hekkert et al. 2007; Misa 1998; Mowery and Rosenberg 1999; Olsen and Engen 2007; Rip and Kemp 1998; Schmookler 1965). Scholars such as Abernathy and Clark (1983), Freeman (1989) and Bijker and Pinch (1997) have extensively discussed the interaction across and amongst "technology, policy/power/politics, economic/business/market, culture/discourse/public opinion" (Geels 2011: 25), as factors that shape innovation and technological changes. Drawing from these theories, Clark and Staunton (1989) observed that all these variables sit at different levels of analysis when studying technological changes. As such, in order to understand the dynamic of technological innovations, they defined an approach based on three levels of analysis: a macro-level, dealing with institutional and international forces that play a role in inhibiting or facilitating innovation and the diffusion of innovation; a meso-level, which considers the significance of institutional cores and interfirm population and a micro-level where organisations are the primary unit of analysis. Although useful, Clark and Staunton's (1989) approach narrows its focus to explain organisational changes through technological innovation as the main trigger to transitions, supplying a limited explanation of the dynamic of technological changes and the interplay of actors within and across different levels. Rather, the literature above has shown how those changes are not driven by technology per se' but from the combination of the latter with socio-economic factors (Freeman and Perez 1988; Perez 2010), policy (Dosi, Freeman and Fabiani 1994; Freeman 1989) and market (Christensen and Raynor 2013).

In the last decade, these debates have been brought together within the new approach of transition theory. The term transition has been often used interchangeably with system innovation (Twomey and Gaziulusoy 2014) to reflect a broad change in technology systems and society. Although these bodies of literature have developed independently, there are several cross-over and shared concepts mostly reviewed in the previous section. Additionally, scholars have argued that "for the purposes of managing change processes to sustainability it is useful to use the concept of a 'transition' rather than system innovation" (Kemp and Rotmans 2005: 35) as it focuses on four points which system innovation processes do not necessarily include:

1. an end state (new equilibrium);
2. a path towards the end state (transition pathway);
3. the transition problem/s which trigger the transition process;
4. the broad range of developments, internal and external, which shape the outcome.

As Markard, Raven and Truffer (2012) discuss, the last decade has seen the growth of an active international community of scholars in the field of transition studies. This community has generated empirical and theoretical knowledge of socio-technical transition, including on transition pathways in Europe and Asia (Berkhout, Angel and Wieczorek 2009; Geels et al. 2016; Geels and Schot 2007), infrastructures and transitions (Loorbach, Frantzeskaki and Thissen 2010), barriers and drivers to take up of sustainable innovation (Berkeley et al. 2017) including policy (Kivimaa and Martiskainen 2018; Rogge, Pfluger and Geels 2018) and actors' strategies (Farla et al. 2012).

Those and other studies (Grin, Rotmans and Schot 2010) have brought to the arena the notion of sustainability transitions. This concept was initially used by the Report of the World Commission on Environment and Development in 1987 (Meadowcroft 2007), and it has since received scholarly attention as it involves "achieving an appropriate balance between three pillars: the environment, economy and society" (Meadowcroft 2007: 299). Sustainability has been empirically explored in numerous contexts, such as water (Fuenfschilling and Truffer 2016), energy (Kivimaa and Martiskainen 2018; Raven 2004; Rogge, Pfluger and Geels 2018; Verbong and Geels 2007; Verbong and Geels 2007) and mobility systems (Geels and Verhees 2011; Geels et al. 2016; Rogge, Pfluger and Geels 2018). Specifically, in the automobility context, the shift to low-carbon sustainable systems has gained particular attention in understanding transition pathways (Geels 2012; Geels et al. 2017) and to offer recommendations for the uptake of Fully Electric Vehicles (Berkeley et al. 2017; Bohnsack, Pinkse and Kolk 2014; Dijk, Wells and Kemp 2016).

2.3.1 Frameworks of transition studies

Over the years, different analytical frameworks have been used to explore sustainability and low-carbon socio-technical transitions, and precisely three approaches have been considered as being at the heart of transition literature (Markard and Truffer 2008; Twomey and Gaziulusoy 2014): Transition Niche Management (TNM) (Loorbach 2010); Strategic Niche Management (SNM) (Kemp, Schot and Hoogma 1998); and the Multi-Level Perspective approach (Geels and Schot 2010; Geels 2010). This section provides a short overview of TNM and SNM before moving the focus to MLP.

The Transition Niche Management (TNM) literature focuses on the dynamics of structural changes and the identification of factors which can enable, facilitate and shape transitions. The starting point of this theory is societal challenges (Van den Bosch 2010), which aim to steer the socio-technical system towards a desirable social outcome. Specifically, to accelerate sustainability transitions, the TNM proposes a multi-actor, multi-level and multi-dimension approach in which the broader participation of different actors (governance) is encouraged and supports the transition. There are very few empirical studies that use this approach, and these have drawn several criticisms, amongst which is the focus on niche level, the difficulty and ambiguity in identifying a shared objective across actors, as well as the biases towards implementation of incumbent actors within the transition process (Shove and Walker 2007; Smith and Kern 2009).

In contrast, Strategic Niche Management (SNM) focuses on how to create technology at niche or micro level which can break through and replace unsustainable technology (Kemp, Schot and Hoogma 1998). In this framework, technologies and users are the main actors of the system, and the focus is on generating processes which enable these technologies to contribute to a more significant shift. Hence, SNM emphasis is on a top-down approach where governments and policy-makers nurture specific niches and their technologies.

2.4 The Multi-Level Perspective Approach

In contrast with SNM and TNM approaches which have "a more normative and governance oriented focus for exploring innovations and system transformation" (Twomey and Gaziulusoy 2014: 12), the Multi-Level Perspective approach (MLP) focuses on the dynamics of transformative societal processes, broadening its focus into multiple innovations which are responsible for the transition process. This section reviews the theoretical foundation of this approach and its proposed transition pathways. Additionally, it reviews the literature which this approach has generated, including the latest discussion on disruption and MLP, highlighting gaps for further research.

2.4.1 Theoretical foundation

In the past decade, research focusing on technological changes within a low carbon, sustainable or energy efficient context, has argued that the multi-level perspective (MLP) approach is the most appropriate to analyse long-term technological transitions and "for informing intervention related to the governance and management of technological change in practice" (Genus and Coles 2008: 1436). Drawing from evolutionary economics, innovation, technological change and system change studies, this approach conceptualises dynamic patterns in socio-technical transitions (Geels 2011; Geels 2004; Geels 2010). This theory is a "middle-range theory that combines specific elements from other theories […], and as such it is geared to answering particular questions on the dynamics of transitions" (Geels and Schot 2010: 19), which "relates various concepts and uses empirical researches to identify recurring patterns and generalizable lessons" (Geels 2011: 27). Specifically, this approach draws from insights of evolutionary economic theories (Dosi and Nelson 1994; Dosi and Nelson 2013) for the development of the structural actors and practice, from SCOT and System Innovation theories for the elaboration of the basis of agency in the process of socio-technical change (Bijker, Hughes and Pinch 1987; Bijker 1997; Bijker, Hughes and Pinch 2012; Latour 2005) and from structuration theory (Anthony Giddens 1984) to order and inform process into social life.

In outlining the MLP approach, Rip and Kemp (1998) and Geels and Schot (2007) explain that socio-technical transitions are, in general, non-linear processes that result from the interplay of developments at three analytical levels: the socio-economic landscape (macro-level), the patchwork of regimes level (meso-level) and the niches level (micro-level).

a. The socio-economic landscape level (macro-level) “forms a broad exogenous environment that is beyond the direct influence of regime and niche actors” (Geels and Schot 2010: 23). It encompasses both tangible and intangible factors of the socio-technical system in which a change happens such as macro-economic factors, political belief, social values, policymakers, institutions, and markets. The function of the socio-technical landscape within the system is to account for external factors in which technology develops (Geels 2002), providing a gradient for technological trajectory[6] (Sahal 1985).
b. The patchwork of regimes level (meso-level) is “the coherent complex of scientific knowledge, engineering practices, production process technologies, product characteristics, skills and procedures, established user needs, regulatory requirements, institutions and infrastructures” (Rip and Kemp 1998: 338). The idea of a patchwork of regimes builds upon the concept of technological regimes used in evolutionary economics (Nelson and Winter 1977; Nelson and Winter 1982) where these groups (regimes) are coordinated and aligned as they share the same operational knowledge and routines. Drawing from Nelson and Winter (1977), Geels recognises the existence of technological regimes where different firms share the same organisational routines and cognitive notions. These regimes produce a technological trajectory as firms tend to search in the same direction, creating stability and balance. Recognising that technological trajectories are not only influenced by technology (Perez 2010), drawing from sociology and institutional theory, Geels (2004) broadens the concept of regimes to include a variety of social groups such as policymakers, societal groups, scientists, banks and users, which are defined as a patchwork of regimes within the MLP approach (Geels and

[6] Geels (2002) uses the term “gradient” associated with a technological trajectory in his PhD thesis. Drawing from topography, he uses the term to indicate a measurement of the degree of inclination of a feature relative to the horizontal plane (slope). This measurement is normally expressed as a percentage, angle or ratio. In topography, this measurement is also used to indicate the changes of the field in other directions, or one direction of greatest changes.

Schot 2010). Therefore, the MLP definition of this meso-level also incorporates relationships amongst those various regimes. These regimes "represent different social groups which share various kinds of rules (regulative, normative and cognitive), and make each regime somewhat distinctive and autonomous" (Geels 2002 cited in Genus and Cole 2008: 1477). Geels (2004) defines the socio-technical regimes as a structure for the interaction of regimes. Their stability depends on the alignment and coordination of each of these regimes.

c. The niches level (micro level) is a "space where networks of actors experiment with and mutually adapt, greener organisational forms and eco-friendly technologies" (Smith 2007: 427). Geels (2002) distinguishes technological niches and market niches. Whilst technological niches are "a specific application domain in which producers and users (sometimes together with third parties such as governments) form an alliance to protect new technologies against too harsh market selection" (Geels 2002: 7), market niches are "applications in specific markets in which regular market transactions prevail" (Geels 2002: 7) and might develop from technological niches. Within the MLP approach, niches are where the technological variety resides, where innovation takes place, a protected space for the development of new technologies, immune from any selection process to establish a dominant design, which instead occurs at a regimes level (Rip and Kemp 1998).

Hence, the MLP proposes a way to understand socio-technical transitions as a multi-level, multi-actor process in which niches form the base of a cone in this multi-level system, and the patchwork of regimes sits directly above it. The socio-technical landscapes level is at the top of this cone, directly above the patchwork of regimes level.

Geels and Schot (2010) explain that the difference between niches and regimes within the MLP approach is on how established rules and norms are. Within the patchwork of regimes level, rules are mostly well-accepted and are not often subject to changes. Contrarily, at a niche level, there are broad visions and general guidelines rather than proper and established sets of rules. Additionally, while the patchwork of regimes level benefits from a broad and robust social network, the social network at niche level is small and precarious (Geels 2002) or, if successful, a community.

The dynamic of technological transition within the MLP approach can be understood from the explanation of the interaction amongst these three levels. Figure 3 offers a representation of this complex process, which, for ease, Geels and Schot (2007) divide into four phases.

Figure 3 The dynamic of socio-technical transition explained by the MLP approach (Geels and Schot 2007 cited in Geels et al. 2017: 466)

During the first phase, radical innovations emerge at a niche level. At this level, companies experiment with different design options. During the second phase, the innovation enters small market niches, choosing a dominant design and developing its technology trajectory. In the third phase, the innovation breaks through and 'attacks' the established regimes. The existing regimes become destabilised as a consequence of the internal problems and the pressure of the socio-economic landscape level. Regime substitutions characterise the fourth phase of the transition, with the patchwork of regimes level reconfiguring around the new innovation. It is at this point that the transition from the traditional or incumbent system to the new system happens.

In his framework, Geels suggests that for a niche innovation to break through, two situations need to happen simultaneously at the niche level and the patchwork of regime level. Firstly, under particular circumstances (e.g. change of regulations, change of processes and institutional push), an innovation might grow a network big enough to be able to break out from niches and link up to the patchwork of regimes-level. Secondly, a window of opportunity needs to open at regime or socio-technical landscape level. These windows cause different technologies to co-exist at a niche level, until the arrival of a dominant design. With the arrival of dominant design and the acceptance from society of such innovation, the technological transition is completed. Hence at the niche level, a new technology gains momentum "if expectations become more precise and more broadly accepted, if the alignment of various learning processes results in a stable configuration (dominant design), and if networks become larger (especially the participation of powerful actors may convey legitimacy and resources to niche-innovations)" (Geels and Schot 2010: 27).

Geels (2011) underlines that although transitions all have very different characteristics, similar patterns can be identified in the interaction between processes at different levels:

> "(a) niche-innovations build up internal momentum, (b) changes at the landscape level create pressure on the regime, and (c) destabilisation of the regime creates windows of opportunity for niche innovations […]. An important implication is that the MLP does away with simple causality in transitions. There is no single 'cause' or driver. Instead, there are processes in multiple dimensions and at different levels which link up with, and reinforce, each other ('circular causality')." (Geels 2011: 28).

2.4.2 Socio-technical transition pathways

Drawing from empirical studies, Geels and Schot (2007) identify four kinds of possible transition pathways for socio-technical changes.

a. The *technological transformation pathway* builds on the fact that niche innovation is not technologically developed for changing the current regimes. Moderate pressure from the socio-technical landscape level and power struggles between actors at the patchwork of regimes level gradually facilitate a regime change.

> *"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"* (Geels and Schot 2007: 406).

The empirical case of the UK low carbon electricity transition from 1900 to 2014 (Geels 2016) best represents this pathway as incumbent actors enacted its transformation pathways, deploying large scale renewable electricity technologies.

b. The *de-alignment and re-alignment pathway* accounts for an extreme event, which pushes for one niche innovation to emerge.

> *"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 *niches - innovations that co-exist and compete for attention and resources. Eventually, one niche-innovation becomes dominant, forming the core for realignment of a new regime."* (Geels and Schot 2007: 408).

Verbong and Geels (2007) use regionally and locally based systems as empirical examples of this pathway. Within this literature, the extreme landscape pressure caused by very high oil prices or gas scarcity (Middle East War, Russia cutting the gas supplies) leads to the regime users losing faith in the usual solutions. Hence, users trial multiple novel solutions mainly at a regional or local level, driven mainly by cultural factors. Once the solution is affirmed locally, this spreads nationally causing the restructuring of the existing electricity system.

c. The *technological substitution pathway* presents a niche technological innovation which is mature enough to break through the regime level and replace the existing regime.

> *"This pathway occurs when there is much landscape pressure at a moment when niche-innovation have developed sufficiently, causing the latter to break through and replace the existing regime"* (Geels and Kemp 2012: 60)

The empirical case which addresses this pathway is the British transition from sailing ships to steamships between ca. 1850-1890 (Geels 2002). Steamships developed over the years in a subsidised niche market and slowly proved to be faster and more reliable than sailing ships, but also more expensive. When mass emigration from Europe to America began, due to political revolutions, the steamship's technological innovation attacked the incumbent. The diffusion of steamships led to economic competition, dropping the prices for steamships through economies of scale. The sailing ship regime was initially disturbed and was, in time, crushed by the steamships, mainly because the incumbent actors could not transition to a new manufacturing process based on iron and steam. Hence, a new socio-technical regime around steamships became dominant.

d. The *reconfiguration pathway* accounts for niche technological innovation gradually being embraced by regimes, initially to solve local problems, and, over time, transforming the patchwork of regime level. Geels (2006b) illustrates this pathway with the empirical case of mass production in American factories. In this case, regimes adopted new technological innovations to solve specific problems (i.e. canning or meatpacking in ca.1850s, battery-driven electric motors for drills in the 1870s), which in time enabled transformative changes on the whole regime.

In all these pathways, two mechanisms drive changes: a structural reason for regimes' changes, as an extreme event or landscape pressure and a push from the niches level for a change in regimes, when a new technological innovation arises. Some empirical cases have shown how these pathways can also happen in combination depending on the dynamics of the developing system (Geels et al. 2016; Verbong and Geels 2007).

Subsequently, Papachristos, Sofianos and Adamides (2013) have suggested a fifth transition pathway - namely a *new system emergence substitution pathway*. Drawing from the analysis of the other pathways and identifying exogenous factors from interrelated systems as possible triggers for transitions, the scholars suggest that to identify the triggers for sustainable socio-technical transition it is important to "shift [the focus] from single regime, single technology approaches to multi regime, and multi technology interactions" (2013: 66). They do so through analysing four case studies, "(i) namely the combined heat and power (CHP) applications, in which the co-generation of heat and power links heat and electricity regimes, (ii) the production of biofuels which links the agriculture, energy and transport regimes, (iii) battery–electric or plug in hybrid vehicles which link road transport and electricity supply regimes, and (iv) natural gas and the development of cleaner alternatives" (2013:66), and show how the interaction of niches and regimes from different systems can trigger a socio-technical transition. Thus this fifth pathway addresses the criticism concerning the MLP being focused only on single niche innovation, without taking account of other mechanisms engendered through interaction amongst regimes of different systems.

2.4.3 The MLP approach in low-carbon transition literature

The MLP approach has been used to explore low-carbon, sustainable changes in water (Fuenfschilling and Truffer 2016), energy (Kivimaa and Martiskainen 2018; Raven 2004; Rogge, Pfluger and Geels 2018; Verbong and Geels 2007; Verbong and Geels 2007) and mobility systems (Geels 2012; Geels and Verhees 2011; Geels et al. 2016; Rogge, Pfluger and Geels 2018). These studies have seen a refinement of the MLP approach to include further processes and bodies of literature which contribute to the understanding of the dynamics of low-carbon socio-technical transitions. Specifically, these bodies of literature have included:

a. Mobilising theories of technological changes and innovation to focus on the identification of significant challenges for and refinement of the dynamics of low-carbon transition (Geels 2012; Geels et al. 2017);
b. Considering the role of actors (including users and policy) in socio-technical transition (Bohnsack, Kolk and Pinkse 2015; Fischer and Newig 2016; Geels and Schot 2010; Rogge and Reichardt 2016; Verbong and Geels 2007);

c. Using the MLP approach for exploring mobility systems (Berkeley et al. 2017; Geels 2012; Geels 2018; Truffer, Schippl and Fleischer 2017).

Geels et al. (2017) have used the case study of German electricity to provide an appraisal of some of the MLP concepts in the view of low-carbon changes. This study articulates four significant challenges in the understanding of the dynamics of low-carbon sustainable shifts:

1. "Low-carbon transitions do not just involve firms and consumers but also a wider range of actors such as civil society groups, the media, residents, city authorities, political parties, advisory bodies, and government ministries" (Geels et al., 2017: 464). Hence these shifts are not driven by a cost-benefit calculation of groups of actors but from complex social relations, beliefs, values and competing interests.
2. Low-carbon transitions are not always about "market diffusion of new technologies but also about changes in user practices, cultural discourses, and broader political struggles" (Geels et al. 2017: 464). Hence transitions are non-linear processes which Geels et al. (2017) defines as disruptive, as they jeopardise the position and the business model of well-established incumbent industries.
3. In order for low-carbon transitions to gain stakeholders' support, this needs to have long term benefit for those stakeholders, rather than just carbon mitigation. Hence, low-carbon transitions "require complex negotiations and trade-offs between multiple objectives and constraints, including cost-effectiveness, equity, social acceptance (legitimacy), policy feasibility, resilience and flexibility" (Geels et al. 2017: 464).
4. Another major challenge of low-carbon transitions is the uncertainty of the long-term benefits of the transition, which in the opinion of Geels is the cause of the lack of stakeholders' engagement. Historical transitions were, in fact, not goal oriented, but "largely 'emergent', with entrepreneurs exploiting the commercial opportunities offered by new technology" (Geels et al. 2017: 464).

Applying the MLP approach to the case of low-carbon electricity transition in Germany (Geels et al. 2017) has brought to the arena valuable recommendations for policy-makers, which, in the authors' opinion, should assume an essential role in creating the condition for the deployment of low-carbon innovation. The paper discusses further the dynamic policy mixes, which should differentiate amongst each phase of the transition rather than being considered isolated or static instruments. Specifically Geels et al. suggest that during phase one and phase two of the transition (Figure 3) policymakers should nurture niche innovations and build an innovation network, whilst in phase three policymakers should be more selective, offering economic incentives to some innovations.

Fischer and Newig (2016) review the role of actors in low-carbon sustainable transition finding that a variety of approaches have been used at different levels of the system for clustering actors at niche, regimes or landscape levels. In order to ensure a robust operationalisation of the MLP approach, these authors suggest a characterisation of each actor typology, identifying their functions and their dependency and agency which are strongly interconnected. Though, in the conclusion of their work, they identify "two types of actors having weak or no agency. These actors include actors on the landscape level and actors on the local government level" reemphasising that "the definition of actors at the landscape level is very difficult and controversial" (Fischer and Newig 2016: 262) within MLP studies.

Investigating the notion that the role of actors "has been neglected in this literature in favour of more abstract system concepts" (Fisher and Newig 2016: 476), Verbon, Schot and Kanger (2016) focus on understanding the role of the user in transition, and specifically in destabilising existing regimes, changing the dominant user's preference.

> "This is achieved by a highly contested and political struggle between actors on various sides: some lobby for a specific niche, some lobby against other niches; some attack the prevailing regime whereas others mobilize to defend it" (Verbong, Schot and Kanger 2016: 4).

Their work argues that historically social movements have initiated the demand for changes and therefore triggered the destabilisation of existing regimes, which, through the media and other channels, have with time led to a change in policy.

Additionally, they correlate different typologies of users to each MLP phase, arguing that user-consumer is only one of the types of user which have a role in transitions.

Recently, Rogge and Reichardt (2016) have used the MLP approach to explore the concept of policy mixes[7] in an attempt to improve the understanding of how these actors/elements/processes “serves as an interdisciplinary analytical framework for studying the link between policy and technological change in the context of sustainability transitions” (Rogge and Reichardt 2016: 1629). Their paper “highlights the need for policymakers to consider instrument mixes and instrument interactions along with the policy strategy with its long-term orientation as equally important elements of a policy mix. It also stresses that policy processes may directly influence innovation and emphasises the relevance of characteristics such as credibility” (Rogge and Reichardt 2016: 1632). They call for unpacking the link between policy mixes and technological changes in empirical contexts, highlighting how the integration of this concept within other research approaches “may further sharpen the analytical clarity and policy advice of such approaches in the context of sustainability challenges” (Rogge and Reichardt 2016: 1632).

In recent years, academics and practitioners have shown a deep interest in applying the MLP approach to low-carbon socio-technical transitions within the mobility sector (Berkeley et al. 2017; Dijk, Wells and Kemp 2016; Geels 2012; Geels 2018; Herrero 2011; Moradi and Vagnoni 2018; Truffer, Schippl and Fleischer 2017). Defining sustainable socio-technical transitions, Geels (2012) suggests that climate change problems and cuts on CO_2 demanded by national and international policies can only be realised by a deep transformation on the structure of the traditional mobility sector, which currently accounts for around 80% of those CO_2 emissions (Geels 2012; Moradi and Vagnoni 2018). While a genuinely sustainable transition would involve a structural change of the model of this sector, where a less car-centred model of mobility would prevail (Geels 2012), Geels et al. (2012) suggest that a less radical shift is possible and more deliverable. Studies on the emergence of the electrification trajectory (Dijk,

[7] Policy mixes is extended from those authors to include policy processes, elements and characteristic (Rogge and Reichardt 2016).

Orsato and Kemp 2013; Geels 2012) have reiterated that this change, although less radical, is a complex multidimensional one, involving interactions amongst different actors of the auto-mobility system, including “firms and industries, policymakers and politicians, consumers, civil society, engineers and researchers” (Geels 2012: 471).

Recognising that the transport system can be conceptualised as “a configuration of elements that include technology, policy, markets, consumer practices, infrastructure, cultural meaning and scientific knowledge” (Geels 2012: 471), Geels suggests that the MLP approach can be applied to the auto-mobility sector to study sustainable development, as broader than other approaches. Specifically, Geels (2012) applies this framework to the empirical cases of British and German mobility sector, suggesting that both these low-carbon transitions are in their early phase (phase one in Figure 3).

The scholar identifies the main drivers of this low-carbon transition to be, “(a) public concerns about Peak Oil and climate change, (b) government policies” (Geels 2012: 479), and suggests that the auto-mobility transition could contain more than one aspects of different transition pathways. Specifically, aspects of the de-alignment and re-alignment transition pathway, as multiple niches innovation, have challenged the incumbent socio-technical regime. These innovations have the efficiency of the existing engine, battery and fuel cell technologies, info-mobility, dynamic traffic management and other technologies which were all adopted, initially, to solve local problems and which, at some point will converge towards a bigger change of the incumbent system. The pathway of this change is still very open, and it will depend on “strategies, belief, interests and actions of various actors” of the system (Geels and Kemp 2012: 61).

Recent studies on the auto-mobility sector have focused on analysing transition pathways based on historical trends (Geels 2018) or on investigating current systems as the process of changes is performed (Moradi and Vagnoni 2018). Specifically, the latter has dealt with gaining a deeper understanding of the composition of each regime and the dynamics of the low-carbon transition, in the view of identifying driving and restraining factors of the transition process. In line with Marletto’s recent study (2014), Moradi and Vagnoni (2018) highlight the main trend destabilising existing regimes is the pressure of the landscape level. This pressure is not enough to enable niche innovation to gain momentum and destabilise the existing regime due to the lack of a long-term vision and infrastructures development.

In addition to confirming that “environmental and energy security pressure have created a favourable landscape ‘push’ for Pure Electric Vehicle (PEV)” (Berkeley et al. 2017: 22) other scholars have used the MLP framework to interpret the uptake of electric vehicles (Berggren, Magnusson and Sushandoyo 2015; Berkeley et al. 2017; Steinhilber, Wells and Thankappan 2013). Analysing the uptake within countries of the European Union, Berkeley et al. (2017) identify “significant multi-level forces pushing against it” (Berkeley et al. 2017: 320), in MLP terms, at the regime level. Those forces included price, infrastructure and technology as well as consumer perceptions surrounding PEV.

Although useful, the majority of these studies have adopted the traditional idea that transitions are driven either by a mature technological innovation at niche level (Geels et al. 2016; Geels and Schot 2007) or by government and policy actions, which have accelerated the introduction of a technological niche innovation within the existing patchwork of regimes level (Foxon, Reed and Stringer 2009; Foxon, Hammond and Pearson 2010; Kivimaa and Martiskainen 2018; Rogge, Pfluger and Geels 2018).

Contrary to this understanding, merging the strategic management literature with the transition literature, some studies have suggested that niches are only one building block of a broader transition, calling for further research to focus on an in-depth analysis of the transition pathways, which are aimed at understanding better the role of actors in regimes (Berggren, Magnusson and Sushandoyo 2015; Skeete 2019; Steinhilber, Wells and Thankappan 2013). Similarly, Ghosh and Schot (2019) have argued that “a sole focus on transitions as regime-shifts reflects a western bias[8]” (Ghosh and Schot 2019: 82). Through the analysis of the urban public transportation regime in Kolkata, they propose a novel framework where “regime actors can run as a front-runner in these change processes and that meta-rules guide directionality of change.” (Ghosh and Schot

[8] The term western bias is used in Ghosh and Schot’s (2019) work to refer to the culture from the Western world, which includes Europe, US, Canada, Australia and New Zealand.

2019: 82). They conclude that sustainable transitions can happen at a regime level, suggesting that further research should focus on studying each building block of the transition pathways aimed at better understanding the role of actors in regimes. The methodological novelty of this article is the operationalisation of the regimes and the use of a map to look at patterns of change in rules, trajectory and selection process at a regime level (Ghosh and Schot 2019). As this study draws mainly from evolutionary and institutional theories of socio-technical changes, this map plots types of regimes change against a number of regime dimensions, trajectories and types of rules. Although the first of its type, the limitations of this study is in the set of data analysed, what the authors define as the non-western context, and the limited development and testing of the mapping tools (Ghosh and Schot 2019: 93).

Skeete (2019) has connected energy efficient, low-carbon transitions in the mobility sector to the motorsport industry, claiming that motorsport has significantly contributed to energy efficient and low carbon innovations deployed in the automobility sector. Reiterating that motorsport is the pinnacle of technology and that many technologies which were intended for gaining performance at the race track, were subsequently adapted and introduced in road cars, Skeete's study shows how the racing industry has actively contributed from the mid-80s to the development of current low carbon technologies used in road cars. Applying an MLP approach to his research, Skeete (2019) concludes that:

> "Public policy, governing passenger car emissions in the EU automotive industry has indirectly influenced the setting of 'relevant regulations' in motorsport. These relevant regulations forced the development of ELC technologies on the race track, which eventually found their way back into passenger cars through a series of causal mechanisms involving tacit knowledge transfer." (Skeete 2019: 683)

Similarly to Ghosh and Schot's (2019) paper, the novelty of Skeete's study is to dispute the traditional assumption of socio-technical transition scholars (Geels 2012; Geels et al. 2016) for which niche actors are the most likely sources of radical or discontinuous innovations. Rather, Skeete argues that change in regulations and global policies can trigger the ability to innovate in new and established firms at a niche level. Additionally, asserting that some firms already established in the auto-mobility sector "are active in a wide range of technological fields along similar trajectories' (e.g. motorsport)", (Skeete 2019: 683), Skeete suggests that one system can influence the dynamics of another adjacent interrelated system, calling for further studies to investigate the effect of inter-system dynamics on socio-technical transitions.

2.4.4 The MLP Approach and disruptive innovation

Recently there have been a number of articles focused on discussing the MLP and the potential value that the theory of disruptive innovation can add to this framework (Dijk, Wells and Kempt 2016; Wilson and Tyfield 2018; Geels 2018). As discussed in section 2.2.2, in the past 20 years, the theory of disruptive innovation (Christensen and Rayner 2013) has been influential as an explanation as to why smaller companies with fewer resources are able to challenge well-established incumbent businesses. This theory sits within theories of innovation at firm level, and underlines that 'disruption' is a relative process, relative to the market that the innovation is disrupting, and identifying market type and value network as the two main variables which influence the dynamic of a disruptive innovation. Disruptive innovation is not per se a radical technological innovation but rather an innovation which, starting from a new, non-consumption market, or from a lower-end product, is able to pull away consumers from the existing value market with a different value proposition. With time this innovation, which Christensen suggests is generally mostly cheaper and/or technologically inferior than well-established products in the market, invades the established market causing incumbents either to fail or rethink their business model, and adapt their value proposition.

Christensen has not directly extended his theory to reach out to system innovation, remarking how the theory of Disruptive Innovation is "in danger of becoming a victim of its own success" (Christensen 2015: 49), being applied to any breakthrough innovation. Yet, drawing from business theory, the idea of creating a new market and a new value proposition has been lately related to the process of change observed by scholars for EV within mobility socio-technical transitions. For example, Dijk, Wells and Kemp (2016) have pioneered an elaboration of Christensen's (1997) typology of disruption within the regime evolution framework using evidence from several Fully Electric Vehicle (FEV) empirical studies, and concluding that this disruptive niche is currently unable to displace the Internal Combustion Engine (ICE) market. Recognising the theory of disruptive innovation has been compiled for industries, whilst the level of analysis of socio-technical transition is system, Dijk, Wells and Kempt identify significant limitations of the theory of disruptive innovation (Christensen and Raynor 2013) at a system level, due to the fact that the theory is less concerned about changing perception and policy which are, arguably, central to transition – in this case from ICE to FEV. Nevertheless, they do highlight the transferability of this theory and the potential applicability at a regime level.

> "Whereas economists and business researchers talk about markets, others have coined the notion of regime (Geels 2002; Kemp, Schot and Hoogma 1998; Rip and Kemp 1998): the socio-technical system that has grown between the hardware and user perspectives and practices (reflecting their preferences and endorsed social connotations), producer capabilities, business models and production technologies, regulations, and supporting institutions" (Dijk, Wells and Kemp 2016: 78).

This idea of using the theory of disruptive innovation (Christensen and Raynor 2013; Christensen 2006) to explain system changes is in line with Wilson and Tyfield's work (2018), who underline that "disruptive innovation is a field of the business and management scholarship specifically interested in the transformative potential of novel goods and services and their spontaneous, if surprising, adoption by consumers" (2018: 212). Hence, "exploring the applicability of disruptive innovation to energy transformation is relevant, timely and important and […] highly contested" (Wilson and Tyfield 2018: 212), calling for more research and empirical studies on this subject.

Recently, Geels (2018) has assessed the usefulness of the theory of disruptive innovation (Raynor and Christensen 2003) within the framework of low carbon system changes. Geels identifies conceptual limitations on the definition of disruptive innovation and several shortcomings. Specifically, amongst limitations, he suggests that Christensen's (2003) definition of disruptive innovation only addresses a small subset of innovations "namely those that introduce new functionalities of value propositions" (Geels 2018: 225), and those technologies which are initially cheaper than the existing one/s. Within the low-carbon transition, Geels suggest that this definition excludes many technologies which can be addressed as sustainable innovation but are initially more expensive than incumbent technologies when they first enter the existing market. Additionally, echoing Dijk, Wells and Kemp (2016), Geels underlines that Christensen's theory was created to analyse innovation and its implications at a micro, niche or firm level and it lacks consideration of the social, political, cultural and infrastructural factors of the transition, "focusing on price/performance competition in the market" (Geels 2018: 225). Hence Geels concludes that the theory of disruptive innovation is not a suitable framework to study transitions instead of the Multi-level Perspective approach.

Yet, although useful, there are limitations in Geels' recent article in evaluating the strengths and weaknesses of the theory of disruptive innovation. Specifically, this scholar addresses Christensen's theory as a framework to apply to the literature of energy transformation, as an alternative to the MLP approach.

Recognising that the theory of disruptive innovation ought to explore innovation at a firm-level, this research argues that progress in understanding the dynamics and the temporal dynamics of low-carbon sustainable socio-technical transitions can be made by mobilising Christensen's theory within the MLP approach, rather than considering these as opposing frameworks (Figure 3B). Specifically the theory of Disruptive Innovation falls within the business and management field of theories of innovation, identifying mechanisms and dynamics for which an innovation (where for innovation Christensen's take account of not just technology but the business model) cause great grief to incumbent actors within a defined and well established market. It is the identification of those mechanics and dynamics, at firm level, which in Christensen's theory destabilising the established market causing a reconfiguration of it, that could be useful in understanding different pathways to transitions within the MLP approach. Additionally, using the theory of Disruptive innovation in the way that this research propose, responds to Geels' call of business and management theories to be mobilised within the MLP approach in order to shed some lights on other factors which could triggers shifts at different levels of the system.

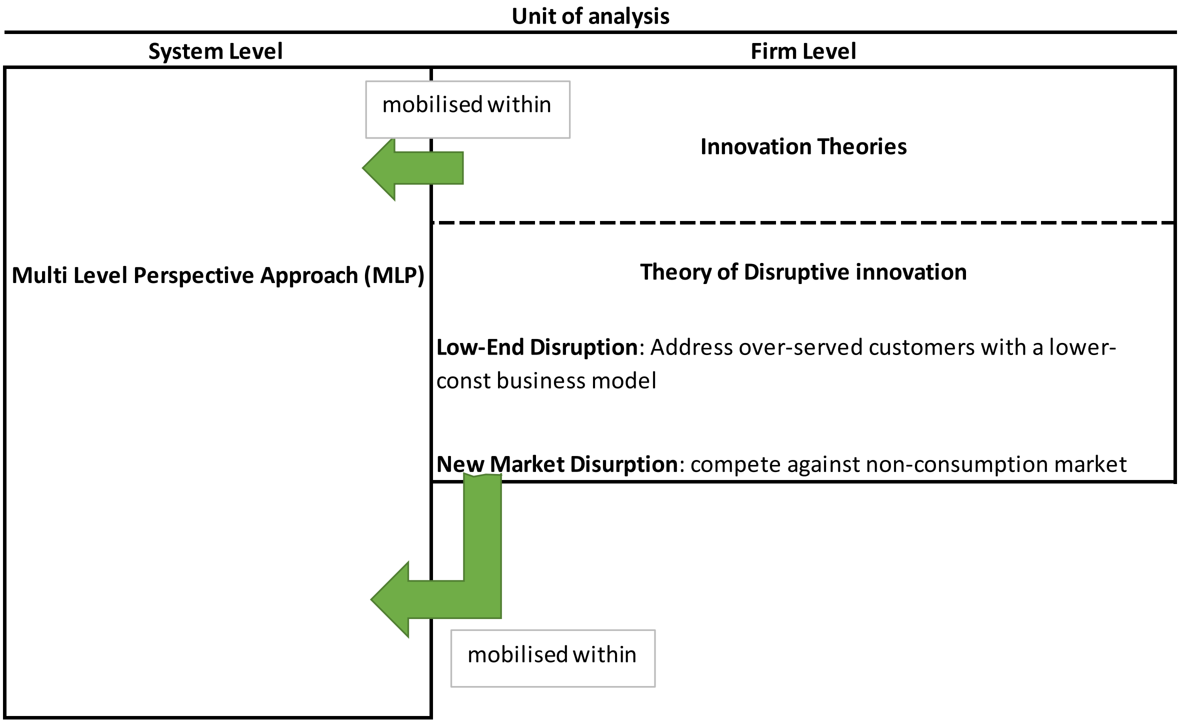

Figure 3B schema to assist the reader in understanding how the theory of Disruptive Innovation is used in this work (author's compilation)

2.4.5 Criticism and potential avenues for improvement

The MLP model has been considered a useful approach to conceptualise socio-technical transitions and explore the interplays of actors and events at different levels. In the past decade, this approach has also generated an enormous amount of literature (Google account for 380,000,000 results under the word search for the multi-level perspective approach), which has studied different aspects of transitions. This has combined "a view on micro-level processes of constructing new technologies, with a view on emerging macro- and meso-level patterns of culture, organisation, markets, regulation and infrastructures" (Smith, Voß and Grin 2010: 436). Nevertheless, there are several critiques to the model which have been pointed out in terms of operational and conceptual challenges.

Aside from critiques on ontology and epistemology of theories which have been mobilised within the MLP approach, to which Geels (2011) has responded, other points are still open to debate. Specifically, the lack of a clear operationalisation of the concept of regimes and levels has been addressed as a substantial obstacle for the advancement of the transition theory, as ultimately it leads to fuzzy empirical applications (Genus and Coles 2008; Markard and Truffer 2008;

Smith, Voß and Grin 2010; Fisher and Newig 2016). The MLP approach defines levels as representing different degrees of structuration, hence differentiating their potential to influence actors and their activities (Geels 2011; Geels 2012). However, since a methodology for identifying levels has not been discussed explicitly, empirical studies have often appeared arbitrary in their definition of levels. Similarly, the identification of actors sitting at regimes level has been often obscure and arbitrary (Genus and Cole, 2008). For example niche and regimes have been differentiated using only the maturity of innovation (sustainable vs radical) (Smith, Stirling and Berkhout 2005) and the concept of regimes has been used in empirical studies either to describe tangible artefacts (Kemp, Schot and Hoogma 1998) or to address the institutional way that semi-coherent rules are set (Geels 2004).

Another structural criticism is the composition and the role of the socio-landscape level that Geels (2011) has often defined as a 'garbage can', accounting for all sorts of external influences on the socio-technical system. The call for a conceptualisation for this level and for studying the interaction between this and other levels has been lately reiterated by Schot, Kanger and Verbong (2016).

Taking into account that the interest of MLP is in socio-technical transitions, Genus and Cole (2008) have argued that the role of power and politics needs more attention within the approach. They suggest incorporating Social Construction of Technology (SCOT), Actor-Network Theory (ANT) and Constructive Technology Assessment (CTA) approach to the MLP, in order to "show concern for actors and alternative representations that could otherwise remain silent" (Genus and Cole 2008: 1441). Geels (2011) responds to this criticism highlighting how actors are implicit within the MLP approach, as each different level is continuously enacted and constructed by actors. He adds that SCOT, ANT and CTA have been used as an input to the MLP approach from the very beginning. However, their incorporation as such could create theoretical inconsistency as, for example, ANT's ontological assumption (flat ontology) is different from the MLP hierarchical level ontology. Recognising that the MLP "accommodates agency in the form of bounded rationality (routines, search activities, trial-and-error learning) and interpretative activities" (Geels 2011:30). Geels calls for an enrichment of the theory by mobilising insights from other theories in order to improve the understanding of the mechanism throughout which various levels and regimes interact. Scholars in a variety of disciplines have drawn from this suggestion. For example, Grin, Rotmans and Schot (2010) have used political science theory to develop the role of power within the MLP, linking different types of power at different levels within the MLP framework. Similarly, drawing on cultural sociology theory and social movement theory, Geels and Verhees (2011) have focused on the cultural dimension of the MLP showing that discursive activities, at niche and regime level, draw on cultural repertoire at a landscape level. Nonetheless, Geels (2011) suggests that further work which incorporates business studies and strategic management within the MLP approach is needed in order to refine further his approach.

Van Driel and Schot (2005) have argued that studies that have used the MLP approach have focused mainly on radical technical innovation. Genus and Coles (2008) argue that it is difficult to recognise when radical transitions occur, especially in a technological context. Additionally, they point out that a deterministic view of technology has permeated most of the work using the MLP, as this approach has regarded technology as an artefact. They explain that it is the winning technology that triggers transitions, undermining the complexity of recent studies on sustainable transitions where policy, society and cultural regimes seem to constrain or enable such changes. Acknowledging these critiques, Geels (2011) argues that the main focus of the MLP approach is on system innovation and not innovation itself, posing the question on how technological changes occur, and highlighting social and cultural aspects of development which may be central to the transformation. Finally, scholars (Papachristos, Sofianos and Adamides 2013; Verbong and Schot 2016; Ghosh and Schot 2019, Skeete 2019) have uncovered the possibility that other levels rather than the niche level can trigger transitions, specifically identifying the regime levels or changes in regulations and global policies as enablers of the low-carbon socio-technical transitions, under certain conditions. Those scholars and new review on the state of the art of the MLP and challenges ahead (Geels 2018) have called for more empirical studies to support those findings.

2.5 Conclusion

Drawing from the definition of socio-technical transitions as complex system changes triggered by multiple factors, this chapter has offered a review of key concepts from theories of technological change, innovations and systems innovation to enable the reader to gain a deep appreciation of the MLP approach, its theoretical foundation and its current limitations.

Specifically, understanding technological change through innovation is a major arena of study, but one which recognises that technological change is not caused solely by a shift in technology (Abernathy and Utterback 1978; Abernathy and Clark 1985; Utterback and Abernathy 1975). Hence section 2.2.1 has presented some of the theories of technological change where these shifts are understood as a dynamic process entailing technical, political, economic and social factors. These theories have shown that these factors are dynamic, changing with time when innovations unfold and that an explicit conceptualisation of the time dimension is needed to uncover these changes (Abernathy and Utterback 1978; Dosi 1982; Dosi and Winter 2002; Dosi and Nelson 2013; Foster 1986).

In line with Dosi (1994), Freeman's (1989) and Perez's (2010) studies considered "creative disruption" (Schumpeter 1942) one of the main triggers to technological shifts. Section 2.2.2 has discussed theories dealing with epochal, revolutionary, radical and breakthrough innovation (Abernathy and Clark 1985; Chandy and Tellis 1998; Clark and Staunton 1989; Tushman and Anderson 1986) with the aim to identify factors that influence technological changes at a meso and niche-level. Specifically, this section then narrows its focus on the theory of disruptive innovation (Raynor and Christensen 2003). Recognising that technology is not per se' disruptive. This theory has emphasised that disruption is relative to the business model the new innovation is disrupting. As such, concepts from business and management theories such as value network and new market become paramount for understanding the dynamics of a disruptive innovation and its effect on existing markets, products and firms.

Despite efforts from theories of technological change and innovation to detect factors that trigger, shape and enact changes, gaps still exist. Specifically, gaps concerning actors, actors' dynamics and temporal dynamics of technological changes have found further development in system innovation theories, which section 2.2.3 has discussed. Within those theories, actors and their relations are identified in order to examine patterns of changes. Although useful, the role of society, policymakers and institutions in influencing, facilitating and shaping innovation have found limited development in those theories.

In order to fill these gaps, drawing from the concept of technological changes being shaped by actors (Dosi, Freeman and Fabiani 1994; Freeman 1989; Freeman 1991; Olsen and Engen 2007; Perez 2010), section 2.3 has introduced the current state of research of the Socio-Technical Transition Theory. Specifically, recognising the need of a multi-actor, multi-level framework in which technological changes can be fully explained through the dynamic space of innovation, section 2.4 discussed in detail the Multi-Level Perspective approach. The MLP approach is one of the approaches of the Socio-Technical Transition Theory, which, in the past ten years, has been extensively used to study the dynamics of those shifts in several different sectors. In this approach, actors and groups of actors are organised within three levels, the socio-economic landscape level, the patchwork of regimes level and the niche level. Section 2.4.1 has discussed the theoretical foundation of this approach, detailing the dynamics of socio-technical transition which argues that when innovation gains momentum, at a niche level, it can displace existing regimes enacting a system's transformation. Finally, section 2.4.2 has presented four different pathways of these transitions (Geels and Schot 2007).

Acknowledging that the MLP approach has been extensively used to explain low-carbon sustainable transition, and particularly to understand how actors shape, trigger and facilitate these shifts, sub-section 2.4.3 summarised some empirical and theoretical studies on low-carbon sustainable transitions (Berkeley et al. 2017; Geels et al. 2017; Geels 2018; Marletto 2014) addressing limitations and calls for further research. Specifically, as low-carbon sustainable transition are purposive and goal-oriented in solving the Global Challenge, these studies have highlighted the latest refinements of the MLP approach, concluding that challenges are still open in order to fully understand this new type[9] of transitions:

[9] As opposed to Historical transition (Geels et al 2017).

(a) further study on society, national and international policy; (b) the consideration of cultural discourse, user practice and political struggles; (c) a way to gain stakeholders support for long-term benefit. Additionally this section has discussed the recent debate on low-carbon sustainable transition pathways in the mobility sector, which Geels et al. (2017) has suggested, including one or more MLP pathways, in this specific type of transition (purposive, goal-oriented), and which Ghosh and Schot (2019) have demonstrated as being driven by the patchwork of regime level in non-western culture.

Drawing from Geels et al. (2017) comment that low-carbon transitions are disruptive as they jeopardise the position of well-established business models (section 2.4.3), sub-section 2.4.4 addresses the recent debate on the value disruption as a trigger for socio-technical transitions. This debate has gained traction in the past couple of years reflecting on how this theory of innovation, translated at a system level, and could help in understanding the introduction of HV, FEV and PEV proposing practical recommendations. The section concludes discussing Geels' (2018) contribution to the debate, where the scholar rejects any claims that the theory of disruptive innovation could help in understanding the dynamics of low-carbon sustainable transitions basing his answer on the interpretation of this theory as an alternative framework for transition, rather than a theory of innovation.

Finally, in section 2.4.5, limitations of the MLP approach and calls for additional empirical studies are presented. Specifically, the composition and the agency of the socio-landscape level and different transition pathways (Geels and Schot 2010; Geels et al. 2016; Geels et al. 2016; Geels 2004; Geels et al. 2017; Genus and Coles 2008; Schot, Kanger and Verbong 2016; Schot and Kanger 2018; Kohler et al 2019) have emerged as crucial gaps of this approach, together with the need of a more robust operationalisation of the MLP levels, in particular of the patchwork of regimes level. It is those gaps that this study will investigate further.

Moreover, this research wants to contribute to other gaps which the latest paper of Ghosh and Schot (2019) and Skeete (2019) have addressed. Precisely, as discussed in section 2.4.3, Ghosh and Schot have suggested a novel regime framework in which changes are triggered at the patchwork of regimes level rather than at a niche level. Although useful to improve the understanding of mechanism throughout which various levels and dimensions interact, limitations on the specificity of the context of this research (non-westerner) and the operationalisation of mapping methods to inform the dynamic of this transition have been highlighted from the authors (Ghosh and Schot 2019). These gaps will be explored further in this study. Additionally, responding to Skeete's (2019) call to explore further how national and international policies could trigger sustainable developments and how other inter-related systems can influence a transition in a specific system (i.e. motorsport into auto-mobility), this study will delve deeper into the intra-dynamics and inter-dynamics of the system.

Additionally, drawing from existing research on low-carbon sustainable technological transitions and disruption (Dijk, Wells and Kemp 2016; Wilson and Tyfield 2018; Geels 2018), this study aims to contribute to the recent literature on how disruptive innovations enact changes to the system. Hence this research framework will mobilise the theory of disruptive innovation (Christensen and Raynor 2013) within the MLP approach in the same way theories of innovation and technological changes have been mobilised in the past. The theory of disruptive innovation allows for a broader, richer and relative understanding of disruptive innovation and could enhance our understanding on how new value network, customers' culture, landscape pressure and costumers' preferences can shape and enact low-carbon transitions at a system level.

To do so, drawing from the observation that theories of technological change, innovation and system innovation entail an explicit and well-defined concept of time, this research proposes a refinement to the operationalisation of the temporal dimension within the MLP approach, which will be tested in this study (chapter 5 and 6) and discussed in chapter 7. Although the concept of time is implicit within the MLP as this approach implies changes to the system, low-carbon sustainable transition studies, which have used the MLP framework, have shown a lack in explicitly conceptualising and operationalising the temporal dimension in transitioning systems. Contrarily, technological change theories have pointed out that the time dimension is paramount to uncover micro-changes in actors or group of actors (Utterback and Abernathy 1977; Nelson and Winter 1977; Dosi 1982; Foster 1986; Bijker, Hughes and Pinch 1987; Callon 1987;

Freeman 1989; Latour 1990; Misa 1994; Olsen and Engen 2007; Perez 2010). These theories have been extensively mobilised within the MLP to understand the dynamic of transitioning systems and transition pathways (Coenen, Benneworth and Truffer 2012; Geels 2011; Geels and Verhees 2011; Geels et al. 2017; Geels 2018) leading to a number of refinements within the MLP approach. Amongst those enhancements, the conceptualisation of the space dimension or spatial conceptualisation has been recently addressed in response to the shortcoming of the MLP in promoting inter and transdisciplinary dialogues and to reflect political implication of implementing sustainable transitions (Coenen, Benneworth and Truffer 2012). Although time and space are strongly interlinked in most theories of innovation and technological change (section 2.2.1 and section 2.2.2), an explicit conceptualisation of the temporal dimension in socio-technical transitions remains underexposed. This research suggests a way to refine the temporal dimension of transitions, suggesting that when a new innovation enters a window of opportunity, only a grain-refinement to the temporal dimension in which the phenomenon is observed, can lead to a better understanding of the dynamics of the transition and its pathway.

Exploring a changing phenomenon throughout its temporal dimension is not new to the business and the change management literature. Those disciplines have often explored patterns of changes in actors and actors' group to shed light on the dynamics of the process of change and how firms can be resilient and respond successfully to those changes at a micro level. Hence, this research also wants to answer the call from Geels (2011), which suggests that further work which incorporates business studies and strategic management theories within the MLP approach is needed in order to refine this approach further.

3. The context of this research

3.1 Introduction

This chapter discusses the context of this research, the motorsport industry. Section 3.1 summarises academic studies which have dealt with this industry explaining why motorsport is particularly suited for understanding low-carbon socio-technical transitions. As socio-technical transitions involve changes in the entire system, including both the innovatory system and the socio-economic context, section 3.2 details the motorsport's innovatory system and its value-chain. Additionally, narrowing the focus down to the most recent low-carbon change within this industry, section 3.3 gives an overview of the FIA Formula Electric (FIA Formula E or Formula E), the first all-electric FIA championship.

3.2 Motorsport as the pinnacle of technological innovation and its value for understanding low-carbon socio-technical transitions

Historically, the motorsport industry has been regarded as the pinnacle of technology as motor racing teams have invested in discontinuous, radical and disruptive innovations in their quest for a competitive advantage (Jenkins 2010; Skeete 2019). This industry is global and provides a turnover of $100 billion per year (Henry et al. 2007). Its total audience is only behind that of the FIFA World Cup and the Olympic games (Henry et al. 2007).

In 2008, the UK government addressed the importance of the motorsport industry for the future economic growth of the country (Skeete 2019) emphasising that motorsport technological developments are transferable to other sectors. Motorsport is crucial for the generation of ideas (knowledge creation) and for being a testing ground for new technologies to be deployed, at a later date, in the automotive and the mass production markets. Examples of technology transfer into the mobility sector are the introduction of composite technology into the automotive market, for example the rear hatch used on the Toyota Prius, the new Aston Martin Hypercar (produced through a collaboration with Red Bull Racing) and the Jaguar CX-75 with battery technology that comes from the advanced engineering department of Williams F1. The motorsport industry has also reached other industrial sectors, to diversify their businesses further; specifically, it has used Computational Fluid Dynamic (CFD) to maximise the efficiency of cooling (Aerofoil Ltd and Williams Advanced Engineering) and race strategy to reduce lead-time and increase efficiency in industrial processes (GSK toothpaste and McLaren Applied Technology). Other examples of technological transfer to other sectors can also be found in the use of composite technology in other sports (Team GB and McLaren racing bikes, and bobsleighs), for the design and production of medical and biomedical equipment (NHS and McLaren Applied Technology, Cardiff hospital and Williams Advanced Engineering) and for the production of artificial limbs (Mercedes AMG F1). Additionally technology developed for the Kinetic Energy Recovery Systems in motorsport, such as the flywheel, have successfully been applied in the energy sector.

In the last two decades there has been a small number of academic studies around the motorsport industry as an excellent example for innovation (Delbridge and Mariotti 2009; Jenkins 2010), diversification, knowledge creation (Jenkins and Tallman 2010; Tallman et al. 2004), and strategic and business management practice (Delbridge and Mariotti 2009; Henry et al. 2007; Jenkins 2014; Jenkins and Floyd 2001; Jenkins, Pasternak and West 2009; Jenkins and Tallman 2010; Papachristos 2014). In their studies, scholars have focused on the way that motorsport, and particularly the motor industry (Henry et al. 2007), can generate radical innovation, highlighting elements of motorsport's innovatory system. Examining different examples of innovation in motorsport within the past fifty years, Delbrige and Mariotti (2009) observe that "in fields where technology is developing rapidly, and the sources of knowledge are widely distributed, no single firm has the necessary skills to remain competitive on its own" (Delbrige and Mariotti 2009: 8) concluding that motorsport companies need to build networks and collaborations with external partners. Historically the choice of these partners has been based on trust, proximity and familiarity, resulting in the formation of what the literature has referred to as 'motorsport clusters' (Henry et al. 2007). Though, due to the high degree of sophistication and complexity which has lately affected motorsport, constructors have collaborated with new partners from different networks, in order to extend their capability and knowledge (Delbridge and Mariotti 2009). Aside from networks, Delbridge and Mariotti (2009) identify time-scales and regulation amongst other factors that influence the number of radical innovations deployed into the sport. They consider regulation as one of the elements that mostly reduces the degree of innovativeness and define motorsport as “highly regulated in order to ensure safety and relatively close competition” (Delbridge and Mariotti 2009: 18). Other studies (Henry et al. 2007; Jenkins 2010; Painter, Rimmer and Brown 2002; Papachristos 2014) have addressed how these institutional actors (the regulators) play a crucial role in technological changes within motorsport, being able to facilitate and drive discontinuous, radical and disruptive innovations. However, most of these studies have regarded regulators and, most specifically the FIA, as the only actor able to drive technological changes (Delbridge and Mariotti 2009; Jenkins 2010; Papachristos 2014; Skeete 2019). This undermines other actors in the system or in other interrelated systems and exogenous events that might have an influence on these shifts.

There is very limited up to date literature available on the business of motorsport since the landmark Henry et al (2007). This is probably due to the inherent difficulty of engaging stakeholders from within a guarded industry, where commercial and competitive advantages are heightened. It may also stem from a perception within the research community that the motorsport industry is highly atypical, and thus of limited value when seeking generalisable insights, whether in relation to business and management, or economic growth and development. Notwithstanding these issues, recently, scholars have started exploring the link between motorsport and low-carbon changes (Huber 2012; Skeete 2019). Skeete (2019) suggests that this contribution is not solely in developing technologies or innovations used for applications in the energy and mobility sectors (i.e. flywheel, EV Battery), but also in changing perceptions, showcasing the electric technology as a marketing strategy for industry and non-industry players.

Historically, the Fédération Internationale de l’Automobile (FIA), the regulator and governing body of motorsport, has fostered and facilitated low-carbon sustainable changes in the sport with a vision to increasing public awareness and excitement about new technologies, and to nurture a better public understanding of issues such as low-carbon mobility and road safety. Examples of how they assisted in the acceptance and diffusion of innovation within a global audience are: the introduction of unleaded fuel into motorsport in the 1980s, the sanctioning of the FIA Clean Energy Cup in 2007, the introduction of KERS and ERS into Formula

1 from 2008 and in endorsing the first all-electric championship (FIA Formula E) in 2014 (Connelly, 2014). Predominantly the latter has since then grown and globalised, making the first page of many prominent newspapers and being regarded as a story of success, not just referring to the media and marketing development of the series, but also for changing perception and facilitating the acceptance and the diffusion of Full Electric Vehicle (FEV) (The Independent, 2017; The Guardian, 2017).

Within the motorsport industry, although regulators (FIA, ASN) can assist in facilitating innovation within the motorsport sector, they are not able to change technical or sporting regulations directly, unless for safety-related reasons. The regulators need the agreement of other stakeholders of the motorsport industry for any new rule to be approved (hence innovations to be adopted). Gary Connelly, former deputy president for the FIA Institute for Motor Sport Safety and Sustainability, representative of the Motorsport Australian Federation and Formula One steward, in a presentation given in 2012 on behalf of the FIA Institute, rehearsed this concept and defined the shift of motorsport towards low-carbon technologies as triggered from behavioural changes in the motorsport stakeholders and responding to a broader demand from society and international policy (Connelly 2014).

It is this relationship between, in the language of the MLP, the patchwork of regimes level and the socio-economic landscape level in shaping and enacting low-carbon socio-technical transitions which this thesis wants to explore and for which FIA Formula E is considered most suitable. As transitions are long-term system shifts, the context of motorsport is particularly appropriate due to its well-known and highly regarded fast pace in enacting change (Delbridge and Mariotti 2009; Foxall and Johnston 1991; Jenkins and Floyd 2001; Jenkins 2010). In this industry, changes happen within five to ten years, rather than fifty to seventy years as in other industries (Geels 2004).

3.3 The motorsport industry as a system: its value chain framework and its innovatory system

This section discusses the value chain and the innovatory system of motorsport. If the value chain offers an understanding of the composition of the motorsport system, detailing its actors and relations, the innovatory system illustrates relevant examples of radical and disruptive innovations that, in the language of the MLP, have triggered changes at different levels of this system.

3.3.1 Understanding actors' categories and their relations: the motorsport value chain framework

Broadly, motorsport has been defined as "competitive racing by equivalent machines on a frequent basis, on designated tracks and circuits" (Henry et al. 2007: 1). Within the literature, scholars have often referred to motorsport as a sector but also industry and as a niche (Foxall and Johnston 1991; Henry and Pinch 2000; Jenkins, Pasternak and West 2009; Jenkins 2010; Jenkins and Tallman 2010; Tallman et al. 2004). Henry et al. (2007) studied this industry from a business perspective, defining motorsport as involving both the *business of sport* and the *engineering industry*, comprising of:

- "Motor: the provision -construction and preparation- of cars and bikes;
- Sport: the infrastructure including clubs, circuits, promotion, insurance and so on which are needed to participate in, spectate, or view the sport;
- A part of the leisure and entertainment industry; and
- A marketing opportunity for the sponsors" (Henry et al. 2007: 1).

They conceptualise this multi-actor business model through a value chain framework. The motorsport value chain (Figure 4) identifies categories of actors within the motorsport industry, grouping firms within these categories, and illustrating some relations between these categories and the supply chain.

Figure 4 The value chain framework of the motorsport industry (Henry et al. 2007: 3)

Within this model the main groups of actors are:

- Regulation: these include the governing bodies which set the technical and sporting norms in the sport, such as FIA, local clubs, safety panels and research bodies (FIA Institute, Global Institute);
- Regulatory and Fiscal environment for business: these include organisations that operate within the broader regulatory environment that affect all businesses;
- Supporting Service Industries: these are specific firms that provide third-party services for the industry such as insurance brokerage, HR management, recruitment, logistics, finance, facilitating sponsorships, legal advice and so forth.;
- Consumption: this group includes all actors involved in the consumption of motorsport, including spectators (at the circuit, on the radio, on television), participants, readers of various specialised magazines, gamers and e-spectators (spectators using channels such as YouTube, Twitter and so forth);
- Distribution: this includes all the actors involved in the dissemination of the events, televisions, radio, internet, press coverage including all media, private and publicly owned;

- Events: organisations that manage and operate racing events are included in this category. It includes promoters, organisations within manufacturers, racing clubs.
- Events Suppliers: this category includes all the firms that supply or produce any component necessary for an event to take place;
- Constructors: a constructor is defined as a firm that manufactures a motorsport vehicle, from F1 teams to club racing;
- Constructor Suppliers: this category includes all firms that supply components to the constructors in order to create a final product. Constructor suppliers include engine suppliers, tyre suppliers, aerodynamics components (including wind tunnel services) gearboxes, fuel and other specialist services.
- Entrants: this includes those firms that enter the sport with a competing vehicle but cannot be included within the manufacturers. Examples are junior category racing teams.

Henry et al. define the relationships amongst these actors as "a complex system of interdependence" (Henry et al. 2007: 6), identifying constructors and events as, ultimately, the two primary categories responsible for the sustainability of the motorsport business model. Specifically, constructors build the vehicle to race (the product), acting as integrators between supporting services and constructor suppliers, and selling the product to entrants. The category events, instead, provides the show, the place for racing and the facilities for these machines to compete (market), being responsible for other categories such as the distribution, consumption and event suppliers (Henry et al. 2007). Hence, the term motor-sport acquires a different connotation, incorporating two industries and, therefore, resulting in being both *product* and *market*-driven, at the same time.

3.3.2 Understanding triggers for changes: the motorsport innovatory system

In order to understand how different actors at different levels interact when a technological change happens, this sub-section offers some examples of the innovatory system of motorsport and specifically: the Ford Double Four Valve (DFV) V8, the introduction of composite technology and the introduction of safety systems and specifically the HALO device. There is a vast literature on examples of technological innovations as triggering changes within the motorsport industry

(Jenkins, Pasternak and West 2009; Jenkins 2010; Wright 2001) but these three examples are most useful in understanding how those changes are not just driven solely by changes in technologies. Rather, they involve other factors within the socio-economic and institutional context (Freeman 1989; Perez 2010; Raynor and Christensen 2003) of the motorsport system.

These examples of innovations in the motorsport industry are interpreted through the MLP lens to illustrate how this framework supports the understanding of the innovatory system of motorsport, giving an overview on how actors and relationships can translate to the niche, regime and landscape levels of the MLP approach (chapter 2).

The Ford DFV V8 engine was introduced in F1 in 1967. With this engine, Ford moved away from the idea that the engine was just an essential component of the car, using it as a critical part of the structure, “substituting a major section of the chassis, to create a lighter, high-powered racecar” (Jenkins 2010: 15). Ford chose to create this engine in partnership with well-known companies in the motorsport sector: Lotus Cars, a motorsport team, whose engineers were to design the racecar in which the engine would have been raced and Cosworth Engineering, an automotive/motorsport company, who were put in charge of designing and building the engine. The Lotus car, which used the new DFV V8 engine, dominated the championship that year from the very first time the engine was introduced, specifically the Dutch GP in 1967. This engine was made available to other teams in 1968.

> “Almost at once I began to think we might destroy the sport. I realised that we had to widen the market for the DFV engine so that other Teams could have access to it” (Walter Haynes, Ford, Robson 1999 cited in Jenkins, Pasternak and West 2009: 169).

The engine costs were estimated at £7,500 per year, and it was given to the teams with a standard gearbox (Hewland Engineering) (Beck-Burridge and Walton 2000 cited in Jenkins 2010: 16) creating what was then named kit-cars, paving the way for modern F1 customer teams.

One of the main factors which facilitated the introduction of this innovation was the change in engine regulations announced by the FIA in 1963 in line with which, from 1966, the Formula 1 engines would either be normally aspirated 3.0-litre engines or 1.5 litres turbocharged (Wright 2001). This change in regulation caused established and successful companies such as Coventry Climax, who dominated the championship until that moment, to quit the sport after 1965, due to the high costs of development involved with a new engine. On the other hand this allowed new entrants, such as Ford, to be able to use their capabilities, knowledge and funds to enter the motorsport sector successfully (Jenkins, Pasternak and West 2009). This example is useful in explaining the motorsport innovatory system when the innovation is triggered by the regulator/institutions (top-down innovation). Although the disruptive technology was created by Ford, in language of the MLP, at a niche-level (chapter 2), the technological transition was triggered by the earlier change of rules, which opened up the market for new entrants (top-down approach for the introduction of technology), reducing existing barriers to entry from new companies. The success of this new product, the DVF V8, triggered a change in customers' perceptions causing a redefinition of the concept of a motor-racing team. A team was not anymore run solely by car manufacturers but, with the advent of the kit-car also single individuals were able to race and to be successful, eventually displacing successful incumbents (Wright 2001). The motorsport sector uses a reliable and measurable unit to define success, such as the number of points scored during a season (Jenkins 2010). Before the advent of the DFV V8 engine and its success, the common understanding of a racing team was that it was able to manufacture both engine and chassis (Jenkins 2010; Wright 2001). With Ford willing to open the supply of the engine (kit-car) to more than one team, the common perception of being able to compete in motorsport changed, redefining the entire value-chain of this industry and resulting in many customer teams taking to the start-line of the 1968 Formula 1 season (Wright 2001).

Differently to the DFV V8 example, the introduction of composite technology in F1 was driven by an innovation generated at a niche level from an incumbent belonging to the existing/traditional technological regime. Historically the introduction of composite materials within this sector can be traced back to 1976 when Brabham used it for the first time to build brake discs (McBeath 2009). Although composite technology was considered a technological improvement, this did not trigger any technological shift in motorsport until John Barnard, McLaren technical director, decided to adopt this material to build a full F1 chassis in 1981 (McBeath 2009). John Barnard worked mostly in sports cars and the U.S. In love with technologies, he believed that composite material, used already in U.S. aerospace, would confer to the car a significant performance advantage due to its lightweight, super stiff characteristics. Ron Dennis, then the Team Manager of McLaren, one of the FIA Formula 1 Teams, after contracting Barnard in 1980, agreed to build the McLaren MP4/1, the first entirely moulded carbon composite monocoque. The process of producing a full carbon-fibre chassis was not easy, as many limitations, such as the dimension and location of available equipment and newness of the technology increased the complexity of the project. Though Barnard managed to find the equipment and the help he needed from the aerospace sector in the USA, specifically in Salt Lake City from Hercules Aerospace (Wright 2001). In 1981 McLaren was taking part in the F1 Championship with the first full carbon fibre chassis, harvesting that technological advantage of using carbon fibre to produce a lightweight and stiff car, for some years and winning the championship in 1984 and 1985. Although other teams had a similar idea in the same year (Lotus team), due to the differences in manufacturing and concept behind the use of this relatively new (to motorsport) material, only the MP4/1 design was successful. The use of this material quickly became a dominant design in the motorsport industry, pushing this innovation from the niche-level to the regime-level (Geels 2004).

Amongst other authors who have dealt with the introduction of composites in motorsport, Smith (2012) identified non-technological factors which contributed to the success of this technology, including the “role of social capital”, used by Smith to mean knowledge network:

> “Almost from the start, the main focus of Barnard’s work had been the racing scene in the US […]. As an outsider, the structure of Barnard’s social capital was uncharacteristic of Formula 1 designers of the period. In structural terms, his network of personal contacts was more diverse than was normally the case. Not only that, but it also extended to groups well beyond the normal confines of the Formula 1 community, to cover other categories of racing particularly in the US. These categories of racing represented different groups or networks of racing personnel located geographically and technologically at a distance from Formula 1.

> […] In this instance, while several established and successful teams in Formula 1 had made limited use of this new material, the leap to using carbon fibre involving completely different construction techniques that bore no resemblance to the methods employed in the industry at the time, was pioneered by an outsider, a team new to Formula 1 (certainly in terms of personnel if not name).” (Smith 2012: 17)

The last example in this section is the introduction of the HALO cockpit protection. This device is a titanium structure that sits above the car’s cockpit to protect the driver’s head from impacts with flying objects. It was introduced in Formula One in 2018. This structure was developed by the FIA Institute (the R&D department of the FIA), in order to add a front roll structure to a single seater (FIA 2015). Several crash tests and modifications were carried out by the FIA with the collaboration of some of the Formula One teams in order to refine the prototype. Teams were not in favour of the HALO, proposing and testing alternative solutions. However, this device was made mandatory from the FIA on safety grounds, resulting in the immediate introduction of this device into Formula One at the start of the 2018 championship and a plan for its deployment in most of the other FIA single-seater categories within the following five years. The HALO is not the only safety device mandated by the FIA due to safety requirements. Ear Plug accelerometers (2015), ADR (2000), SDR (2004) and the biometric glove (2018) were amongst devices that were mandated by the FIA without the need of a collective agreement by other motor-racing actors.

3.4 FIA Formula E: a context for understating low carbon socio-technical transitions in the motorsport system

The concept of an all-electric powered formula, racing solely on street circuits, was born in Paris in 2011, according to the Formula E and the FIA communication department, during a conversation, at a dinner table, between Agag, former politician, founder and CEO of **Formula E Holding**[10], Todt, **FIA** president and Tajani, the sitting president of the **European Parliament** (Formula E 2012). The discussion fitted with the global vision of the FIA president for motorsport to

[10] In this section the use of bold guides the reader through the text drawing attention to actors and groups of actors within FIA Formula E.

contain an electric championship and for motorsport to be considered an incubator and R&D department for new technologies, as well as to facilitate the acceptance and the adoption of technologies amongst society:

> "I thought it was important to have a **vision for new technology for the development of the motoring industry** and that is why we changed the regulations in Formula 1 that is why we supported new regulations in the World Endurance Championship. Moreover, then came the idea of making a specific flagship championship with **electric technology**. Many people were enthusiastic about this idea. For me, the electric car is really the future of motoring in the cities. Moreover, that is why we began with hosting races in world cities. It is a **new approach**; it is a **new product**" (Todt, 2014 cited in Biesbrouk 2014).

In 2012 the FIA and Formula E Holdings, headed by Agag, announced the start of the FIA Formula E, forecast for September 2014 in Beijing. The FIA and Formula E sent an invitation to tender in 2012, for supplying parts to this championship in **seasons 1 to 3 of Formula E**, to well-known **incumbent motorsport stakeholders** in order to prepare some components of the car for the **single-make series**.

The following list provides an overview of the actors involved in building the Formula E car:

- The chassis –from season one to season three **-Dallara**
- The electric powertrain **-McLaren Applied Technology** –for season one and two only. From season three the powertrain was opened for the Teams to create a partnership with any company;
- The battery and the Battery Management System —–**Williams Advanced Engineering** for season one to three only. Initially, from season four onwards the battery and the BMS should have been open, but in order to contain costs and due to pressure from some of the stakeholders, a new tender was undertaken for seasons four and five **by McLaren Applied Technology;**

- The tyres –for seasons one to three –**Michelin;**
- The gearbox –for seasons one to four –**Hewland;**
- The electronics – for seasons one to four –**McLaren Applied technology** (on-board) **Magneti Marelli** (off-board);
- Any ancillary equipment (rims) –**MRTC** (Radio); **OZ** (Rims); **Charge** (battery chargers).

This list proves how in motorsport, a **season** defines the temporal dimension of a championship, which is the time from the first test of the series to the last race of that championship. In Formula One, for example, a season is equivalent to a year, starting in February of each year and finishing in November. Peculiarly the Formula E season starts in August/September of each year and ends in July/August of the following year. The temporal dimension of championships in motorsport is a season, and each season includes events, races and tests. Hence, across all motorsport championships, different actors use the term season to refer to a specific moment in time in this industry. In the context of this research, season 0 for Formula E ran from August 2012 to July 2014, Season 1 ran from August 2014 until August 2015, season 2 from September 2015 until August 2016 and season 3 from September 2016 until August 2017. In the same way, this study defines season to include all the events from the announcement of FIA Formula E (2012) until the first race of the championship (August 2014).

Spark technology, a French company, led by motorsport entrepreneur Vasseur, was appointed by the FIA and Formula E to assemble the cars and coordinate all suppliers. In terms of the value chain framework (section 3.3), Spark technology represents a **constructor**, whilst all the suppliers mentioned above, sit as **constructor suppliers** on the motor industry part of the business (Figure 4). The **participants** are identified as the **Teams** taking part in the Formula E series. Tables 3-A and 3-B detail the Teams taking part in Formula E over the three seasons highlighting the **changing dynamics** of a series when **innovation unfolds**. While in season one no development on any part of the car was allowed, from season two rules were opened, allowing teams to pursue their development of the powertrain, including the e-motor, inverter, gearbox and cooling system. Allowing some development resulted in the formation of partnerships with suppliers and manufacturers and, in some cases, in a change of stakeholders within teams. Specifically, in table 3B, two rows were added: manufacturers and powertrains. The implication of those changes will be discussed in chapters 5 and 6.

Table 3-A List of teams taking part in season 1 of FIA Formula E championship (author's compilation)

	Formula E Teams
Season 1 (2014/2015)	Virgin Racing
	Mahindra Racing (technical partnership with Carlin Racing)
	Dragon Racing
	e.dams Renault
	Trulli Formula E (former Drayson Racing)
	Audi Sport ABT
	Venturi Formula E Team
	Andretti Formula E Team
	Amlin Aguri
	China Racing

Table 3-B List of teams taking part in season 2 and season 3 of FIA Formula E championship (author's compilation)

	Formula E Team	**Manufacturer**	**Powertrain**
Season 2 (2015/2016)	NEXTEV TCR Formula E Team	Spark-NEXTEV	NEXTEV TCR
	DS Virgin Racing Formula E Team	Spark-Citroen	Virgin DSV
	Venturi Formula E Team	Spark-Venturi	Venturi
	Dragon Racing	Spark-Venturi	Venturi
	Renault e.Dams	Spark-Renault	Renault ZE15
	Trulli Formula E Team	Spark-Motomatica	Motomatica JT
	ABT Schaeffler Audi Sport	Spark-ABT Sportsline	ABT Schaeffler

Season 2 (2015/2016)	Mahindra Racing Formula E Team Amlin Andretti Formula E Team Aguri	Spark-Mahindra Spark-McLaren	Mahindra ELECTRO SRT SRT
Season 3 (2016/2017)	DS Virgin Racing NexEV NIO Venturi Formula E Team Faraday Future Dragon Racing Renault e.Dams ABT Scheffler Audi Sport Mahindra Racing Formula E Team Panasonic Jaguar Racing (technical partnership with Williams Advanced Engineering) Techeetah MS Amlin Andretti (partnership with BMW)	Spark-Citroen Spark-NEXTEV Spark-Venturi Spark-Penske Spark-Renault Spark-ABT Sportsline Spark-Mahindra Spark-Jaguar Spark-Renault Andretti	Virgin DSV NEXTEV Venturi Penske700EV Renault ZE 16 ABT Schaeffler Mahindra ELECTRO Jaguar I-type Renault ZE16 ATEC

Within this new all-electric championship**,** Formula E Holdings coordinates Formula E's actors. These actors include the support services industry, events, events suppliers, distribution and consumption (Figure 4). Formula E Holdings also manage the supporting services industry, including the logistics, through their **global partner DHL,** and sponsorship of the championship (**VISA, BMW, Julius Baer, ENEL**).

FIA Formula E was conceived as a street race series, introducing racing in the principal city of each nation, in order to showcase the power of electric cars (Agag 2014). Hence, the host cities (events), their **local government** (regulatory environment) and **educational bodies** were included as stakeholders of Formula E:

> “In the run-up for each e-Prix, we have been researching sustainable credential reports for each or our hosting cities […]. This allows us to know the areas in which we can have the greatest positive impact on our engagement with the community” (Formula E Sustainability report 2016:2 8).

Data shows differences in actors involved in the consumption and distribution of FIA Formula E between season one and the later seasons. Particularly, while in 2014 Agag and Banjoules mainly owned Formula E Holdings, in March 2015, **Liberty Global plc** and **Discovery Communication Inc.** acquired a share of the business. These two powerful media companies brought strong financial backing to Formula E but also a strong strategic vision for the consumption and distribution of the series (FIA Formula E 2012). Within this vision, Formula E has started to develop a new philosophy on how electric motorsport should involve the **public** more, specifically, **millennials**. Fan Boost (a social media vote for a driver allowing him to have a boost of extra power during the race) was added to engage more interactively with the fans. With this view, in January 2017 Formula E Holdings organised a virtual race in Las Vegas, during the **Consumer Electronics** Show (CES), amongst **gamers** and real drivers.

In 2016 **BMW** announced their partnership with Andretti Formula E Team for season three and their intention to run their team by 2018. In the same year, before Christmas, **Mercedes AMG** broadcast their interest in Formula E reserving a space for season four. At the same time, **Audi** withdrew from the FIA World Endurance Championship, announcing that they will concentrate on supporting ABT Schaeffler within Formula E from season four onwards. These changes in actors’ and relations at different levels, at different times (season) during the unfolding of this innovation, make FIA Formula E a suitable case study for exploring the dynamic and temporal dynamic of low-carbon sustainable socio-technical transition using the MLP approach.

3.5 Conclusion

This chapter has presented the context of this research, the motorsport industry, explaining why this context and specifically FIA Formula E is most useful to understand low-carbon socio-technical transitions.

From this chapter, the motorsport industry has emerged as a complex multi-actor system, inclined to fast-paced technological shifts. In recent decades, the focus on motorsport as a way to develop innovations that are transferrable to other sectors has been a topic for policy and academia. Section 3.2 has addressed these matters, supplying the reader with practical examples of technological innovation in the motorsport industry which have leapt across other sectors. Amongst these innovations, low-carbon energy-efficient applications have been used in the mobility and energy sectors, showcasing how motorsport can actively contribute to low-carbon technological transition. This section has also shown how the contribution of motorsport to these transitions is not only via the R&D department for other sectors, but also as a powerful way to change societal perceptions and accelerate the adoption of new technologies and alternative mobility models (Skeete 2019; Huber 2012). Hence motorsport is a suitable context in order to shed some light on the academic gaps on low-carbon sustainable socio-technical transitions (chapter 2).

As socio-technical transitions are changes to the all socio-technical systems, section 3.3 has discussed the motorsport value chain framework (Henry et al. 2007) and motorsport's innovatory system. Specifically, the value chain framework (sub-section 3.3.1) has offered an understanding of the actors embedded in this industry and their relations. This framework shows that the motorsport industry includes two industries, both equally important: the motor industry and the sports industry. Sub-section 3.3.2 has discussed the innovatory system of this industry. Three examples of innovations were used to explain the agency of institutions and actors within this innovatory system: the Ford DFV8, the introduction of composite technology and the introduction of the Halo device. These examples have shown that, in the motorsport system, changes to the system can be triggered by actors sitting, in the language of the MLP, at different levels of the system. These examples have also outlined the influence of other interrelated systems in triggering changes to the motorsport system.

Finally, with a view that motorsport is transitioning to low-carbon and sustainable innovation, section 3.4 has introduced the story of FIA Formula E as the most recent and powerful example of low-carbon sustainable socio-technical transition in this industry (Huber 2012; Skeete 2019).

4. Research Methodology

4.1 Introduction

This chapter discusses the methodology used for this research. It begins by explaining the philosophical position of this study (4.2), my positionality and the influence it has had on the choice of methodology, before outlining the research ethics (Section 4.3). Finally, sections 4.4, 4.5 and 4.6 explain this research design and its operationalisation, describing methods used during the process of gathering and analysing data.

4.2 The philosophy of this research: ontology and epistemology

Geels (2011) repeatedly underlines how the MLP approach is not a theory but an open framework approach which helps researchers to think through the problem. Defining the MLP as a framework implies that this approach does not benefit from a research philosophy, but requires

> "Both substantive knowledge of the empirical domain and theoretical sensitivity (and interpretive creativity) that help the analyst to 'see' interesting patterns and mechanism". (Geels 2011: 34)

Sorrell (2018) has argued that, although the MLP is an approach, it entails an implicit and explicit philosophical orientation which, overcoming its limitations, can be reconciled with the position of critical realism.

> "[The MLP] include[s] assumptions about the nature of reality (ontology), the status of claims about that reality (epistemology) and the appropriate choice of research methods". (Sorrell 2018: 1267)

Easton proposes a comprehensive definition of critical realism, detailing the ontology and epistemology of this philosophy:

> "Critical realism proposes an ontology that assumes that there exists a reality 'out there' independent from the observer. A naïve realist epistemology would assume that this reality can be readily accessed […]." (Easton 2010: 120)

Jarvis and Dunham (2003) argue that in critical realism the philosophy of realism is a layered ontology consisting of three overlapping domains: (a) the domain of the empirical (human experience), (b) the domain of the real (hidden structure and causal mechanism) and (c) the domain of the actual (events). This definition means that the context in which the phenomena are observed, together with the identification of cause and effect, plays a role in the explanation of the phenomena. Hence, placing the phenomena within space and time is crucial to analysing it.

Specifically, in the context of this research, low-carbon sustainable socio-technical transition in the motorsport industry, it is possible to identify these three overlapping domains as (a) the experience of actors and stakeholders which were involved in FIA Formula E, (b) the informal or hidden actors, their structures and causal mechanism, and (c) events within the timeframe considered (from season zero to season three). Understanding these overlapping domains is essential for the choice of methods for data collection. As the emphasis of this research is on systems and this involves scrutinising relationships within actors, and across MLP levels during S0 to S3, qualitative approaches are most useful to gather data. Section 4.5 will discuss these methods in greater detail.

Critical realism accepts that reality is socially constructed, but not entirely so, and recognises that social reality exists independently of the object of study and the researcher. This position does not deny the possibility of explaining phenomena but, considering observation as fallible, it demands the researcher to acquire a significant amount of data and to rely on a community of scholars to debate it thoroughly. Hence the epistemological position of critical realism considers critique an essential element and demands that a multitude of methods be used in data collection.

4.3 Positionality and reflexivity

> "Bias comes not from having ethical and political positions – this is inevitable - but from not acknowledging them. Not only does such acknowledgement help to unmask any bias that is implicit in those

> views, but it helps to provide a way of responding critically and sensitively to the research.” (Griffiths 1998: 133)

Critical realism considers reality socially constructed and knowledge historically situated and context-based (Mauthner and Doucet 2003). This statement implies that some factors could influence the process of knowledge production. Acknowledging these factors is considered good practice in overcoming any bias that the researcher could carry in terms of choice of the methodological process and interpretation of the data gathered. Scholars suggest that researcher self-reflection is an “explicit self-aware meta-analysis”, for explaining these factors ex-ante and the choice of appropriate methods overcomes any biases (Finlay 2002, Bryman 2015).

I understand my positionality during this research as an Italian motorsport engineer, novice researcher, mature student, working in the motorsport industry since 1999. My reflection on this positionality for research practice is structured around three main areas (Savin-Baden and Major 2013): the subject, the context and participants involved in the study.

Understanding my positionality against the subject of this research has been probably the most challenging of the three considerations, as this is embedded within myself rather than constructed during my years of work (Flick 2014). My curiosity towards science and technology from an early age led me to use the scientific method to research and explain the world. Having confidence that hypothesis and predictions can explain most phenomena, I joined the ‘scientific lyceum’ in my hometown and subsequently the engineering department of the University of Bologna. After graduating in industrial engineering, I moved to the UK where I completed an MSc in motorsport engineering at Cranfield University. Having been involved in motorsport during my years at university, I then started to work in F1 as a data analyst and system engineer. Data analysts make sense of the world through data, measure and observe phenomena, which can be reproduced in certain conditions. It was during 2009 when trying to integrate some novel technology into motorsport that I began to appreciate how innovation is influenced not exclusively from technology and its feasibility, rather from an array of external factors including society and users. The challenge has been to recognise the implications of the different philosophies of science, disciplinary training and ‘world views’ in the move from engineering into science and technology studies and business and management.

With reference to my positionality within the context of this research, as a senior motorsport engineer, I have had deep and extensive past involvement in some of the categories identified in the motorsport value chain framework (Henry et al. 2007). Most directly within the context of this research, my engagement with FIA and Formula E Holdings. Between 2004 and 2009, I was subcontracted to FIA as a data analyst within the FIA F1 technical department. I was deeply embedded in the structure of the motorsport governing body and heavily involved in Working Groups and commissions. This involvement continued through subsequent motorsport positions, including management of motorsport projects for the newly established Williams Advanced Engineering (WAE) – a key supplier in the new FIA Formula E from season zero to season three.

Being part of the motorsport community has provided privileged access to the world and informants of FIA Formula E, and a better understanding of the shape of the technology system, key actors and stakeholders, processes and individuals. Concerning the key activity of semi-structured interviews, this has not, however, led to choice first and foremost based on criteria such as accessibility and familiarity. The need for robust criteria to choose key informants is paramount in any research to avoid any issue related to the validity and reliability of the sources. As such this research has used different criteria to select informants during different phases of the study, which will be explained in greater detail in this chapter in section 4.5 and reiterated in chapters 5 and 6. Above all, the different involvement of informants within the context of this study, the role they currently have and their reputation within the industry, have been discriminant factors in deciding if and when to interview them. There is, however, one example which brings an understanding of the boundaries of positionality into sharp relief. Early on in my data collection, I requested that the FIA grant me access to the Technical Working Groups’ minutes of FIA Formula E and the documents from the New Energy Championships Committee. This request was answered by the FIA presenting me with a Non-Disclosure Agreement (NDA) to sign. I decided not to sign the NDA, given other methods of accessing the range of data I needed, whilst reflecting on the boundaries of the motorsport community and academic researcher.

4.3.1 Research ethics

This research adheres to the ethical regulations and procedures set by the university. Appendix 1 supplies all documents concerning ethical approval. During the interviews, a series of measures were put in place to ensure compliance with the ethical procedures (Kvale and Brynman, 2009). Informants' consent, confidentiality of the data, anonymity and access to the thesis before publication were all considered as per the requirements of Coventry University ethical review system of approval. Specifically, when meeting an interviewee, he/she was provided with a summary of the research, participant information sheet, in which the ethical approved status of the research was explained, and the confidentiality of the interview material was guaranteed (Appendix 2). It was essential making these steps as operational as possible, including evidence and documentation of procedures, to ensure repeatability, replicability and reliability of this process (Punch 2005). In a further attempt to minimise bias, relevant information concerning the themes of interviews were supplied ahead of the meetings (Appendix 2) to allow informants to gather their thoughts on the discussion and relevant materials. This last document was compiled to make structured interviews less prone to variation, supplying robustness and repeatability to the process. However, semi-structured interviews are not necessarily intended to be repeatable as they reflect reality at the time they were collected (Bryman 2015). All interviews started with an informal discussion between the researcher and the interviewees, where all key-informants were reminded of my role as an independent researcher and this was reiterated by the contents of the documents.

To ensure anonymity, all the interviewees' names were removed and replaced with letters attached to quotes. As motorsport is a small industry where only a handful of people cover specific senior roles, names of companies where interviewees worked at were removed and replaced with numbers. The role of the interviewees was maintained, where possible, to highlight the seniority of these informants at the time of the interview.

Participants were asked their permission to audio-record interviews, and in three cases permission was denied. The denied permission did not constitute an issue, as notes were taken during the interviews. Any evidence used throughout the thesis is fully referenced and acknowledged.

4.4 Research design

This section outlines the research design of this study (Figure 5). The research design had to be planned carefully to ensure the reliability and robustness of the data. In particular, to avoid the bias of interpreting data based on preconceived knowledge, an initial scoping phase was added to the research design. The scoping phases used two different methods for gathering the data from a variety of fronts, motorsports and non-motorsport related sources.

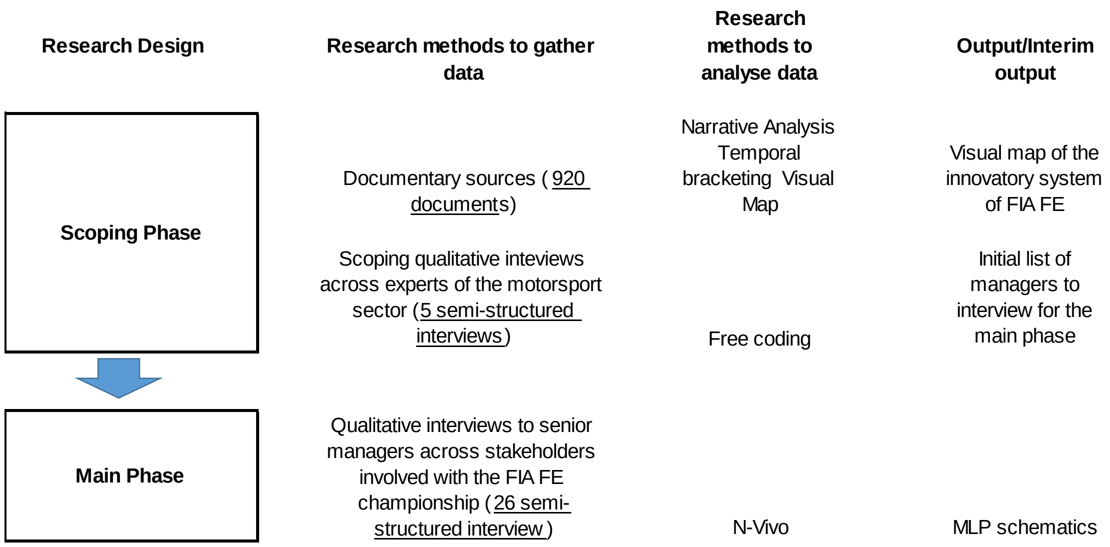

Figure 5 Research Design (author's compilation)

Data from documentary sources and qualitative semi-structured interviews across experts in the motorsport sector were analysed with the help of strategies typically used in business and change management studies (Langley et al. 2013; Langley 1999). The use of these strategies allowed a robust classification of the vast amount of data based on three main categories (regulation, business and technical). The output of this analysis was a visual map of the innovatory system of FIA Formula E, which included events between 2012 and 2017 (chapter 5). Considering the objective of this research, which is studying actors and their relations to understand the dynamics of this low-carbon socio-technical transition, data collected in the scoping phase from documents and interviews informed the initial list of key-informants for the main phase.

The main phase of the research design used qualitative semi-structured interviews to collect primary data to gain an in-depth understanding of the actors and factors involved in FIA Formula E. This is different from the selection process used in the scoping phase of this research design, which was mainly through personal networks.. One of the requirements for this selection was that these people had to be directly involved with Formula E in the time considered by this research (from S0 to S3). Informants from the main phase belong to teams' senior management, technical experts, stakeholders, regulators and sponsors, chosen to cover across different groups, or in the language of the MLP, different regimes. This data collection method accounts for social and cultural influence on the subject of investigation (Bryman 2015).

Whilst the interviews in the scoping phase of this research were manually coded, semi-structured interviews in the main phase were coded using N-Vivo software, due to the richness of data gathered (26 interviews).

Data collection is a fundamental part of research (Bryman 2015). As such it needs to be planned adequately in order to guarantee the validity and measurability of the phenomenon. Table 4-A offers an overview of the methods used against the objectives of the overall research.

Table 4-A Relevance of the data collection methods vs research objectives (author's compilation)

Methods / Objectives of the research	Documentary Analysis	Scoping interviews	Main interviews
RO1: Understand the temporal dynamics of FIA Formula E, defining key moments, events and activities.	✓	✓	✓
RO2: Identify the main factors, events and activities that drive changes in this innovatory system.	✓	✓	✓

Methods / Objectives of the research	Documentary Analysis	Scoping interviews	Main interviews
RO3: Identify actors and institutions through the lens of the multi-level perspective (MLP) to understand how these and their relations facilitate, shape, and enact disruptive low carbon socio-technical transition in the motorsport industry, over time.	✓		✓
RO4: Consider implications for policy for informing strategy building towards coherent low-carbon transformation in other sector than motorsport		✓	✓

4.5 Scoping phase

The scoping phase of the research design has used documentary data and qualitative semi-structured interviews to define key-concepts of this study. The outcome of this combination of documentary data and scoping qualitative semi-structured interviews is the production of a detailed map of events and activities of the innovatory system (Figure 6). This visual map of the innovatory system of FIA Formula E identifies events and activities of FIA Formula E during August 2012 and August 2017, and provides an initial analysis of the actors that shape, facilitate and enact this innovation. This map and the qualitative interviews inform a preliminary list of interviewees for the main phase of the research.

4.5.1 Documentary data

The scoping phase of this research has used both records and documents to carry out a documentary analysis. Lincoln and Guba (1985 cited in Flick 2014: 353) define documents as produced from informants embedded in the research context and in need of interpretation. Records, instead, are created for political and administrative use. This distinction, very similar to the one that classifies documentary data in primary and secondary sources, brought out some ethical considerations concerning gaining access to documents from institutions and governmental organisations (i.e. Formula E Holding). As Bryman suggests, gaining access to institutions is almost always a negotiation referred to as “the research bargain” (Bryman 2015: 60). Often the access is mediated by a gatekeeper that can influence the research with a specific political agenda.

Recognising these influences and limitations ensured the validity and reliability of the data. Data were also scrutinised to assess authenticity and representativeness, due to the tendency of corporate documents to display only positive aspects of the industry and not always reflect reality (Watts 2013). While FIA TWG's reports are closed-access documents and challenging to access, most of the FIA Formula E documents and reports are in the public domain (open access). These reports were mostly published by FIA, MIA, FE, teams and sponsors. Issues concerning the political agenda of these materials were considered, and triangulation of data collected from different data sources was implemented to counteract any possible bias.

Secondary data gathered have included sustainability reports, teams' websites, grey papers[11], press reports, white papers[12] and press releases. Initially, search engines were used to identify these articles, company reports, blog posts and industry reports for gathering insight from various bodies of publicly available documents. The criteria selected for this search was the identification of any documents related to combinations of words used in the research question and the context of this research (FIA Formula E). Specifically, FIA Formula E AND history AND stakeholders AND actors were initially selected as the string to search. The choice of the logical operator AND in the advance search reflects the necessity of all three terms to be true for results to be found. As envisaged, due to the media attention received from Formula E and the motorsport industry, the initial search resulted in 134,000 documents. Information on the temporal dimension of the data needed was added to the search criteria to restrict the number of results. Table 4-B shows four different searching criteria used and the number of results.

As with any research, it was essential to consider the reliability and the validity of the secondary data. Hence only documents coming from well-known and affirmed websites within the motorsport industry were considered, assessing the sources of the data against their longevity, experience of authors and trustworthiness of each publication. Additionally, in order to evaluate the quality of documents, three

[11] Grey papers are studies that are either unpublished or have been published in non-commercial form including government reports, policy statements and issues papers.
[12] White papers are government reports giving information or proposal on a specific issue.

criteria were used (Flick 2014): credibility (the accuracy of the documentation and the reliability of the writer), representativeness (if the document is typical) and meaning (if the evidence is clear).

Table 4-B Documentary search criteria and results (author's compilation)

Search criteria	Number of results
FIA Formula Electric AND history AND stakeholders AND 2012 AND 2013	57,800
FIA Formula Electric AND history AND stakeholders AND season 2014-2015	16,200
FIA Formula Electric AND history AND stakeholders AND season 2015-2016	82,600
FIA Formula Electric AND history AND stakeholders AND season 2016-2017	39,200

These documents were grouped according to the type of source in which they appeared (websites, books, newspapers, grey papers, white papers and blogs). A total of 920 documents were selected and analysed (Table 4-C).

To compliment this search a range of academic and industry publications were accessed mainly from specialist databases such as ProQuest, Business Collections and Science Direct. Besides, books were also used. English, Italian, French and Portuguese (Brazilian)-language publications were considered for this research, due to the unwillingness of using translated documents to avoid alteration on the meaning of the content. Appendix 3 offers a more detailed publication list including dates of searches.

Table 4-C Documentary data bibliography (author's compilation)

Types of secondary documents	Number of documents used[13]	Notes
Newspaper/Media	30	
Specialist publications	316	Motorsport Automotive Business Books

[13] A web article has been considered the equivalent of one document.

Types of secondary documents	Number of documents used[13]	Notes
Websites	543	Teams FIA Formula E Partners Suppliers
Grey papers	12	
Government reports, business and industry reports	4	
Journal, academic papers, academic thesis	7	
Blogs	8	
Total document analysed	**920**	

Strategies to handle process data were used to make sense of the vast amounts of raw data gathered. Amongst those strategies three were selected based on their key-anchor points (Langley 1999):

(1) Temporal bracketing strategy was chosen to help decompose the innovation process into successive periods. Drawing from the structuration theory of Giddens (1984 cited in Langley 1999: 703), the central concept of this strategy is that actions are constrained by structures (formal and informal norms), but they also serve in reconstructing those structures over time. Acknowledging the difficulty in exploring multivariable phenomenon whose effects can be affected by different factors simultaneously, the temporal bracketing strategy, along the same lines as structuration theory, affirms that decomposing the phenomenon in a sequence of events is useful to study how 'actions' in one period have repercussions on decisions in the following period.

(2) Narrative was selected as a sense-making strategy and time and the embeddedness of the temporal dimension within the raw data collected were signposted and selected for their capacity to make sense of the data:. It involves the construction of detailed stories, conceptual models, from the recollection of events from people who have participated personally in the events. The narrative strategy offers an output that

includes the sequence of events, processes and activity of the phenomenon of study but also mechanisms to explain the causal mechanisms (time, place, etc.), focal actors and what the literature has defined as canonical features (Pentland 1999).

(3) Visual mapping strategy allows the visualisation of a large quantity of data efficiently and effectively, within a limited amount of space. By ordering events within a temporal dimension, this strategy produces a sequence that can be used to examine patterns and to observe relationships amongst occurrences and decisions. Hence, visual mapping results in an intermediate step between the raw data and the theory (Langley 1999), and summarises the high degree of complexity of the phenomena, being able to include a multitude of variables within the map.

As suggested by Langley (1999), these strategies were used in combination as "each approach tends to overcome the overwhelming nature of boundaryless, dynamic, and multi-level process data by fixing attention on some anchor point that helps in structuring the material but that also determines which elements will receive less attention" (Langley 1999: 694).

4.5.2 Scoping qualitative semi-structured interviews

The purpose of qualitative semi-structured interviews in the scoping phase of the research design was threefold: (1) to understand the industry experts' perceptions, (2) to capture the complexity of the research phenomenon and (3) to identify key stakeholders, paramount for the exploration of the dynamics of FIA Formula E, informing a preliminary list of interviewees for in-depth interviews (section 4.5). Personal network and snowballing were used to identify and obtain access to 5 UK and European based participants (table 4-D).

Interviews took place between June 2017 and January 2018. Factors such as (1) the number of years these informants worked in the motorsport industry; (2) the level of involvement and knowledge of technical changes within motorsport; (3) the awareness of Formula E and (4) the accessibility of these people, were considered within the selection process. All informants occupied high managerial positions, belonging to what the literature defines as technical and non-technical elites (Nichols and Savage 2017).

Table 4-D Informants to coping interviews (author's compilation)

	NAME	COMPANY	POSITION	TIME/DATE	DURATION (MIN)
1	Informant A	Company 1	Chief Executive	06/07/2017	55:00
2	Informant B	Company 2	President	05/07/2017	42:00
3	Informant C	Company 3	Race Director	14/07/2017	27:00
4	Informant D	Company 4	Technical Expert and Former Technical Director	15/07/2017	32:00
5	Informant E	Company 5	Director of Motorsport	17/09/2017	35:00
TOTAL INTERVIEW TIME					**191 mins 3.18 hours**

The semi-structured qualitative interviews total time was 191 minutes. The choice of semi-structured qualitative interviews was such that the informants were not limited to answering specific questions, but the conversation could flow considering the research and scoping themes that needed to be discussed. As shown in Appendix 4, the questionnaire for the scoping interviews was kept broad, not including questions about FIA Formula E until the very end of the interview. The questions asked to informants were divided into themes, based on the research question and objective of this study (chapter 1). These themes included innovation, motorsport, low-carbon motorsport and technological changes. Contextual definitions of terms such as motorsport, innovation, disruptive innovation and low carbon or sustainable innovation were asked to all participants, in order to gauge the level of understanding and interpretation of key terms of this research.

These qualitative semi-structured scoping interviews were freely coded using an open-code approach (Corbin, Strauss and Strauss 2014), identifying categories and themes. For instance, technological, business and regulatory themes were identified in such a way that could facilitate the explanation of the changes within the temporal dimension considered. The motorsport literature has also addressed those themes as main leitmotifs which are responsible for changes in motorsport's innovatory system (chapter 3). Technology, business and regulation were used to reorganise the data and to produce a visual map of the FIA Formula E innovatory system presented in chapter 5.

4.5.3 Triangulation of methods: Documentation and scoping interviews

During the scoping phase, both primary and secondary source documents and scoping semi-structured interviews were used to collect data in order to avoid tunnel vision (Van den Berg 2008). Additionally, data gathered from interviews were triangulated with the documentary sources to avoid self-reporting bias, halo or horn effect responses (Bryman 2015).

4.6 Main phase

The main phase of this research builds upon the outputs of the scoping phase of this study, reinterpreting the visual map of the innovatory system of FIA Formula E with the lens of the MLP approach. It does so to explore and understand actors and actors' dynamics and to answer this thesis research question (chapter 1). This phase used additional qualitative interviews to capture individual experiences (Patton 1990) of key-informants that were or are directly involved with the phenomenon, during the time scale considered (from S0 to S3), to understand deeper relations and changes within the system.

As the primary purpose of these interviews was acquiring empirical data to provide an insight into actors and actors' dynamics, a discriminant factor for the selection of representative sample groups was direct involvement. Informants were selected from an initial list compiled with the help of the output data from the scoping phase. Senior managers were favoured in order to increase the reliability of the data gathered. Teams' websites, FIA and Formula E's websites were used to determine the level of seniority of informants. The list also included journalists and technical experts due to their influence and direct involvement with the FIA Formula E championship. Care was taken to choose a balanced sample of interviewees to include informants from technical, sporting, management, marketing and research areas. The need to balance the interview sample within actors belonging to, in the language of the MLP, different regimes, was fundamental to have a full understanding of the phenomenon.

Although this study recognised the clear role of consumption within this phenomenon, categories such as consumers and users were not interviewed directly due, for the first category to the pragmatic difficulty in reaching a significant and representative sample within the time of this research, and for users to the sudden unavailability at the time in which interviews took place. Specifically, racing drivers were the main representative within the user category and, although every effort was made to book time in advance with them during Marrakesh E-Prix, a chain of events, such as race incidents and last minutes race meetings, resulted in their unavailability for interviews. Instead, after an initial analysis of data gathered from interviews to experts and journalists, after checking their alignment with users' and consumers' data from the scoping phase of this research, it was decided that industry experts and journalists could act as a suitable proxy as their interviews provided some insight on 'the consumer and user regime', as presented in section 6.3.2.5.

Defining the sample size of interviews has been addressed in academia as one of the main problems with qualitative interviews (Bryman 2015). Although it is crucial to ensure that enough interviews are carried out, their number needs to be meaningful and not too large. This research has used saturation as a way to establish when to terminate the process of interviewing. Hence, the informants' sample was considered significant enough when questions were generating very similar answers and, therefore, were not supplying any additional information to this research. To reach this point, it was essential to maintain the consistency of the themes around which interviews revolved.

Twenty-six key informant interviews took place between July 2017 and January 2018. During the Marrakesh e-Prix, between 11th January and 14th January, I interviewed seventeen key-informants. Other interviews took place on different dates and locations, as detailed in table 4-E. Two of these interviews (informants N and W) were conducted on the format of what the literature defines as 'walking interviews' (Evans and Jones 2011). Although these two walking interviews were not recorded, notes were taken on the spot. Another informant requested that the interview was not audio-recorded (informant F), resulting in notes having to be taken manually while interviewing. Even though they are accurate, the notes taken from the walking interviews and the non-audio-recorded interview presented limitations, such as the transcript could not be checked against the original conversation at a later date. Twenty-three (23) interviews were audio-recorded and field notes were taken contemporaneously.

Table 4-E supplies the complete list of interviewees. Interviewees highlighted in bold did not agree to be audio recorded. Each interview lasted between 15 and 80 minutes, resulting in a total of 852 minutes of interview material.

Table 4-E Key informants to qualitative interviews in the main phase (author's compilation)

	NAME	COMPANY	POSITION	DATE	INTERVIEW DURATION (MIN)
1	**Informant F**	**Company 6**	**Sustainability manager**	**18/07/2017**	**52:00**
2	Informant G	Company 7	Partnership manager	05/09/2017	75:01
3	Informant H	Company 6	CCO	11/01/2018	38:50
4	Informant I	Company 3	Sporting Director	11/10/2018	25:50
5	Informant L	Company 8	Former Technical Director and Head of R&D	11/01/2018	23:29
6	Informant J	Company 6	Technical Director	11/01/2018	20:22
7	Informant K	Company 9	Managing Director and former project support leader	12/01/2018	18:06
8	Informant M	Company 10	Managing Director	12/01/2018	28:59
9	**Informant N**		**Expert and Presenter**	**22/01/2018**	**68.59**
10	Informant O	Company 11	Sporting Director	12/01/2018	19:11
11	Informant P	Company 12	Head of Performance Programs and Team Principal for FE	12/01/2018	34:31

	NAME	COMPANY	POSITION	DATE	INTERVIEW DURATION (MIN)
13	Informant R	Company 13	CCO	12/01/2018	26:37
14	Informant S	Company 3	Technical Delegate	13/01/2018	16:38
15	Informant T	Company 6	Sporting Director	14/01/2018	28:58
16	Informant U	Company 3	Technical specialist	14/01/2018	27:34
17	Informant V	Company 3	Project Manager FE	14/01/2018	37:53
18	Informant X	Company 14	CTO	14/01/2018	68:31
19	Informant Y	Company 15	COO	14/01/2018	38:47
20	**Informant W**	**Company 16**	**Sporting expert**	**14/01/2018**	**25:00**
21	Informant AA	Company 16	Senior Engineer FE program	18/01/2018	41:32
22	Informant AB	Company 17	Former Director	18/01/2018	37:49
23	Informant AC	Company 18	Journalist	22/01/2018	41:43
24	Informant AD	Company 19	Group CEO	26/01/2018	28:02
25	Informant AE	Company 20	Head of Communication	29/01/2018	26:29
26	Informant AF	Company 3	Policy actor and technical expert	30/01/2018	42:04
TOTAL INTERVIEW TIME					**858: 02** 14 h 18 m and 02 sec

All key-informants were interviewed in their place of work, either at their headquarters or at the racetrack, acknowledging Elwood and Martin's (2000) view that the interview location is significant within this research method.

> “The interview site itself embodies and constitutes multiple scales of spatial relations and meaning, which construct the power and positionality of participants in relation to the people, places, and interactions discussed in the interview”. (Elwood and Martin 2000: 649)

Specifically, I attended the FIA Formula E race in Marrakesh, interviewing 17 informants in 4 days at their temporary offices. Races are temporary and temporally well defined, and co-locate in the same space many actors from the same network. This concept of temporary offices and its relations with knowledge creation is well known to economic geographers (Maskell, Bathelt and Malmberg 2004; Palmer, Medway and Warnaby 2017; Rinallo and Golfetto 2011). These studies recognise the significance of Temporal-Spatial Cluster (TSC) for shaping and facilitating business creation and bringing together networks of actors. Hence a race can be seen as a TSC and an appropriate place to interview informants.

Being part of the sector meant I was able to take advantage of the TSC phenomenon to hold a substantial number and variety of research interviews and conversations in the niche of time available on the 4 days. My familiarity and relationship with this group of interviewees and my embedded knowledge of the sector allowed this process to be a highly effective and efficient mode for data collection. This favoured access was a result of my positionality (4.3) but equally must be recognized. During semi-structured face to face interviews, Flick (2014) suggests reflecting on intimidation and power barriers between interviewer and interviewees, in terms of how certain places could be more intimidating than others (Flick 2014). Due to my embeddedness in the motorsport industry (section 4.3), conducting interviews at a racetrack during a race weekend has not been any different than conducting those interviews in offices. Rather, it has saved significant time and has allowed greater access to informants.

In consideration of the expected richness of the data gathered from these in-depth interviews, a semi-structured interview process was selected as most appropriate, and a formal set of pre-prepared questions was produced (Appendix 5). These questions aimed to assist the conversation still allowing fluidity in clarifications or diversion, ensuring that the full view of the informants was conveyed. The questionnaire included themes and categories that were uncovered during the scoping phase, mainly centered on FIA Formula E, stakeholders and temporal dynamics, as explained in the next section.

Rather than using semi-structured interviews, a survey or a digital data collection (through a LinkedIn discussion group) could have been used to minimize biases and reaching out a bigger sample. Aside of increasing the amount of data generated, these methods alone would not have guaranteed that the correct sample of people would have been reached. Checks could have been put in place, resulting in a more time consuming way to acquire the information needed. Whilst a survey and a digital data collection could have been useful to complement semi-structured interviews, time was a constraint of my PhD. Hence these methods were disregarded in favour of rich and in depth semi-structured interviews to senior managers.

I have personally transcribed all interviews due to the specificity of the subject. Each transcript was then corroborated against field notes taken at the time of the interviews. Interviews conducted in Italian (2) and French (2) were translated into English to ease the process of coding. The interviews that were not audio-recorder due to the request of key-informants, were written out and imported into N-Vivo.

Due to the overall number of key-informants' interviews and in order to make full use of the richness of the data, all interviews from the main phase of this research were coded using N-Vivo, a computer-based program which allows the researcher to code and to retrieve text (Bryman and Bell 2015). Appendix 6 supplies an example of this process.

4.6.1 Nvivo coding framework

Nvivo is a powerful qualitative data analysis software (QDA) that has been used in this research to code categories, sub-categories, concepts and relationships within the 26 additional interviews (Corbin, Strauss and Strauss 2014).

Aware that automated programs for coding do not analyse the data but impound the collecting, sorting, cutting and rearranging tasks which qualitative researchers used to do with note cards, scissors and paper (Weitzman and Miles 1995), I created a strategy to add information to the research question and objectives. Figure 6 shows this strategy and highlights the iterative nature of the coding process using N-Vivo software. The amount of data gathered and their richness was the main reason behind the use of N-Vivo for processing the information.

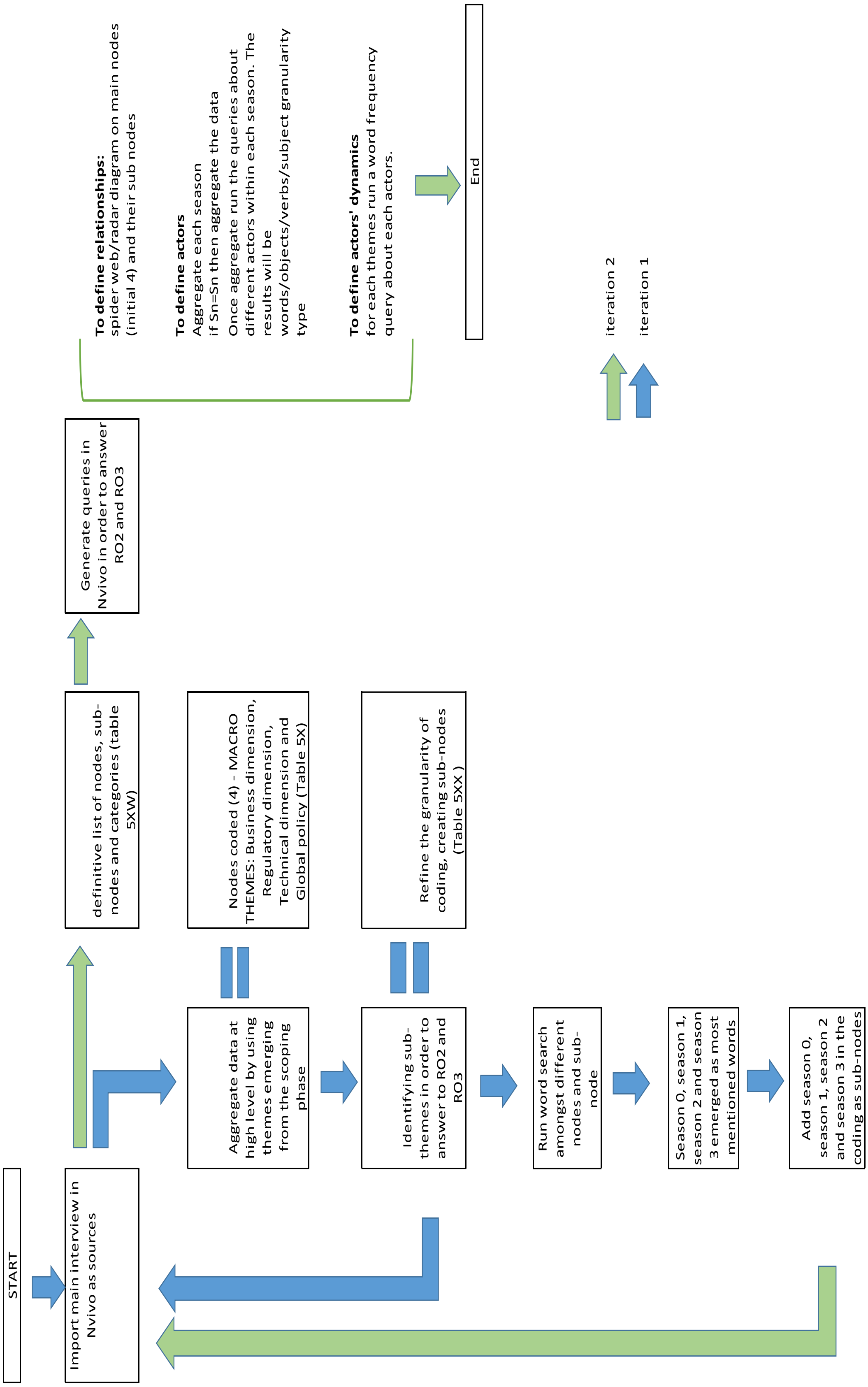

Figure 6 N-Vivo coding framework (author's compilation)

During the first phase of coding of interviews, a provisional star-list of codes (nodes) before fieldwork was generated (Miles et al. 1994). This first list originates from the scoping phase of this research, which supplies the main themes and the concept of seasons as outputs in the analysis of the documentary data and scoping interviews. The star-list was checked against the additional data and nodes were generated in accordance (Table 4-F).

Table 4-F List of themes (first category) (author's compilation)

1	**Regulatory**	**Descriptive information on how the rules are proposed and enable in FE**	**RO2**
2	Technological	Descriptive information on the technological context and actors involved in the technological dimension	RO2
3	Business	Descriptive information of the actors behind the business model of FIA Formula E	RO2
4	Time/season	Descriptive information about the changes between seasons on actors and tasks/rules	RO2/RO3
5	Global policy	Descriptive or inferred information on the influence of global policy and socio-economic landscape in shaping and enabling the innovation	RO2/RO3

Conscious of the richness of the data and the need to overcome biases in interpretation, other nodes and sub-nodes were added to this initial coding framework. Specifically, using functions as identification of the most used words and frequency of words in each transcript made this process of coding additional nodes and sub-nodes far more relaxed. N-Vivo offers ways to visualise the most used words and relations between nodes and sub-nodes which were considered useful to investigate these transcripts further. Figure 7 presents an example of the graph of the most used words.

Although functions of the N-Vivo software allow generating an initial list of additional nodes and sub-nodes, it was only by reflecting on these nodes and sub-nodes, scrutinising the coded textual materials and their link with the research question and objectives which allowed refining the initial list of nodes to a more significant and compact one.

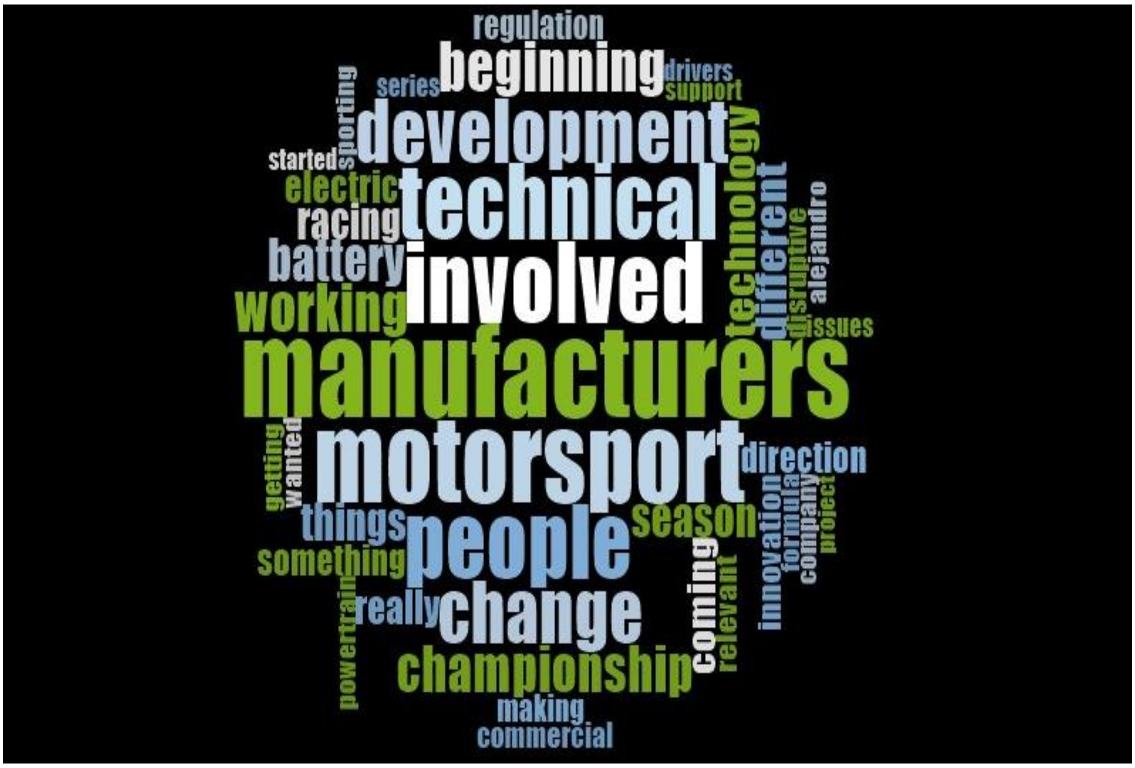

Figure 7   N-Vivo graphical visualisation of the most used words in transcripts (author's compilation)

To help this interactive process, two functions of the software were useful: the function which provides for each node all relevant extracts of the transcript interviews and the function which clustered nodes by word similarity. Whilst the first function was used to refine the nodes and sub-nodes bearing in mind the scope of this study, the second was used to understand relationships and their intensity amongst nodes and sub-nodes, ensuring that those categories where coded robustly. The outcome of this refinement can be observed comparing table 4-F with the new table 4-G.

Once all the interviews were coded, they were reviewed using a grounded approach (Glaser and Strauss 1967) in search for any part of the text that referred to new nodes and sub-nodes.

As N-Vivo allows for different ways to analyse text, I have used most of them in an attempt either to generate findings or to validate them using idea generation and visual data harvesting techniques (Meadows 1992). Specifically, I have used techniques such as network charts, matrices, a hierarchical chart and words frequency tables to underlined nodes and sub-nodes.

Table 4-G Themes and subthemes (second categories) which have emerged from the initial coding (author's compilation)

Users/fan/ fan engagement	**Descriptive or inferred information on the role of users for shaping and enacting innovation**	**Sub-themes**
Technology road map	Descriptive or inferred information of the technology road mapping process in FIA FE	When coding this was found to be a **sub-themes**, included in vision and strategy theme
The relevance of FIA FE for automotive/motorsport/society	Descriptive or inferred information on the relevance of FIA FE to the sectors/industry/content described	Sub-themes of the themes Relevance of motorsport
Adoption of innovation	Descriptive or inferred information on the role of motorsport as a vehicle to promote energy issues and mobility transformation	Sub-themes of 5
Governance	Descriptive or inferred information on governance structures, changes to structure, accountability and governance frameworks	Themes RO3 RO4
Technology	Descriptive or inferred information on levels of technology available during the temporal dimension considered (inferior technology of DI)	Sub-themes to 2 RO1 RO2
Vision and strategy	Descriptive or inferred information on the approach to setting and delivering on the FIA FE vision and strategy	Themes RO3 RO4
Disruptiveness of innovation	Descriptive or inferred information on the disruptiveness of FIA FE	Themes
Regulatory model of F1	Descriptive or inferred information about the regulatory model of F1	

The word frequency and the word search were particularly useful in identifying actors to build the MLP's schematics (chapter 6). These findings were triangulated using the N-Vivo functionality which allows aggregation of all the sub-nodes dealing with the temporal dimension and launches a word search on specific actors (i.e. all the sub-nodes named S0 were aggregated. Then a single word search with the word FIA was conducted. The output of this search generated many quotes, all containing the word FIA. These quotes were used to understand at which MLPs' level and in which regime different actors were sitting during season zero. The same process was repeated for all the other seasons).

4.6.2 Ethnography and narrative technique as methods

Ethnography is a qualitative method used to study culture, communities and organisation where the researcher is embedded in the community or the organisation (Bryn 2015). This method, first used in anthropology, involves living in the community or working in the organisation researched, and learning their language, their culture in order to understand the 'emic' perspective, the native point of view of a specific culture. Due to my positionality within the motorsport industry (section 4.3), and my ability to collect first-hand experience, I considered ethnography but decided against it. Nevertheless, I did need to recognise that my position within the sector did support my research (see section 4.3). Indeed, being embedded in the industry allowed me deep and rich access to senior interviewees. This was reflected in my decision to allow my data analysis, especially in chapter 6, to follow more closely to a narrative technique.

Narrative is generally regarded as universal mode of verbal expression (Bruner and Kalmar 1998) and it is used in academia as a method to understand data preserving their context and particularity (Bryn 2015). Its advantages are that it supports insight that befits the complexity this phenomenon and x and y.

This, in chapter 6, whilst I have constructed the analytical narrative I have used substantial verbatim quotes as a key form of data; chapter 6 provides accounts of personal experience from senior managers involved directly with FIA Formula E and my embeddedness within the sector, alongside reflections on my positionality, allowed me to have analytical confidence in these quotes and the narrative technique more broadly., Narrative methods have been criticized due to a possible lack of analytic goal. Ellis, Bochner and Tillmann-Healy (2000) affirm that "if you are a storyteller rather than a story analyst then your goal becomes therapeutic rather than analytic" (2000: 745). Other scholars (Atkinson and Delamont, 2006) have pointed out that narrative is not a method to discover the truth as it is based on the informants' experience which is often constructed through other people's stories. Hence, the use of narrative must be complimented with supporting evidences and arguments to gather consistent and reliable data.

4.7 Measurement validity, internal and external validity

A crucial issue to consider throughout the research was assessing the quality of the research. Mason (1996) argues that reliability of the data, validity (internal and external) and replicability "are different kinds of measures of the quality, rigour and wider potential of research, which are achieved according to certain methodological and disciplinary conventions and principles" (Mason 1996: 21 cited in Bryman 2015: 383). Hence, posing the question about the internal validity of this research is implicitly asking if the overall research design is capable of detecting causal relationships when they exist. In detail, this research design (section 4.4) has ensured the identification of dependent and independent variables; and that those followed a specific order (the test of temporal order); were connected (the test of association), and any of the rival explanations of the dependent variables were ruled out (the test for spuriousness). Specifically, the test for spuriousness has included reviews of interim research outputs from some field experts, in an attempt to gauge their interpretation of data and gather feedback.

In terms of external validity, this is concerned with the extent to which the findings can be generalised across other social settings. This research acknowledges that further research is needed to be able to broaden these findings to other sectors. However, drawing from Flick's (2014) suggestion, to ensure validity and generalisation, appropriateness of the methods and the choice of theories, perspective of each participant and their diversity, reflexivity and variety of methods used to gather and to analyse have been included in the research design, as mentioned in section 4.4, 4.5 and 4.6.

4.8 Conclusion

This chapter has given a detailed explanation of the research design and the choice of research methods to gather and analyse data. Firstly section 4.2 has discussed the philosophical orientation of this research, critical realism, its ontology and epistemology. Section 4.3 has presented my positionality, including its influence on the choice of this research design and methods, ethical issues and how these were dealt with within the PhD. Finally, section 4.4, 4.5 and 4.6 has detailed the research design and the research methods used to gather and analyse data. This research design has included two phases in a linear progression (the scoping phase and the main phase). The choice for different research methods for collecting and analysed data was made in the awareness that the robustness of the process lay in the possible triangulation of the data (Bryman 2015; Flick 2014), which was discussed in the chapter.

The next two chapters report on the outcomes of this research design. Specifically, chapter 5 will discuss data from the scoping phase of this research and chapter 6 will present data and findings from the main phase of this study.

5. Scoping the innovatory system of FIA Formula E

5.1 Introduction

This chapter provides a narrative for the innovatory system of FIA Formula E answering two objectives of this research (Table 5-A).

Table 5-A Research objectives 1 and 2 of this study

RO1: Understand the temporal dynamics of FIA Formula E, defining key moments, events and activities.
RO2: Identify the main factors which drive the change in this innovatory system

Drawing from documentary data and scoping interviews, this chapter recounts events and activities, explaining how the introduction of FIA Formula E has not been merely concerned with technical advancement but has included social, political and economic factors (Bijker, Hughes and Pinch 2012; Freeman 1989; Perez 2010). These factors have all played, in turn, and/or in combination, an essential role in shaping and enabling this low-carbon transition in the motorsport industry.

Section 5.2 opens this chapter by presenting a visual map (Figure 8) that is the output of the data from the scoping phase of this research. This map summarises events and activities of FIA Formula E from season 0 to season 3 clustered around three key-themes, in line with the literature in chapter 2: technology, regulation and business.

Following this, section 5.3 unpacks this map offering a narrative of the dynamics of FIA Formula E through the lens of documentary data and scoping interviews. Borrowing terms from theories of technological change (chapter 2) and particularly from the theories of Sahal (1981) and Foster (1986), this section rearranges the data around the infancy (S0 and S1) and the growth phase (S2 and S3) of FIA Formula E. It is this extended concept of life-cycle that this chapter takes into account when referring to these phases. Section 5.4 provides a summary of this chapter.

In order to generate a representation of the innovatory system of FIA Formula E that was robust and significant for the operationalisation of the MLP approach (chapter 6), strategies to process data were chosen to build upon (chapter 4).

Specifically, data were analysed and reorganised using three strategies from theorising process data (Langley 1999): (a) temporal bracketing, (b) narrative and (c) visual mapping.

A note regarding the use of language in the interview quotes is necessary at this point: some quotes are grammatically incorrect and include jargon or repeated terms. However, to preserve the original nature and authenticity of the interviews, all the quotes have been left unedited (verbatim quotes) in terms of language and grammar.

5.2 Mapping the innovatory system of FIA Formula E

The outcome of the scoping phase of this research is the visual map presented in Figure 8. This visual map organises the primary structure of the data gathered outlining the high degree of complexity of FIA Formula E from S0 to S3. Those events and activities, which form the innovatory system of FIA Formula E, are clustered around three themes (1) business, (2) sporting and regulation and (3) technology, which are represented in the Y axis. These three themes were chosen in accordance with the literature in chapter 2 and specifically considering theories from Nelson and Winter (1982) and Dosi (1982) in which both economic and technical parameters are a key sources of variation, and TEP (Perez 2010), for which the institutional sphere is important for the understanding of changes in business models.

The X-axis of this map (Figure 8) uses seasons to decompose FIA Formula E into sequences of events and to study how 'actions' in one period have repercussions on decisions in the following period (Giddens 1984 cited in Langley 1999: 703). As already outlined in chapter 3, the concept of seasons is a well-established temporal dimension within the motorsport industry, used to measure changes and performances across time (Jenkins 2010; Jenkins and Tallman 2010; Papachristos 2014). Data from the scoping phase of this research has confirmed that season is the unit of the temporal dimension of the motorsport industry. Though, in this research context, seasons appear to have a different connotation from the one that this term holds in traditional motorsport. Traditional motorsport refers to seasons as periods of time running from February to November of the same year. Contrarily, data gathered have shown how, in FIA

Formula E, seasons run from August/September to August of the following year (chapter 3), if including tests, or October to June if considering only a racing season. The extract below, from the director of motorsport of a technology company, clarifies this concept.

> “Season is a concept very much related to a championship, and it can really be defined as a function of the championship. Most seasons start with winter testing, in January or February, and end in November, these days. […] In FE the seasons are a bit out of phase as they start in September, October or November and they go on until June or August.” (Informant E)

Events and activities were colour coded to ease the reader’s understanding of the visual map. Events and activities linked to The Global Challenges (chapter 1) were highlighted in green, whilst events and activities related to the business model of FIA Formula E were highlighted in orange. Blue was used for coding events and activities involving technology, including change or rules. Events and activities involving Governance and policies were coded colour in pink.

The whole visual map is presented to give the reader an understanding on how these themes changed, during the infolding of FIA Formula E.

Due to the richness of the data presented in the map, it was necessary to slice the visual map into six sections for allowing the reader a better understanding of the impact that activities and event had in the dynamics of FIA Formula E. The first five sections (Figure 8A to Figure 8D) refer to part of the map presenting on the Y axis of the graph Sporting/Regulation and Business related activities from Season 0 to the end of Season 3.Figures 8E and 8F refer to the bottom part of the visual map, which details change in technologies during the seasons considered.

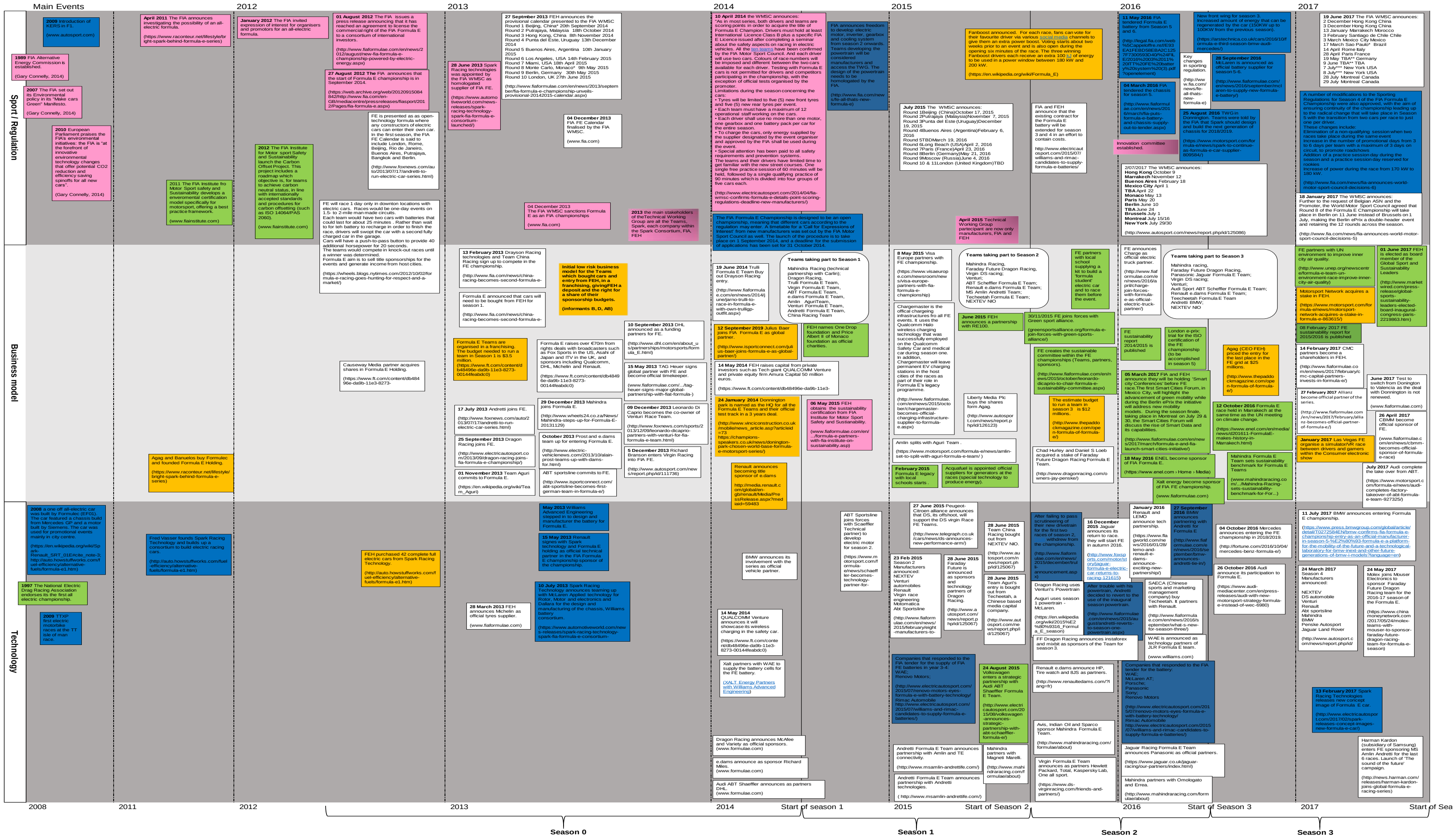

Figure 8 *Visual map of the innovatory system of FIA Formula E (author's compilation)*

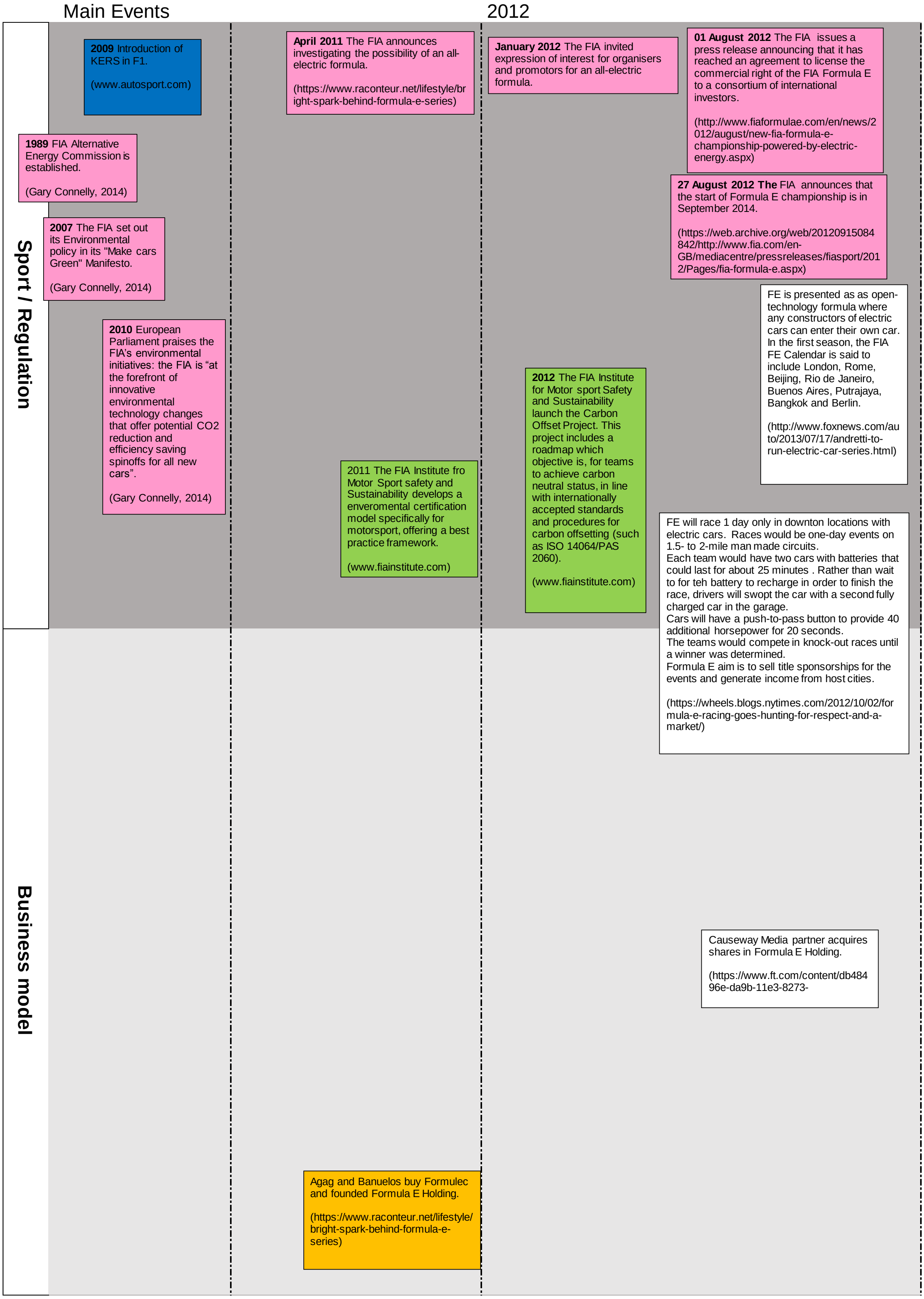

Figure 8A: Slice of the visual map to ease the reader's comprehension

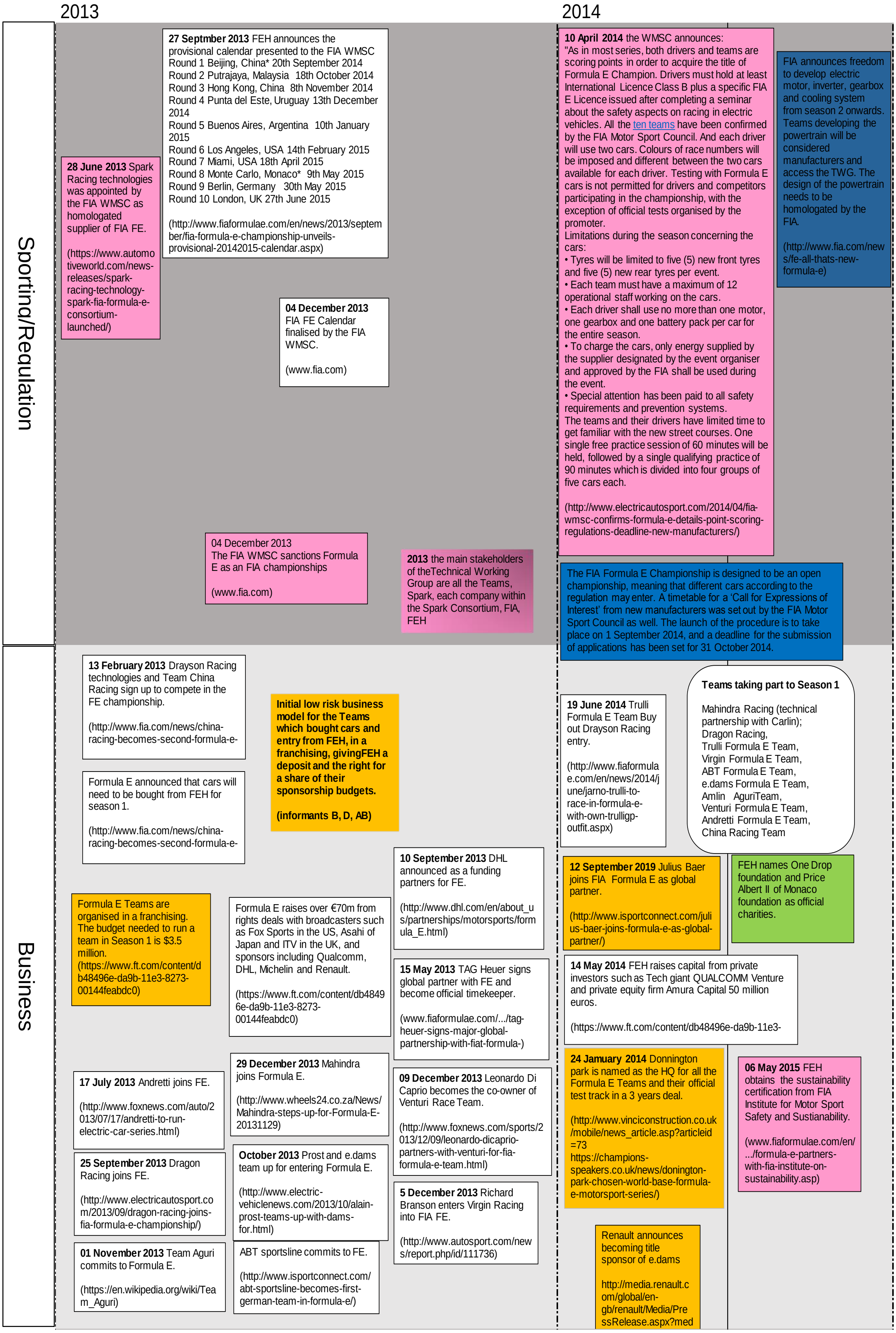

Figure 8B: Slice of the visual map to ease the reader's comprehension

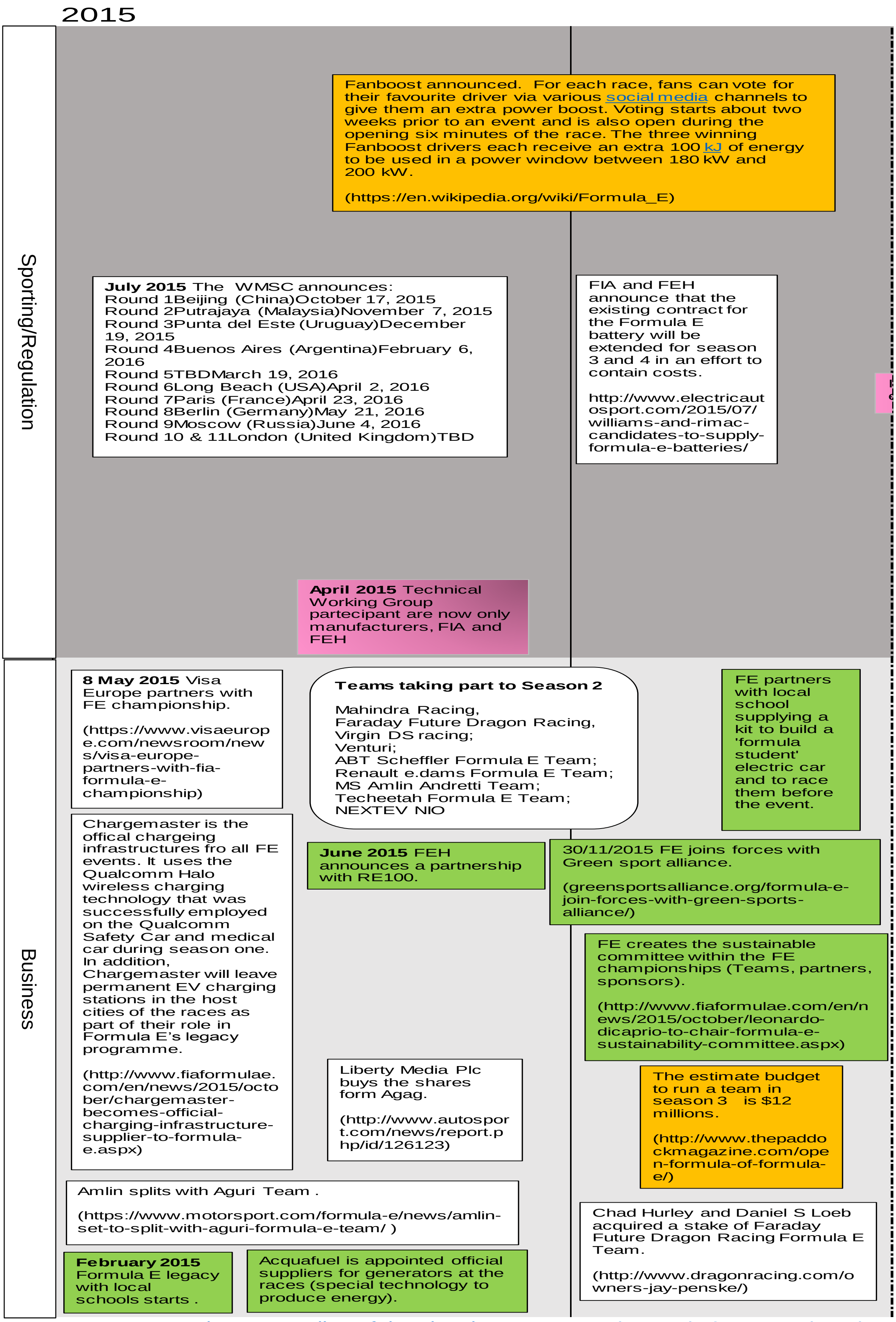

Figure 8C: Slice of the visual map to ease the reader's comprehension

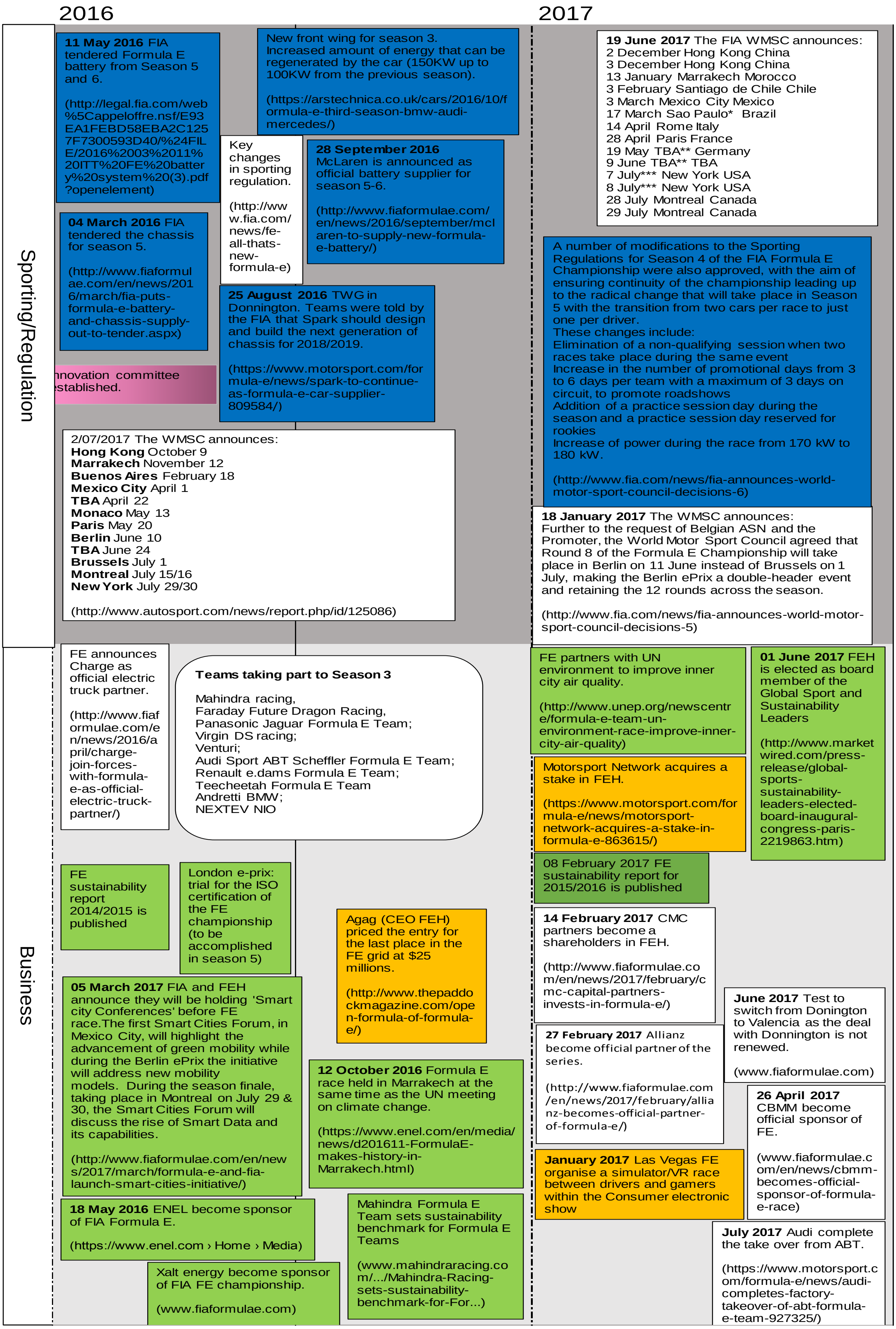

Figure 8D: Slice of the visual map to ease the reader's comprehension

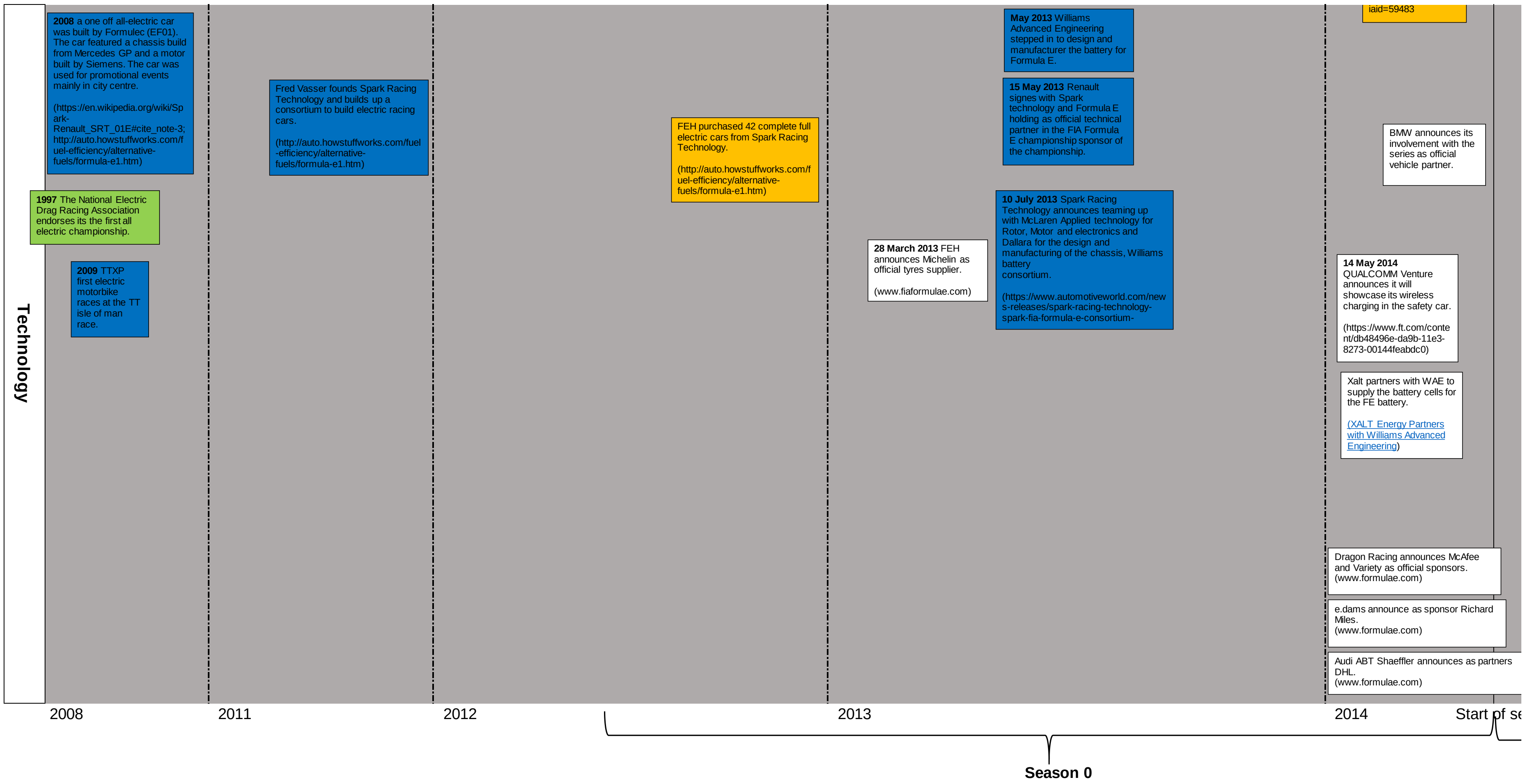

Figure 8E: Slice of the visual map to ease the reader’s comprehension

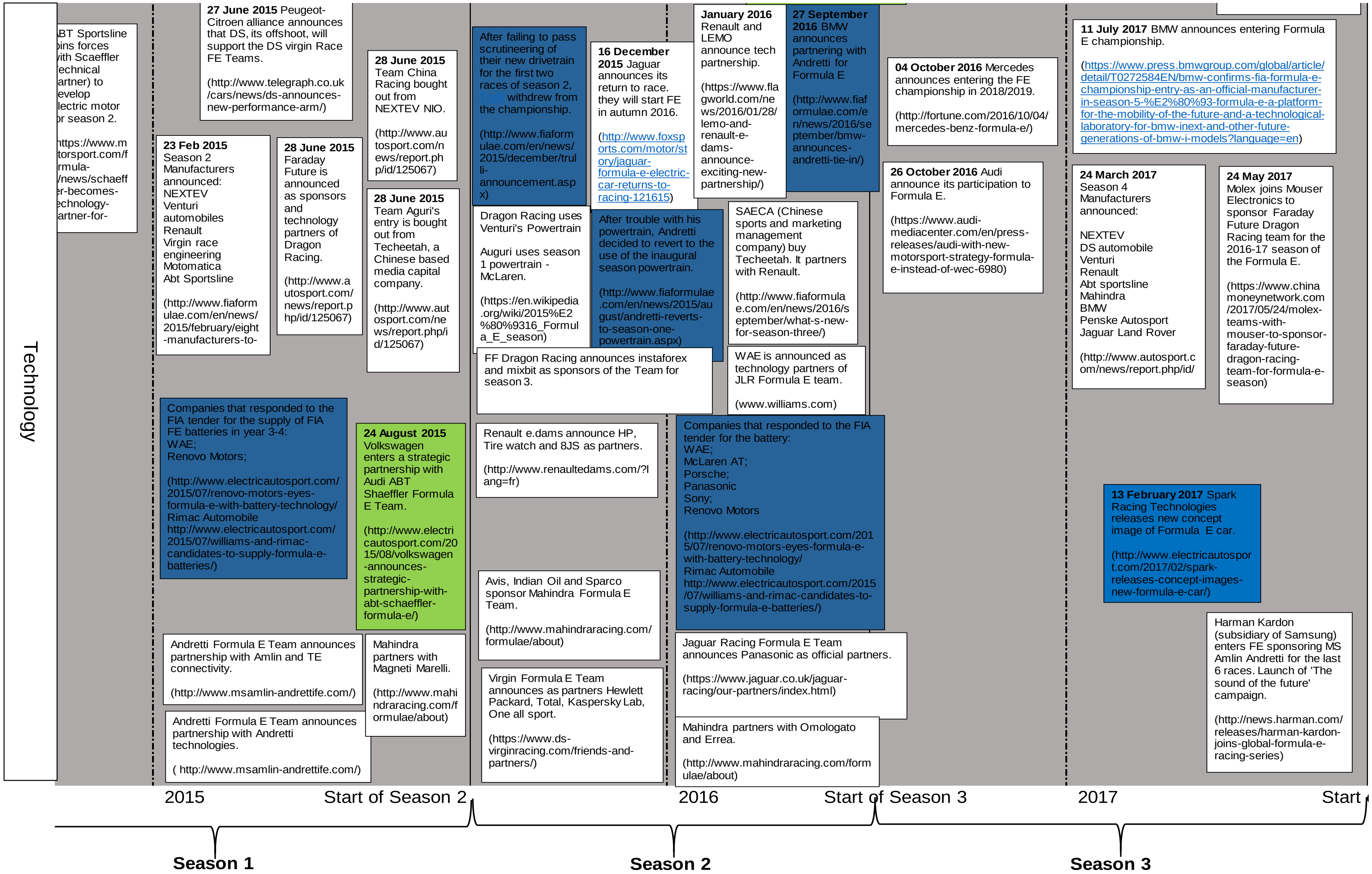

Figure 8F: Slice of the visual map to ease the reader's comprehension

5.3 Exploring the dynamics of FIA Formula E

The following two sections walk the reader through the visual map given in Figure 8, 8A, 8B, 8C, 8D, 8E and 8F, exploring factors, actors and events that have contributed to its shape and drive and enabled this low-carbon transition. These factors, actors and events encapsulate the innovatory system of FIA Formula E and are highlighted in bold in the text.

Drawing from Foster (1986) and its concept of phases of innovation, section 5.3.1 presents the narrative of the infancy phase of FIA Formula E (figure 8A, 8B, 8C, 8E and 8F), detailing season zero (August 2012 - July 2014) and season one (August 2014 – August 2015), whilst section 5.3.2 (figure 8D and 8F) discusses the growth phase of innovation, narrating season two (September 2015 - August 2016) and season three (September 2016 - August 2017).

5.3.1 The 'infancy phase' of FIA Formula E: season 0 and season 1

Figure 8A, 8B, 8C, 8E and 8F illustrate in details the infancy stage of FIA Formula E. Identifying the main events and activities of the infancy phase of FIA Formula E has proven difficult due to the number of press releases and storytelling generated post-hoc, in order to fill different agendas. Within the 920 documents analysed, less than one third were issued between season zero and the beginning of season one. Truthful and coherent information about how the idea of an electric formula started was difficult to trace. Many versions of the story exist, including the FIA being fully committed to a switch to low-carbon and electric motorsport (Biesbrouk 2014) and the story in which Tajani (EU president in 2012), Todt (FIA President) and Agag (FEH) had the idea of this completely new championship at a dinner table in Paris (Formula E Holdings 2012). However, it is not the scope of this research to debate which event marked the start of this 'electric revolution' (informant B) but, rather, to investigate the factors and actors which have shaped, facilitated and enacted this innovation. The official FIA press release, issued on the 28th of August 2012 (Figure 8A), is considered, for this research, the starting event for season zero (Appendix 7). This announcement identifies the main actors involved in this phenomenon.

> “The Fédération Internationale de l'Automobile (**FIA**)[14] has reached an agreement to licence the **commercial rights** of the FIA Formula E Championship to a consortium of **international investors**, Formula E Holdings Ltd (FEH). […] **FEH**, the **new promoter**, has as anchor investor London-based entrepreneur **Enrique Bañuelos**, and as CEO and shareholder **former MEP** and **racing team owner Alejandro Agag**, who has a long experience in the **motorsport business**. Also associated with the project are **Lord Drayson**, Managing Partner of Drayson Racing Technologies, and **Eric Barbaroux**, Chairman of the French **electric automotive company** Electric Formula”. (FIA Formula E 2018a)

Alongside quotes from Todt and Agag, the press release includes a comment from Dr Professor Goeschel, President of the **FIA Electric and New Energies Championships Commission**, which addressed the long-term interest of the FIA in sustainability and technology-relevant championships.

> “Formula E will be a milestone for the future of motorsports, driven by the FIA. It follows the **global megatrends** of our world, like **sustainability**, the growth of the **megacities** and the **digital** world of **connectivity**. I would like to say thanks to all **partners**, who supported us in creating this new project and also to the partners who will accompany us to a successful launch of Formula E.” (Goeschel 2012 cited in Appendix 7)

If at the time, Todt and Dr Professor Goeschel were established actors in **institutional** positions within the motorsport industry, respectively as FIA president and as president of the FIA Electric and New Energy Commission, the press release presents another important actor for the FIA Formula E championship: Agag. He is defined from documentary sources as:

[14]As already mentioned throughout this research, innovation comprises of a multitude of factors. Words in bold highlight the factors, actors and organisations, which are important for understanding the dynamics and the temporal dynamics of this phenomenon. This criterion will be used in the entire chapter 6. These factors will be then summarised in section 6.5, which conclude this chapter.

> “A former member of the **European Parliament**, soccer club chairman, and boss of a GP2 (another **motor-racing** championship) team, Agag is well connected in European sports. […].” (Mirani 2014b)

Aside from traditional motorsport actors and politicians, the analysis of the data outlines how the main investor in this project was, in S0, London-based entrepreneur **Banuelos**, a billionaire **businessman** who made his fortune within the real estate business in Spain and Brazil. Informant B, president of the proving ground and testing facilities explained.

> “It was just a very clever investment. The foundation of all **commercially good enterprises** is somebody who takes the risk.” (Informant B)

The analysis of primary documents shows that the FIA Formula E was technically conceived as an open championship. The first draft of the FIA Registration procedure for the supply of cars in the FIA Formula E championship (FIA 2012), includes paperwork for each team to apply for the homologation[15] of a fully electric car to race (Figure 8D). When Lord Drayson announced his intention to enter a team in the FIA Formula E championship, he is reported to have been very enthusiastic about the technical rules being so open.

> “From 2015, the team plans to be a **constructor** in its own right fielding a new drivetrain developed from the advanced DRT 4X2-640 electric system featured in the **Lola-Drayson** B12/69EV car that set a new electric record this summer at the Goodwood Festival of Speed.” (Lord Drayson 2012 cited in Krivevski 2013)

Data describes **the technology model** of this championship in season zero as an **open multi-chassis** and **multi-powertrain** series.

> “FIA’s objective is to develop a **multi-brand championship.**” (FIA 2012)

[15] Homologation is a process to certify and approve a product confirming that it meets certain standards, in this context the FIA standards.

However, key-informants agree that if FIA Formula E would have been implemented as an open championship, the **barriers to entry**, **financial** and **technological,** would have been too high for the championship to attract teams (Informant A).

The documentary analysis shows how, in June 2013, to reduce these barriers to entry, the FIA World Council Motorsport approved the application for the homologation of Spark Racing Technology as a single supplier for season one (Automotive World 2012).

> "Formula E Holdings (FEH), the **official promoter** of the new FIA Formula E Championship, has announced the **purchase of 42 electric Formula cars** from the newly formed company, **Spark Racing Technology** (SRT). The cars will be used in the Formula E Championship inaugural race in 2014." (Formula E Holdings 2012)

The involvement of SRT's shareholders with FEV is not new to the motorsport industry (Figure 8E). Data shows that ART Grand Prix, an established French Team competing in the main single seater categories, owned by Vasseur, was previously involved in the running of a fully electric racing car on behalf of a company called Formulec (between 2008 and 2011). Together with Segula Technologies Group, Formulec developed a **technology demonstrator** of a fully electric single-seater, which was presented at the 2010 Paris Motorshow (Gaignault 2010). The 100% electric single seater was built over a period of 2 years, using a Mercedes AMG Petronas Formula One chassis, two Siemens motors, Shaft cells technologies, Hewland gearbox and Michelin tyres and was designed to demonstrate that full-electric technology had a similar performance to ICE technology and, amongst all, that it was ready to race (Gaignault 2010). It was with the help of ART Grand Prix, and its drivers Bianchi and Premat, that the EF01 was developed and fine-tuned to reach a maximum speed of 250 km/h and an acceleration from 0-100km/h in 3 seconds, which made this car the quickest electric monocoque in the world, at that date (Gaignault 2010).

Data shows that, in 2011, Formula E Holding (Banuelos and Agag) acquired Formulec and its **technology** (Figure 8B), renaming it Electric Formula and incorporating its people within FEH organisation (Belson 2012). It is Formulec car, its technologies dated 2010, that was used initially to demonstrate FIA Formula E to the governing body of motorsport.

The **technical regulation** of FIA Formula E for season one (Figure 8E) reflected this change of technological trajectory from an open championship to a **single maker** championship, as the extract below outlines.

> “In one respect [FE] is a traditional racing series, you have **one organiser**, **single maker cars**, teams competing with each other for the teams’ and the drivers’ championship”. (Informant A)
>
> “All teams will be required to use a **common chassis** being developed by Renault together with Spark Racing Technologies. Named Spark-Renault SRT_01E Formula E, it will feature **technology** from a range of **different companies**. […] Once the championship has got off the ground, the organisers will make Formula E an open series in its second year. This means that each team will be free to develop its own car, with whatever configuration of electric motors, batteries and charging systems that they believe will give them the biggest advantage in the race”. (Nathan 2013).

Single-marker championships have always been considered in the specialised press as a lower product to open technology championships such as Formula One, World Rally Championship (WRC) or World Endurance Championship (WEC). These kinds of championships usually involve lower costs and offer inferior technological products than those found in traditional motorsport (informants A, C, D).

Documentary data shows that within a few months from the appointment of SPARK Racing Technology as the suppliers of 42 FEV racing cars, a consortium was formed (Figure 8E). This consortium included **five members** with well-defined roles and responsibilities (Table 5-B) that were chosen amongst personal networks of the main actors shaping and driving FIA Formula E, all **incumbent to motorsport**, (Automotive World 2013).

Table 5-B FIA Formula E consortium in 2013 (author's compilation)

Company	Role
Renault	Powertrain architecture, systems integration, powertrain electrical safety & performance optimisation.
Williams	Design, manufacture and assembly of batteries and their battery management systems.
McLaren Electronic Systems	Development, manufacture and supply of electric motor, gearbox and power & control electronics.
Dallara	Design and construction of the monocoque.
SPARK	Car design and conception (chassis, aerodynamics, assembly, suspension).

Data shows how this technical consortium remained mostly the same during the infancy phase of innovation, season zero and season one, working together as a team to achieve the best technical product within available technologies (Figures 8E and 8F).

> "We are proud to be part of the FIA FE **family** from the beginning, where we have a role of **technology platform enabler**, letting the championship kick off". (Informant D)

> "Spark Racing Technology is extremely proud to **bring together** some of the **biggest names in motorsport** […] as they accompany us in the highest level of the first championship for electric cars." (Automotive World 2013).

In order to reduce the financial entry barriers for teams, sporting and technical **regulations** played a significant role in **capping the cost** of the car to £225,000 (informant B; informant C) and mandating the teams' operating budget for S0 at $3.5 million (Fox News 2013). From key informants' interviews it has emerged that, initially, teams were asked to pay $1 million to reserve a place in this championship. This deposit would have allowed them to run for the first year while assigning part of the sponsorship budget to FEH in order to repay the operating costs up to the budget cap (informant A; informant B).

Lowering the economic barrier to entry resulted in an increase of interest from **privateers** and **entrepreneurs** to join this new fully-electric championship (Figure 8B and 8C). Up until the unveiling of the regulation and the enforcement of the budget cap, only Lord Drayson had officially announced taking part in FIA Formula E. Documentary sources show that, in February 2013, a group of Chinese investors joined the championship (FIA 2013). Liu, chairman of Team China, commented on joining the FE championship.

> "Our experience in racing event management will contribute to a successful Formula E city race in China showcasing electric formula cars with a futuristic sound and zero-emissions. We also believe this is a **good platform** for Chinese and global EV companies to do our part to help create a **sustainable planet**" (Liu 2013 cited in Electric Race News 2013).

If during the infancy phase of innovation, no technological development was allowed to help keeping costs under control, documentary data shows how, during the months approaching season two, things started to change. Far from FIA FE becoming an open championship as in its initial vision, and aware that a single-maker series was of limited interest for any incumbent actors in the motorsport industry who wanted to pursue FIA FE as a platform for electric R&D, the FIA announced **opening up the development of the electric powertrain**[16] (Figure 8B and 8E). Data shows how the technical regulation was changed to allow the development of the car's electric powertrain within certain **technological and commercial constraints**. FIA put in place some limitations on the **costs** of some items to avoid a quick ramp-up of the expense of the championship. These included the powertrain which shall not exceed €440,000 ex-work, full powertrain kit which shall not exceed €120,000 ex-work and the leasing fee for powertrain which shall not exceed €72,000 per year as for FIA regulation (Formula E 2014a; Formula E 2015).

On the sporting and technology side, opening the powertrain development creates a distinction around **manufacturers** and **teams**. Data shows how this

[16] This change within the technological dimension 'dictated' by creating a market for this innovation (interest from incumbent) underlines how multiple factors play a role in the unfolding of innovation.

distinction, not new to motorsport (i.e. F1 or WEC), pushes teams, regulators and championship organisers to define a **roadmap**, a technique to support strategic medium and long-term planning of the championship (Figure 8F). Scoping interviews have suggested that the need for a road map for FIA Formula E was driven mainly from the discovery that the set of available technologies was not as developed as the initial actors thought. This road map was driven forward by technology suppliers as the chief executive of a UK industry association explained:

> "Do the **teams** have anything to do with the early roadmap of FE or available **suppliers** have?" (Informant A)

The extracts below show how the definition of a clear road map for the future quickly became a hot topic between FIA, FEH and teams.

> "Together with the **Federation**, which has the **ownership of the technical and sporting regulations**, we want to work to define a kind of **road map** of the **technological development** of Formula E to identify areas on which to leave freedom and those on which to freeze the situation." (Formula E 2014a)

In February 2015 a first draft of the technology road map was presented to the press:

> "In order to **limit costs** and **promote investment** and **innovation** in the most important areas, the manufacturers' scope is initially limited to the powertrain – specifically the e-motor, the inverter, the gearbox and the cooling system. All other parts on the cars will remain as they are, with the aim being to prevent costly aerodynamic developments. […] The next regulation progression – scheduled for season three - will see manufacturers extend their efforts to the batteries, with the objective being the use of a single car per driver during races from the fifth season" (Formula E 2015).

The analysis of the text from this announcement shows how technical and regulatory factors were linked to business factors, **as economic variables (cost and investment) demanded a technical road map**. However, the data does not explicitly describe which actors were involved in the process of defining this roadmap. The data also confirms that the previously outlined concept of seasons is a clear way to describe time within the motorsport industry and how this technology road map changes with time, hence season.

If the technology and regulatory factors of the first all-electric championship were very much aligned with incumbent motorsport models (chapter 3), data analysis identified the **format** and the **business model** of FIA FE as a novelty of this championship (Figure 8B and 8C). The format of the race weekend of FIA Formula E was, in fact, new to motorsport as free practice, qualifying and the race would have taken place in one day. The business model of the championship was also different from the one used from 'traditional motorsport', where teams own cars, factories and are in charge of all the R&D. Specifically, from the analysis of documentary data, it emerges that in this first all-electric championship cars were leased by the teams, together with the units in which they operated when not racing. Most documents and industry experts define these novelties of FIA Formula E as disruptive, as the quotes below outline.

> "You might argue that [FE] disruption is more on the **commercial** side than the technical side. You know the thought of bringing a racing series in the **centre of the city**, setting up a circuit for a day, **racing and taking it away**, that is a disadvantage, but you could not do it with ICE racing cars, as the city will not accept it, noise, pollution… so one mild disruptive technology has allowed a disruptive innovation in the total." (Informant D)

> "They are completely different. […] They take the race to the middle of the **city**, they **build the track** in a quick way, as mostly they are quite short and bring it right to the people. I have a lot of respect for what they have done, a remarkable job in being able to take it to so many cities' centre, remarkable, I really did not think they would have been able to fulfil all the initial promises, but they have exceeded them." (Informant C)

The first informant further underlines the difference between this full electric championship and traditional motorsport, naming two factors, amongst others, as the key of FIA Formula E success: marketing and racing location.

> “It is **well promoted,** and I think this is a large part of their success, and also had a huge advantage to **take racing to the people** rather than people to the racing and that is probably the major part of its success, we have seen it recently with F1 cars running in London […]. Formula E is racing at the doorstep, but we should not denigrate the technical side of it.” (Informant D)

Documentary data show that both these factors were rooted in the idea of an FEV championship from an early stage. Specifically, in an interview given in 2010 at the Paris Motor show, Barbaroux, the then owner of Formulec and since 2013 vice CEO of FEH, underlines the **need for a different format in electric car racing**, which is discussed here by the COO of FEH.

> “Every sport has its own way of doing things, and I think that is the best way to go […]. The best way to illustrate what I am saying is to compare skiing and surfing. Downhill racing is spectacular and magnificent, but surfing is a completely different culture. There is music; there is much more of a festival. I think that we should aim for that and change the way things are done and not try to compete with conventional racing cars. They are not comparable, and thus you need a **different strategy**. […] The 100 metres in the Olympics takes just 10 seconds, but it is the biggest media event in all sport, so the key is to build an event around the main race and create the right kind of atmosphere. We do not see this being a three or four-day event, but we will do it all in one day. In terms of TV coverage, the main event of 30 minutes live-racing, packaged with 20 minutes of highlights and interviews creates a package of around 50 minutes which is what the broadcasters are looking for” (Russel 2012 cited in Saward 2012).

This differentiator included the location of the races but also its format, as the extracts below outline:

> “Races would be **one-day events** on 1.5- to 2-mile tracks. Each team would have **two cars** with batteries that could last for about 25 minutes of racing. Rather than wait to fuel up, drivers would run

> about 100 meters to their second car. Cars will have a **push-to-pass button** to provide 40 additional horsepower for 20 seconds. The teams would compete in knock-out races until a winner was determined."(Agag 2012 cited in Belson 2012)

> "Races will be held **from September 2014 to June 2015** and were initially announced as stopping in **Rio de Janeiro**, **Rome**, **Miami** and **Los Angeles**, out of the ten races scheduled". (Agag 2012 cited in Fox News 2013).

This novel format of FIA Formula E was soon embraced and prized by some motorsport experts, who describe it as best suited to the **new market** that the championship aimed for: the **millennials** and the **Y generation**[17]. Chris Aylett, chief executive of the Motorsport Industry Association (MIA), commented in an interview to the BBC.

> "It will be a very trendy, very modern, futuristic form of racing. We are not talking about appealing to the grey market with these cars. We are looking at the 15-year-old today who will be **tomorrow's car buyer**." (Aylett 2012 cited in Leggett 2012)

From the analysis of this and other documents, it emerges as this championship was **targeting a different typology of users** (Schot, Kanger and Verbong 2016; Jarvenpaa and Standaert 2017)**,** creating **a new market**.

> "Older fans may lament the lack of a howling exhaust note [but] what we are trying to do is create a new racing experience. It will be a **different type of car**, racing through the **city streets**, before **new audiences**, in places where we have not raced before." (Lord Drayson 2012 cited in Leggett 2012)

If on one side, positive reactions were expressed by new actors or actors already involved with the championship, on the other side, negative comments did not take long to come as shown in a sarcastic article dated October 2012, from The

[17] Millennials and Y generation have been used in this context to identify a well-defined category of users. Specifically millennials is used to refer to people reaching young adulthood in the early 21st century, which are often also called the Y generation as these people follow from the X generation (born 1965-1979).

New York Times, echoing the thoughts of "old fashioned motorsport" experts and fans (Belson 2012). What Ken Belson did not consider in his article was the **different business model** for the teams and investors that Formula E implemented in order to incentivise teams and entrepreneurs to join in. Specifically, from the corroboration of documentary data and scoping interviews, relevant details on the **business model of the championship** and the **business model of the teams** during the infancy phase of innovation emerges. This connection between market, business model, value-creation and motorsport is underlined by the following three extracts. The first quote describes FIA Formula E as a gap in the existing market and a way to create financial value for new and existing actors in the motorsport industry. The last two quotes offer views from incumbents to motorsport and entrepreneurs, who entered this championship to differentiate their business and its relevancy within the wider automotive industry.

> "Entrepreneurial zeal from Agag, he saw an opportunity to **create value**, he knew Ecclestone very well and understood the **business model** of F1 well. He saw an opportunity to create a series that was different from F1, different from junior series; he was creating **financial value**." (Informant A)

> "We are in the business of racing, and we have been looking for **opportunities to diversify**, and when we were contacted about this, we felt it was something we needed to look into. […] and the more we looked into it, the more interested we got. We like the relevancy of the series because one of the problems auto racing is starting to face – and is going to face more of in the future – is relevancy." (Andretti 2013 cited in Fox News 2013)

> "I think **relevancy** is going to be addressed with the electric cars. It is a good way to hook our younger audience into racing, and I am excited to be involved and be involved at the ground floor." (Branson 2013 cited in Fox News 2013)

From September 2013, data confirms that this fully-electric championship gained momentum (Figure 8B, 8C and 8D). FIA Formula E starts to attract incumbents and new entrants' actors to the motorsport industry. Jay Penske, owner and president of Dragon Racing and PMC, an international media company, who at the time entered two cars in the IndyCar Series, joined Formula FIA E in September 2013. The extract below underlines the reasons behind its choice.

> "It is an honour for Dragon Racing to have been selected as one of the founding teams in Formula E. Formula E symbolises a vision for the **future of motorsports** and the **automotive industry**, while directly appealing to a **new generation** of global race fans. Formula E offers a tremendous opportunity for our many **technology** and **media partners**, and we look forward to its inevitable growth and ascendancy over the next decade." (Penske 2013 cited in Biesbrouk 2013)

Four announcements made by well-known actors in the motorsport industry followed. In October 2013, Alain Prost, former Formula One driver and World Champion, together with e.dams, a French team competing in some of the other motorsport series, mostly single-seater, announced a partnership to enter the FIA Formula E championship (Tsport100 2013). Shortly after, ABT Sportsline, Audi factory Team **competing in Deutsche Tourenwaegen Motorsport** (DTM), Team Aguri and Virgin Racing, both **incumbents to Formula One,** announced they were entering the fully-electric championship.

> "As a company that has been active in the field of regenerative powertrains and electric mobility we are convinced of the series' concept. It is innovative, delivers motorsport at the highest level and a great show for fans around the world – all of which are a perfect fit for ABT Sportsline." (Abt 2013 cited in Formula E 2013a)

> "The need to create fast, dependable and durable race cars will help to accelerate the sector and **showcase electric cars** to a **large global audience**." (Branson 2013 cited in Virgin 2013)

At the end of 2013, the announcement which brought FIA Formula E on to the radar of a very different audience was that of **Oscar-nominated actor**, Leonardo DiCaprio, who partnered with Venturi Automobile to enter a team in this championship. Although Venturi Automobile was a new entrant in motorsport, this small firm, based in Monaco, was **incumbent** to the development of **electric**

vehicles. The company was then the holder of the world land speed record for an electric vehicle: a Buckeye Bullet 2.5 clocked 307 mph in 2010 (Venturi 2013). In a statement, which was broadcast in major entertainment magazines and on television, Leonardo DiCaprio, actor and environmental activist, commented:

> "The future of our planet depends on our ability to embrace fuel-efficient, **clean-energy vehicles.**" (Associated Press 2013)

Clean energy vehicle, air pollution, decarbonisation of transportation are all broader topics of concern which have also emerged as factors influencing FIA Formula E from an early stage (Robeers and Van Den Bulck 2018; Robeers 2019). These factors, which academic literature has referred to as global challenges (Jenkins, McCauley and Forman 2017), appear in many early press releases linked to the concept of sustainability.

> "We are not just a race! We are a technological and **sustainable development test bed** for some of the leading companies in and out of motor racing to address **mobility** and **environmental issues**. […] The concept of sustainability for Formula E is to reduce our footprint as much as possible and have a **positive impact** on both people and the planet." (Agag 2012 cited in Leggett 2012).

Shortly after the announcement about DiCaprio's involvement, Fox News, a US media channel, signed a multi-year deal with the FIA Formula E (Formula E 2013b), triggering attention from **broadcasters** and **TV companies**.

The last of the ten teams to enter the championship was Mahindra, an Indian incumbent **automotive company**, already engaged in developing electric car technology (Chackraborty 2013). Maini, the founder of the Mahindra Reva, an Indian-made electric car that sells in Europe as the G-Wiz, declared that the determinant factor for his choice was not the relevance of this championship for his existing business, but the **size of the initial investment**. Supporting this opinion, car historian Heitman comments:

> "One reason could be that the **risks** are **small**. The money involved is not huge; its **start-up** nature means there is not very much glamour; there is little prestige in winning a brand new championship. However, if it works, there is inordinate promise for

> **technology transfer** to go from racing to production." (Heitman 2013 cited in Mirani 2014a)

Data has unveiled that another differentiator between this championship and traditional motorsport was the co-location of the teams during the infancy phase of FIA Formula E. Key informants define this co-location as a further measure to control and contain costs (Informant A, informant C). In 2013, it was announced that all the teams were to be based in purpose-built facilities at Donnington Park Circuit, in Leicestershire.

> "The new 44,000 ft² bespoke premises will house all ten race teams along with offices, workshops and stores. At the cost of £5.7 million, the new centre will create 150 jobs and kick start growth for Donnington Circuit as a centre for electrical technologies after losing out to the British Formula 1 contract in late 2009." (Champions 2014)

In an interview at the time of the announcement, Agag, shareholders and CEO of FEH, commented:

> "Our new facilities at Donnington Park provide the perfect **central location** for operating the FIA Formula E Championship. It means we can take advantage of the technology and skills all around us." (Champions 2014)

This geographical co-location of suppliers and teams also influenced the development of technologies and community culture within strategic niches or clusters. These findings are in line with academic studies (Geels and Schot 2007; Porter 2011) that have emphasised how co-location in the early phase of innovation accelerates the rate at which companies can innovate.

Despite cost capping, data shows how in 2013 FIA FE incurred economic difficulties. In order to raise funds and to allow this championship to continue to operate, many global partners, mostly incumbents to motorsport, were announced, including TAG Heuer, Mumm champagne, Renault Sport, Michelin, DHL (Sylt 2015b). Additionally, during the first quarter of 2013, other revenue streams, mainly from **broadcasting**, as well as partnership, were added to the initial investments of Agag and Banueles.

Three out of the five scoping interviews outline how shareholder dynamics is a powerful example for understanding the transformation of the business model of the championship, as the quote below confirms.

> "If you study the **business shareholding**, it is very interesting to show the changes, it is not easy to identify them, but they are there, in the public domain. […] I think it has now moved into a commercial entity with investors and I would say if there is a common theme, sounds cynical, they bought into this to save the planet, save the polar bears, all comms and marketing. It is not a negative, but there is a powerful **marketing** need across the world to make something positive out of this: we are, and we can make a difference." (Informant B)

Specifically, in season zero, the **commercial right holders** of the FIA FE championship (Formula E Holding) belonged initially to two wealthy individuals, Banueles and Agag (Figure 8A). As the first investment of FEH, they bought out Formulec, which already had the technological expertise of producing a single seater electric racing car appointing Barbadoux, co-owner of Formulec, COO of FEH. Involving just wealthy individuals was not capable of generating the investment needed for the championship to kick off. As a result, in 2013, a third shareholder was recruited: Causeway Media Partners. This new partner acquired shares in Formula E Holding in order to increase the capital needed to fund the championship (Formula E 2013c). Grousbek, owner of Causeway Media Partner, was soon added to the Board of Directors of Formula E Holding in order to bring expertise and advice concerning the **entertainment** side of competition (Figure 8B).

> "At Causeway, we know the power of **competition** and **entertainment**, and will bring our knowledge to the **development of the market** for electric vehicles." (Higgins 2012 cited in Formula E 2013c)

> "Wyc brings with him extensive knowledge and experience of the US **sports market** which of course remains a key area for Formula E given we have two US-based teams, two US cities, broadcaster

> FOX Sports, and of course the US's ever-expanding Electric Vehicle market." (Agag 2012 cited in Formula E 2013c)

At the beginning of 2014, during season 0, FEH raised a further 50 million euros of capital from private investors (Figure 8B) such as Qualcomm Venture and private equity firm Amura Capital (Formula E 2014b). Commenting on this, Pazol, General Manager for Qualcomm, addressed market and non-market factors which drove the decision of Qualcomm to invest in FIA FE, mainly technology and sustainability.

> "We are very excited to deepen our relationship with Formula E. We look forward to demonstrating our technology throughout the race series, including our Qualcomm Halo wireless charging on the Qualcomm Safety Car, and wireless data connectivity and other technologies on the race cars themselves. Formula E is the perfect way to demonstrate the leading edge of technology of this next generation of **environmentally responsible transportation**." (Pazol 2014 cited in Formula E 2014b)

If season zero was populated by events gravitating towards the financial means and needs for the series, documentary data shows how, during season one, concerns about the financial stability of the championship started to preoccupy teams and suppliers.

> "I think the most important thing for us is to break even financially, and we are in a very good direction to get there. Then just wait, because it will take time for everything to be electric, but at some point, it will be mainstream, and we will be there. So basically the key to success for us is long term survival." (Agag 2015 cited in Sylt and Hewitt 2015)

In September 2015, just before the start of season two (Figure 8B and 8C), **Liberty Global and Discovery Communications**, both owned by Malone, announced they were taking over the majority of shares of FEH from the previous majority shareholders (Watkins 2016) and nominated Agag CEO of FEH.

> "They are providing a lot of support in terms of management, people, procedures and systems – the whole **management**

> capacity that they have. Obviously, we were a start-up, and now we are becoming a proper company. We need to put in place the procedures, systems and controls that a **proper company** has, and they are helping us with that." (Agag 2015 cited in Sylt and Hewitt 2015)

On this topic, the Financial Times added that a person near the deal commented that:

> "This investment takes Formula E to the next level, from being a **start-up project** to being a **solid league** which has a much more guaranteed future." (Shubber 2015)

These two quotes identify two distinct phases of the shareholding structure of the championship. The first is the one defined as "the start-up period", running from S0 to the middle of S2, and the other running from S2 onwards. These phases show similar characteristics to the infancy phase and the growth phase of innovation (Foster 1986). In the latter, the technology and the shareholding structure of FIA FE consolidate to allow growth and to guarantee the survival of the championship. This financial consolidation of the championship's business model came at the same time as the consolidation of the technical and sporting regulation.

It is this relationship between business, technology and regulatory factors, at different times of FIA Formula E, which emerges from the data as key to understand how actors shape, drive and enact the temporal system dynamics of this low-carbon socio-technical transition.

5.3.3 The 'growth phase' of FIA Formula E: season 2 and season 3

Figure 8D and 8F illustrate the growth phase of FIA Formula E. Towards the middle of season one, changes to the **technological model** of the championship (opening up the development of the electric powertrain) and the rights-holders composition (the acquisition of the majority of the shares from Liberty Global) brought FIA FE towards a new phase in its lifecycle (Figure 8C and 8F). This phase corresponds with season two and season three of FIA Formula E and shows similarities with what the literature has defined as the growth phase of innovation (Foster 1986; Raynor and Christensen 2003).

A comparison of tables 3A and 3B in chapter 3 offers a useful way to understand changes between the infancy phase and the growth phase of FIA Formula E. Those tables present a list of teams taking part in the championship from the comparison of which the following changes can be deducted:

1. Team ownership and their shareholding changes considerably between the infancy phase of innovation and the growth phase;
2. Main sponsors migrate too (i.e. Amlin);
3. In S2, the concept of manufacturers is introduced, to reflect a popular concept in traditional motorsport. A manufacturer is the supplier of the electric powertrain, rather than the battery, which is a direct result of the direction taken from the technology roadmap of this championship (the possibility to develop the powertrain component only in the car);
4. There are crucial changes in actors between the two phases, and specifically, during the growth phase, OEMs and new and incumbent powertrain manufacturers start to enter the championship, next to or to replace entrepreneur or privateers from the infancy phase.
5. During the growth phase of innovation, another way for the OEMs to enter the championship start to be implemented, for example, technical alliances, between privateers and automotive manufacturers and partnerships (i.e. BMW).

Amongst those changes in actors during the different phases of this low-carbon sustainable socio-technical transition, data has outlined the changing position of actors initially involved in the SRT consortium. Some of those actors, in fact, started to branch out from the consortium and differentiate their involvement in FIA Formula E, in the growth phase of innovation. For example, documentary data shows how McLaren Applied Technology (which then incorporated McLaren electronic systems) in season two became a supplier for the electric powertrain for some teams, and, in season three, Williams Advanced Engineering (WAE) became involved in providing racing services for the Jaguar Panasonic Team.

Those changes in actors' positions and their involvement with the championship, reflects **changes** in the **road map** of FIA Formula E. Contrary to the initial plan of the FIA to allow R&D for the battery technology to any manufacturers, the FIA announced a tender for the battery system for season five (Figure8F).

> "In accordance with the FIA Formula E Championship Technical Roadmap - the objective of which is for each driver to be able to complete the current race distance with the use of only one car - the Formula E Committee and the Electric and New Energy Championships Commission will proceed with two calls for **tender**. These are:
>
> 1) To identify a **single provider for batteries** from the fifth season onwards
>
> 2) To identify a **single chassis supplier** for the fifth season onwards.
>
> The applicants will be presented for selection at the next World Motor Sport Council." (FIA 2016)

At least nine manufacturers responded to this tender including incumbent to motorsport, automotive and electronic companies such as Williams Advanced Engineering, McLaren Applied Technologies, Porsche Motorsport, Panasonic, Sony, Mahindra, Red Bull Technology, Renault and DS (Smith 2016). The different sectors where these companies operate is symptomatic of the markets that this championship attracted.

Data shows how the **regulators and the organisers** (the policy and the business model) have driven and enacted this transition from the infancy phase of innovation to the growth phase, with awareness of the different market that they were targeting. Thanks to the regulators, that mandate the battery and the chassis from single supplier components (supplied by Spark Racing Technology –SRT-) the championship managed to contain costs while promoting a mixed model championship, with real competition on the innovation of the fully electric powertrain.

> "There are lots of **OEMs** coming to the championship, and I think more are going to come and to give them a very clear path for many years is important to them and can help save costs. I think for **manufacturers**, what really drives up the cost is **time**. If they are confronted with very short spaces of time to develop a powertrain, the cost goes up exponentially. So the longer lead time we can give

> them to develop the better, and that is what we are going to try to do with the FIA. Sustainability is a key area for Formula E, and it is also about ensuring **costs** are controlled." (Agag 2016 cited in Formula E 2017)

In **S3**, the FIA announced other significant **technical** and **sporting changes** (Figure 8F).

> "There are three key changes in the sporting regulations that come into effect for this third season. The first is that setting the fastest race lap is now worth just one point instead of two to a driver. When it comes to energy management, article 37.9 of the Sporting Regulations has been modified […]. This change has been introduced so that the **spectators** can instantly understand when there has been a violation of the rule regarding how much energy can be used, without having to wait for a decision from the stewards. It means that the Formula E cars will fall into line with cars that use combustion engines, which have to stop trackside if they run out of fuel.
>
> Finally, there has been a 50% increase in the amount of **energy available** from the regeneration process, from 100 kW to 150kW. This means that a number of strategic possibilities open up for the **drivers**, who can now store energy in a more efficient manner and for longer, partly thanks to an evolution of the standard battery produced by Williams Advanced Engineering." (FIA 2016)

This interest shown by OEMs and companies in other sectors is explained by senior experts as a direct consequence of overcoming major limitations on technology.

> "Unfortunately Formula E is almost a little bit too early and in a way highlights the big aspects of EV that are problematic to buy a car. For example, the fact that you have to change the car is not exactly a great advert for electric vehicles, but in a year's time they go to a single car, and this is largely because of the improvement on energy storage of the battery." (Informant D)

> ‘I think they were very intelligent businessmen who saw a clear **opportunity** which was unexploited, **transportation** is going **green**,’ (Informant B)

Aside from OEMs, data shows how other **technology partners** announced their involvement in the development of the electric powertrain during the growth phase of innovation (Figure 8F). At the end of S1 a partnership between ABT Audi Formula E Team and Schaeffler, one of Europe’s largest technology companies specialising in automotive and industrial appliances, was announced. Schaeffler would build and develop the whole powertrain exclusively for the ABT Audi team. Prof. Dr Gutzmer, deputy CEO and CTO of Schaeffler AG commented on this announcement:

> “Schaeffler builds technology for the future. It is challenging and innovative in Formula E which is **technology driven** and has **global reach.**” (Gutzmer 2015 cited in Smith 2015)

In June 2015, a new entrant to single-seater motorsport, DS Automobile, Citroen’s standalone division, announced joining forces with Virgin Racing Team. The company assisted with research and development of the electric powertrain. Bonnefont, chief executive of the DS brand, commented on the announcement:

> “The engagement of the DS brand in Formula E with Virgin Racing is fully consistent with the **brand’s positioning**. We fully share the values of Formula E: avant-garde technology and **proximity to the public**. The experiences that we will accumulate thanks to the races are key factors for us in the improvement of our technology directly serving our customers.” (Boneffont 2015 cited in Robbins 2015)

Shortly after, Faraday Future, a start-up in the automotive sector of electric cars, partnered with Dragon Racing, bringing new OEMs to the racing industry (Figure 8C):

> “You have the classic manufacturers involved, such as Mercedes, Renault and others but also **new automotive manufacturers** and **startups** are now part of the game, Faraday, Mahindra. It is very interesting as this is the one championship where the conversion

point between the **new world of automotive** and the **traditional world of suppliers** are converging in competing with each other as they are doing in the automotive market." (Informant E)

In season three, after the release of the detailed technology road map of the FIA Formula E, BMW, which was already a partner of the championship supplying the FEV safety car, announced their partnership with Andretti Formula E Team for season three (Figure 8F). Marquardt, Head of Motorsport for BMW discussed his thoughts on FIA Formula E and the partnership with Andretti in an interview, an extract of which is reported below:

> "Formula E has developed fantastically as a racing series and, as a new, technology-based project, it is perfectly suited to the BMW Group and **BMW Motorsport**. Forging new paths and driving innovation – these are values shared by BMW and Formula E. […] The **changes** we required for our involvement will come into effect in **season five** – these include, for example, the omission of the car changeover. We are already seeing in our development work that colleagues from the production and motorsport departments are **collaborating** in a completely new way. The result is new paths, which we are forging together in the matter of electric drivetrains. In Formula E, we will demonstrate both our innovative expertise and our sporting spirit." (Marquardt 2017 cited in BMW group 2017)

Documentary data shows how, during these years, wider automotive issues such as **Dieselgate**[18] contributed to accelerating the enforcement of policies aimed to increase the uptake of electric vehicles and the transition of OEMs towards electric platforms for mobility. This migration of automotive companies towards FEV is often linked with the increased interest of OEM in FIA Formula E in many interviews to senior management. Worthmann, Senior Vice President Brand BMW explains:

> "Through our involvement in Formula E, we are addressing the development towards **sustainable and emission-free mobility** in the automobile industry and are also making a contribution to the

[18] The world Dieselgate has been used to identified the Volkswagen emission scandal, in 2015

> brand's progression to BMW iNEXT.[…] We are using Formula E as a development laboratory, operating under the unique conditions that prevail in motor racing – with very unique demands and opportunities. […]" (Worthmann 2017 cited in BMW group 2017)

This interest of the automotive sector into the FEV championship triggered a series of significant announcements which, temporarily, can be placed months after dieselgate and after the announcement of a new low-carbon policy in Germany, following the nuclear disaster of **Fukushima**. As a consequence, Audi withdrew from the FIA World Endurance Championship, announcing that they will concentrate in supporting ABT Schaeffler within Formula E from season four onwards and Mercedes AMG reserved entry into this championship for season four (Figure 8F). The two extracts below, respectively from Wolff, Team Principal of Mercedes AMG Petronas Formula One team and shareholder of Daimler AG, and Stadler, Chairman of the board of management of Audi AG explained the reason behind this move.

> "**Electrification** will play a major role in the future of the automotive industry -- racing has always been a technology R&D platform for the motor industry, and this will make Formula E very relevant in the future." (Wolff 2016 cited in Anon 2016)

> "We are going to contest the race for the future on electric power. As our **production cars** are becoming increasingly electric, our motorsport cars, as Audi's technological spearheads, have to even more so." (Stadler 2016 cited in Audi Mediacenter 2016)

A month later, after retiring from their Le Mans Prototype One (LMP) program, Porsche announced its entry into FIA Formula E, in season five (Figure 8F).

Several initiatives were embraced from the championship to raise awareness of **global challenges** and **new mobility model** (Figure 8B and 8C), before and after those one-time events. Specifically, to name some:

- FIA Formula E published the first **sustainability report** for season one and, the following year for season two. The first report, published in 2016, was made by a well-known consulting firm and established the identity (brand, value, initiative) of the championship. The second report, published in 2017, was written by the newly formed Formula E sustainability department.

- In October 2016, a FIA Formula E race was held in Marrakech at the same time as a UN meeting on climate changes (**COP16**) where Formula E and some of its championship partners contributed to the debate and showcased this 'sustainable technology':

  > "[…] the spotlight will be focused on the crucial issue of infrastructure for the implementation of the Paris climate agreement." (Enel 2016)

- In 2017, FIA Formula E partnered with UN Environment to improve inner-city air quality. Solheim, Head of UN Environment commented:

  > "Formula E puts a fresh spotlight on electric vehicles and is an exciting glimpse of what is to come - the age of clean, viable transport. Formula E and UN Environment share the aim to usher in this era and speed up **acceptance** of these technologies to **combat air pollution**. Air pollution has taken centre-stage this year as a serious public health threat." (Solheim 2017 cited in UN Environment 2017)

- In March 2017, FIA and FEH announced the creation of Smart City Conferences before some of the FIA Formula E races which addressed the advancement of **green mobility, new mobility models, Smart Data** and its capabilities (FIA 2017).
- FIA Formula E joined forces with sustainability organisation including Green Sports Alliance (*greensportsalliance.org/formula-e-join-forces-with-green-sports-alliance*) and the Global Sports and Sustainability Leaders (Beecroft 2017).

These initiatives proved the connection between FIA Formula E and sustainability, low carbon and energy efficient motorsport, which was later further developed. The quotes below, respectively from Agag, CEO of FEH, and Todt, president of FIA, are crucial for the understanding of the awareness of this link between FIA Formula E and global challenges.

> "When we created Formula E, one of our main goals was to raise awareness of issues of environmental sustainability and drive the

development of technology which will be beneficial to our future and that of our planet” (UN Environment 2017)

> “We face big challenges ahead of us - **climate change**, **inner-city pollution** and producing energy in a sustainable way all around the world. [...] Formula E and the FIA aim to make the switch to electric cars make sense for consumers - more efficient and more affordable” (FIA 2017)

If regulators, global challenges and the business model from the team have changed from the infancy phase of FIA Formula E to the growth phase, data shows how, between these two phases, also the **business model** of the championship changed significantly. Specifically, whilst in 2014 Formula E holding was mainly owned by Agag and Banuelos, in March 2015, as already mentioned above, Liberty Global plc and Discovery Communication Inc. acquired the majority shareholding. During S2 and S3, the growth phase of this championship, these two media companies brought strong financial support to FIA Formula E and also a strong strategic vision for the consumption and distribution of the series. With the view of attracting a different market, in January 2017 Formula E organised a virtual race in Las Vegas, during the Electronic Consumer show, amongst video games player and real drivers. This strategy and vision for the championship, and the link to societal issues and technology development for the OEMs also emerged from the analysis of the scoping interviews.

> “As FE is owned by an **entertainment company** I have to say they will go where the fans want to go, there is no choice; if you do that, as FE has proven, funnily enough, the OEM comes to the party. If you got the bottle, they will go in that direction because you see they want **brand value.**” (Informant B)

> “If looking forward we are an **entertainment business**; if that is what we are talking about for future business, you have to assume to entertain people on the way they are transported, cars, boats, horses, plane, […] This is really the entertainment stream you are in the future. It is not necessarily going to be a battle of energies,

> but the culture in the next fifty years to be inefficient in the use of energy sources in general life is likely to be unpopular with fans, […] you are going to be out of touch with your **fans**." (Informant B)

Figure 8 places these changes within the temporal dynamics of the FIA Formula E innovatory system.

5.4 Conclusion

This chapter has used documentary data and scoping interviews with industry experts to explore the innovatory system and temporal dynamics of FIA Formula E between season zero and season three (August 2012- August 2017). In doing so, it has answered the research objectives 1 and 2 of this study (table 5-A) providing:

1. An understanding of the innovatory system of FIA Formula E and its dynamics, defining key moments, events and activities (Figure 8);
2. A way to identify the main factors which have driven changes in this innovatory system.

Section 5.2 has presented the output of the scoping phase of this research, a visual map (Figure 8) outlining the complexity of this system and the interplays of different factors at different times. This map was generated with the help of strategies used for processing data in business and change management studies as discussed in chapter 4 (Langley 1999). The documentary data and semi-structured interviews have also validated the unit of time chosen for the temporal bracketing of this phenomenon (chapter 4), which is seasons. Specifically, seasons have emerged as a useful and well-known concept to define a time in the motorsport industry although, in the context of FIA Formula E, season has a different connotation from the traditional motorsport, referring to a period of time approximately from September till August of each year.

Through the analysis of the data from the scoping phase of this research, the temporal system dynamics of FIA Formula E have been interpreted through two phases. Those phases have shown similar characteristics of the one identified from theories of technological changes (chapter 2) and specifically from Foster's (1986) technological lifecycle. Hence, section 5.3 has offered the narrative of FIA Formula E clustering events and activities around the infancy phase (season zero to season one) and the growth phase of this championship (season two to season three). This narrative has also revealed significant difference amongst these two phases of FIA Formula E, unveiling how the spectrum of technology, regulatory and business factors have evolved between the infancy phase (season zero and season one) and the growth phase (season two and season three) of FIA Formula E. These factors help to comprehend the innovatory system of this fully electric championship. Table 5-C summarises these factors and their changes.

The narrative in this chapter has also argued that, aside from technology, business and regulation, broader socio-economic and political factors played a role in triggering, shaping and driving FIA Formula E. Specifically, in this empirical case, these factors have included international policy, one-time events such as Fukushima and Dieselgate, environmental concerns (Robeers 2019) and the need for the technological trajectory of the motorsport championship to be aligned with the one of the automotive market and national and international policy. These findings explain that motorsport is not a system per-se', but other adjacent interrelated systems influence its temporal dynamic. These interrelated systems embody the different sets of invested interests, strategies and knowledge that drive technological changes (Bijker, Hughes and Pinch 2012), which the transition literature (Skeete 2019) has addressed as being in need of consideration when shining a light on low-carbon sustainable socio-technical transitions.

Table 5-C Factors determinant of innovation and their changes between the infancy and the growth phase of FIA Formula E (author's compilation)

The three overarching themes	**Factors affecting the innovation process**	**Infancy phase (S0 an S1)**	**Growth phase (S2 and S3)**
Business	Commercial Right holders	Entrepreneur and single investors	Media and entertainment company as major shareholders
	Teams business model	Privateers, entrepreneurs	OEMs, manufacturers
	Championship business model	Single-make formula	Powertrains open for development, hence Teams and Manufacturers championship

The three overarching themes	Factors affecting the innovation process	Infancy phase (S0 an S1)	Growth phase (S2 and S3)
Regulation	Regulation		New technical regulation on the homologation of powertrain New technical regulation about the use of energy
	Sporting regulation		Change in some of the sporting rules
The three overarching themes	Factors affecting the innovation process	Infancy phase (S0 an S1)	Growth phase (S2 and S3)
Technology	Technology	The technology was strictly controlled, and all the technical partners were incumbent to motorsport	The opening up of R&D attracted many technical partners new to motorsport
	Institutions		Unchanged
	The operational model of the championship		Unchanged
	Global challenges	Perceived as a trigger for this championship	Driving OEMs and partners' engagement with the championship

Finally, the visual map in Figure 5.1 has also presented an initial understanding of actors and actors' groups involved in the innovatory system of FIA Formula E, during the temporal dimension considered. Those actors and actors' groups constitute a draft list of additional key-informants that were interviewed in the main phase of this research to explore in greater depth and breadth the dynamics of FIA Formula E.

The next chapter will analyse those additional interviews investigating further the dynamic of this low-carbon sustainable transition using the lens of the MLP approach.

6. FIA Formula E: a disruptive innovation triggering a socio-technical transition

6.1 Introduction

This chapter reinterprets the innovatory system of FIA Formula E through the lens of the MLP approach answering the third objective of this research (Table 6-A). To do so, this chapter draws from the insight gained from the visual map (Figure 8) and a second round (main phase) of key-informant interviews (chapter 4).

Table 6-A Research objective 3 (author's compilation)

RO3	Identify actors and institutions, through the lens of the multi-level perspective to understand how these and their relations facilitate, shape and enact this disruptive-led low-carbon socio-technical transition in the motorsport industry, over time.

To aid in the understanding of the narrative presented, section 6.2 provides the output of the data analysis of the main phase of this research, the MLP schematics for FIA Formula E. Differently to Geels' framework (2007, 2012, 2016) that uses a single MLP schematic for explaining the transition of a system, section 6.2 provides four MLP schematics, one for each season of FIA Formula E. Those four schematics, which acknowledge and operationalise the concept of time in transition (section 2.4.5), allow for a deeper understanding of micro changes between and amongst[19] actors and levels.

Following this, section 6.3 illustrates those MLP schematics, providing a narrative for each level through the eyes of the 26 additional key-informants' interviews. As the aim of this research is to dig deeper into the actors' dynamics, section 6.4 presents data related to the interaction of different actors and actor's groups within this innovatory system (what I term intra-system dynamics). Reporting on comments from some of the key-informants, section 6.5 assesses how other sectors have influenced the system's dynamic of FIA Formula E (what I term inter-system dynamics). Specifically in line with theories of technological change and system innovation (chapter 2) this section underlines that systems are not 'per

[19] The terminology between and amongst actors refers to the change of actors that sit at the same level (between) or actors that sit a different levels (amongst).

se' but part of a broader context of which the researcher should be mindful when exploring low-carbon sustainable socio-technical transition.

As additional interviews have often defined FIA Formula E as a disruptive innovation, section 6.6 assesses the disruptiveness of FIA Formula E through the eyes of the 26 senior managers, linking these data back to Christensen and Raynor's (2013) theory (sub-section 2.2.2). Finally, section 6.6 summarises this chapter.

6.2 The operationalisation of the MLP approach: understanding the temporal dynamics of FIA Formula E system.

As one of the main critiques of the MLP approach has been on the robustness of its operationalisation (Genus and Coles 2008; Markard and Truffer 2008; Smith, Voβ and Grin 2010; Fischer and Newig 2016), this research has used a variety of methods to ensure that the FIA Formula E MLP schematics are as robust and free as possible from bias. Accordingly, the visual map in Figure 8 was translated into interim flow-charts to identify actors and actors' group during the temporal dimension considered (from S0 to S3). As the success of research lay in the possible triangulation of the data (Bryman 2015), these flow-charts were triangulated with twenty-six additional semi-structured interviews to senior managers (chapter 4) to produce the MLP schematics.

Due to the complexity of the visual map and the difficulties in representing the changing dynamics of actors and actors' groups within just one flow-chart, four different flow-charts, one for each season of FIA Formula E, were produced. The need to produce one flow chart for each season to understand actors' dynamics is in line with this research claim that a better conceptualisation of the temporal dimension of transition can help in analysing the process of change in greater depth (sub-section 2.4.5).

The flow chart for season one is presented below for discussion (Figure 9) while Appendix 8 covers the other three. As this is an interim process, which translates events and activities in actors and actors' groups, the key themes presented in the visual map (Figure 8) were used to organise actors and actors' groups. Flow-charts are a graphical representation of the process of change (in change management studies) or problem-solving (in operational research and engineering disciplines) which use symbols to epitomise steps, logic, operators and the start or the end of one or more functions[20]. Similarly, this flow-chart uses symbols to identify changes in actors' and actors group, making the process of grouping actors into MLP levels and regimes replicable and less inclined to biases. Specifically:

a. green boxes identify actors that remain active during the following season at the same level/regime;
b. red boxes pinpoint actors that end their involvement (i.e. Motomatica);
c. red dotted lines indicate the change of involvement of a company, or in the language of the MLP, the change of regime/level (i.e. Renault Sport moved from being a championship partner in S1 to be a shareholder in FIA Formula E team in S2).

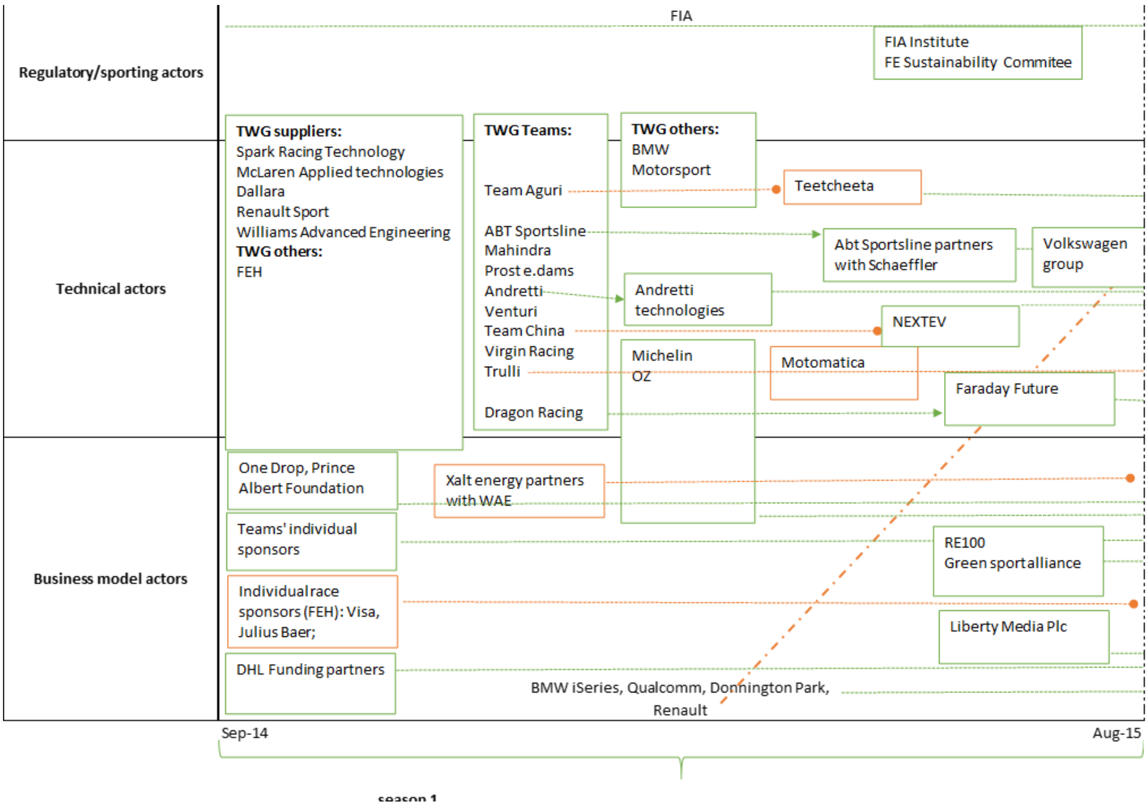

Figure 9 Interim flow-chart of FIA Formula E actors, actors' groups and relations during S1 (author's compilation)

The triangulation of these flow-charts with additional semi-structured interviews from the main phase of this research helped to develop four different MLP

[20] Flow charts are widely used in engineering and management and specifically in operational research and change management studies.

schematics (Figures 10, 11, 12 and 13). With the MLP theoretical background discussed in chapter 2, these MLP schematics place actors and actor's group in three different levels, offering a representation of the FIA Formula E socio-technical system.

Even though section 6.3 will guide the reader through a comprehensive explanation of the changes to these three levels, the narrative below seeks to provide the reader with an overview of this changing system dynamic, outlining the main differences amongst the four MLP schematics (Figures 10, 11, 12 and 13).

Figure 10 below illustrates the MLP schematic for season zero, defining each MLP level (the socio-economic landscape, the patchwork of regimes level and the niche level) and each regime, sitting at the patchwork of regimes level (policy regime, technology regime, market-user regime, science regime, socio-cultural regime).

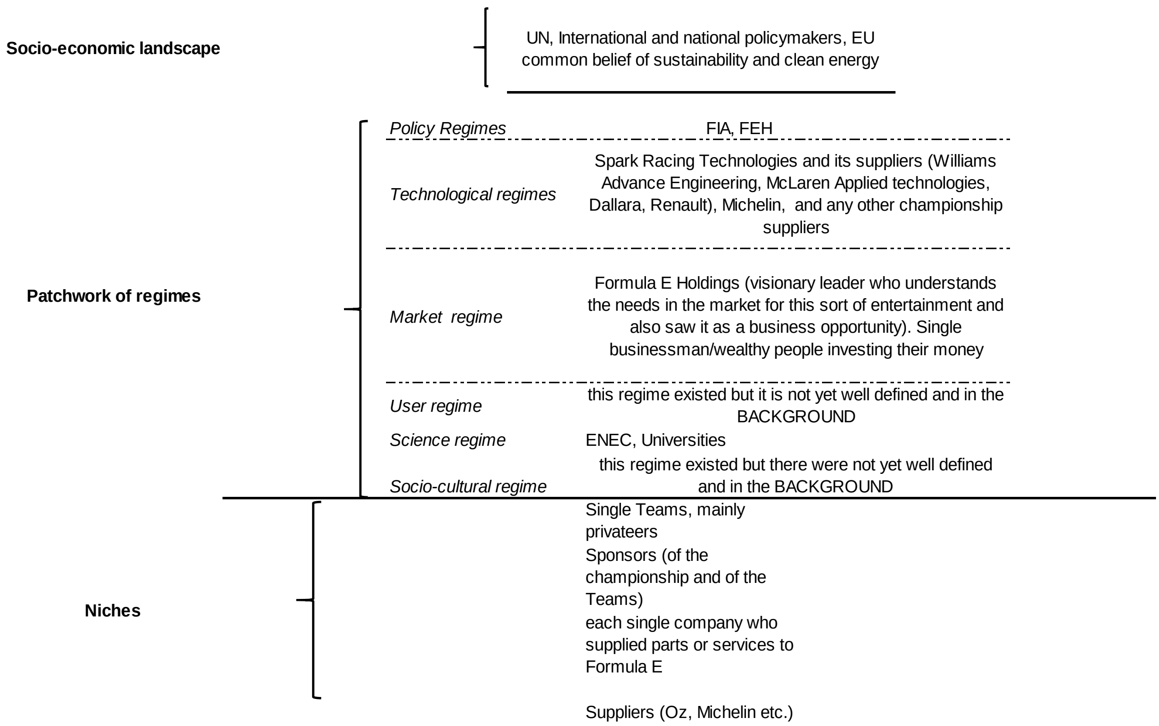

Figure 10 FIA Formula E MLP schematic for S0 (author's compilation)

Contrary to Geels' (2012) empirical studies and in line with Schot, Kanger and Verbong (2016), Figure 10 shows two separate regimes for market and user, which appear in two different lines. In this early phase, key-informants have pointed out that while actors involved in the market regime were well defined (entrepreneurs from the business and sports sectors, aiming to the entertainment market rather than motorsport), the composition of the users' regime was still unknown.

Similarly with other empirical studies (Geels and Verhees 2011; Geels and Verhees 2011; Geels 2018), the niche level of MLP schematics is populated by companies involved in the development of technologies and services. These companies are mostly the same companies which sit at the patchwork of regimes level (mainly in the technological regimes) but with a different set of rules and norms (chapter 2). Though, from a first analysis of the dynamics of this system, the niche level (i.e. single firms) does not appear alone to be able to trigger, shape or drive any radical or disruptive innovation that is able to disturb the traditional motorsport system. Rather, the collaboration of some of the regimes (technological, policy and science in season zero) at the patchwork of regimes level is responsible for enacting this low-carbon socio-technical transition. Hence, the niche level of the schematics for S1, S2 and S3 is not as detailed as the other levels.

Figure 11 shows the MLP schematic of FIA Formula E for season one. The comparison between the MLP schematic in S0 and the one in S1 (figures 10 and 11) outlines three main changes to the FIA Formula E system:

i. As innovation unfolded, new actors entered the system.
ii. The policy regime change, started to include Formula E Holding (from season 1 in charge of all the sporting regulation of the championship) and teams/manufacturers which have a vested interest in the championship (the Technical Working Group –TWG- refer to section 6.4).
iii. The socio-economic landscape level increases its pressure on the level below due to a series of exogenous events, which caused significant changes in international and national policies, namely the VW emission scandal called Dieselgate and the explosion of a Nuclear power station in Fukushima, Japan. Those events belong to interrelated systems but still bare weight on the dynamic of the FIA Formula E system, as section 6.3 and 6.5 will explain further.

Socio-economic landscape	UN, National and International policymakers, EU Events: Diesel gate, Fukushima Climate change reports and agreements
Patchwork of regimes	
Policy Regimes	FIA, TWG, FEH
Technological regimes	Spark Racing Technologies and its suppliers (Williams Advance Engineering, McLaren Applied technologies, Dallara, Renault) Teams (Mahindra, Dragon Racing, Trulli, ABT, Virgin, e.dams, venturi, Andretti, Amlin Aguri) OEMs (informal working group with possible manufacturers interested in the championship) Technology companies
Market regime	Liberty Media Plc and Discovery channel, Motorsport events, entrainment market, consumer electronic market
User regime	spectators, fans, gamers, young generation, people who leave in mega-cities
Science regime	Universities, R&D departments of technological regimes
Socio-cultural regime	ONE DROP; Prince Albert II Foundation; local schools; Formula E Sustainable Committee; the Climate Group, RE100; The Green Sport Alliance
Niches	Sponsors (of the championship and of the Teams) Single Teams, mainly privateers, Suppliers Companies which supplied parts and services to Teams or FIA Formula E

Figure 11 FIA Formula E schematic for S1 (author's compilation)

Figure 12 and figure 13 outline the MLP schematics for S2 and S3.

Socio-economic landscape	UN, National and International policymakers, EU reduction of energy demand movement (energy security) international and national policymaker climate changes reports and agreements (shaping industrial, policy and consumers' actions) Consequences (political and socio-cultural) of disastrous global events: Diesel gate, Fukushima
Patchwork of regimes	
Policy Regime	FIA, FE innovation committee, SWG, CWG, TWG
Technological regime	Michelin, Spark technology, McLaren, Renault Sport, Mahindra Racing Formula E Team, Faraday Future Dragon Racing; Penske Plc; Panasonic Jaguar Racing (owned by JLR entered the Formula E field in 2016); Virgin DS Racing (partnership between Virgin and Citroen); Teecheetah Formula E Team (owned by SECA bought out Trulli Formula E team in 2016); Audi ABT Schaeffer Formula E Team (from 2017 Audi is officially involved), Renault e.dams (Renault Sport); Ms Amlin Andretti (from 2016 BMW Andretti and then from 2108 BMW Formula E team); Mercedes (from 2018);
Market regime	Motorsport , Entertainment, Manufacturers of FEV, future mobility, Consumer Electronics, Sport , Liberty Media, Motorsport network,
User regime	Spectators, fans, gamers, young generation, millennials, EV savvy
Science regime	Universities, R&D departments of technological regimes
Socio-cultural regime	ONE DROP; Prince Albert II Foundation; local schools; Formula E Sustainable Committee; the Climate Group, RE100; The Green Sport Alliance
Niches	Williams advanced engineering, Hewland, Dallara (supplier to Spark technology) every and each company supplying services or product or technologies to Teams, Formula E and FIA FE events.

Figure 12 FIA Formula E MLP schematic for S2 (author's compilation)

Socio-economic landscape		
	UN, National and International policymakers, EU reduction of energy demand movement (energy security) international and national policymaker climate changes reports and agreements (shaping industrial, policy and consumers' actions) Consequences (political and socio-cultural) of disastrous global events: Diesel gate, Fukushima Consumer Awareness Switch to the electric mobility model	
Patchwork of regimes		
Policy Regime	FIA, FE -innovation committee, TWG, CWG, SWG, FETA,	
Technological regime	Spark technology; McLaren Applied technologies; Renault Sport; Mahindra; Penke Plc; Jaguar Racing ; Citroen, Virgin; SECA ; Audi ABT ; Renault Sport; BMW; Mercedes (from 2018); Penske ; NEXTEV; Andretti, Venturi	
Market regime	Automakers, OEM, Cities, Sport, Motorsport, Costumer Electronics, Sustainable Companies, Liberty Media and Motorsport Network	
User regime	Spectators, fans, gamers, millennials, sport and motorsport followers	
Science regime	Universities, R&D departments of technological regimes	
Socio-cultural regime	ONE DROP; Prince Albert II Foundation; local schools; Formula E Sustainable Committee; the Climate Group, RE100; The Green Sport Alliance	
Niches		
	Magneti Marelli; WAE; Dallara; Chargemaster; Michelin; each individual teams and their partners for the development of technologies; each suppliers of parts, product and services, involved in each event (including entrainment) Discovery communication Inc., Julius Baer Group; Qualcomm Technologies Inc., BMW, Visa, QUALCOMM Technology Inc., G.H. Mumm; Charge ltd; Enel; Aquafuels, Chargemaster;	

Figure 13 FIA Formula E MLP schematic for S3 (author's compilation)

The comparison of Figures 12 and 13, both refer to the growth phase of this championship (chapter 5), and outline the following micro-changes:

i. FIA Formula E starts gaining momentum, attracting new and incumbent actors from the traditional motorsport system. Amongst these new actors, companies from systems interrelated to motorsport, such as automotive, energy and consumer electronics, join the FIA Formula E championship.

ii. The composition of each regime becomes more defined, evidently resulting from observing those regimes which were previously just in the background of the system: the socio-cultural regime, the market regime and the user regime.

iii. The composition of the policy regime resulted very different from S0 and S1. In S2 and S3, this regime started to include Sporting Working Group (SWG) Innovation Committee (IC) and Commercial Working Group (CWG) in an attempt to consider different stakeholders' interest to the championship roadmap.

It is this difference in actors and their relations between the infancy stage of innovation (season zero and season one) and the growth phase (season two and season three) which the narrative in section 6.4 and 6.5 explores through the quotes of the additional 26 key-informants

6.3 Reinterpreting FIA FE through the MLP approach

This section takes the reader through a more detailed narrative of the composition and the changing dynamics of the three MLP levels using quotes from the twenty-six additional semi-structured interviews from the main phase of this research.

6.3.1 Landscape level

As explained in chapter 2, Geels defines the landscape-level as the "external environment that influences interactions between niche(s) and regime" (Geels 2011: 26). At this level, amongst stakeholders, scholars have included factors such as public awareness, government commitment and change in the international economic situation (Foxon, Reed and Stringer 2009; Geels et al. 2017; Schot 2005; Scoones et al. 2007).

If the narrative in Chapter 5 has already uncovered global challenges, the main phase interviews have confirmed the role which these global challenges have played in triggering and shaping FIA Formula E, giving additional insights. The two transcripts below are both taken from key-informants sitting at, in the language of the MLP, the policy regime of the system, and are an interesting example in understanding how actors perceived the role that these global challenges played in this system.

> "I think they [global issues] have contributed to the championship, so has the **diesel emission** issue, **the legislation** which is coming in a number of countries. Timing was right, and the championship has grown because what he has done and what collectively has been done, from Teams and FIA, but it has also grown because of **legislation**, **emissions issues**, because the time is right now for people starting to consider buying electric cars because of the reasons we all know, and it is a combination of all of these which brought FE where it is now." (Informant Q)

"I had discussions with Jean Todt [FIA president], to go in a different route, to go into the cities and electric and he was also pushed forward from **politics** and **community**, **EU commission**, **Mayor of Paris**, that the future of racing will be electric so we got a lot of support even from very different areas than we thought." (Informant AF)

Previous research on the relationship between the socio-economic landscape level and other MLP levels are limited in sustainable transition literature (Geels 2012). The transition management literature, on the other hand, defines this relationship as indirectly steering the action of the regime level and redirecting the choice of actors (Loorbach 2010). However, the main phase interviews offer a rather different picture, suggesting that this relationship is direct as both former technical director of company 8 and sporting director of company 11 explained.

"I think the problem was already there from S1 as we had a big problem, like **Fukushima**[21], after that Merkel said we are going to kill all auto and I think then different sources of energy become of interest." (Informant L)

"**Zero emission**, **urban mobility**, has played a big role [in shaping FIA Formula E] and it is continuing to play a big role." (Informant O)

Data shows that this direct relationship between the landscape level and other levels is dynamic, and changed with time as the championship evolved. Different groups of actors address this changing dynamic in their interviews, including the CCO of company 13 and the former technical director of company 11.

"I think the level of awareness [of global challenges] was tiny, very low in S1, it still has a long way to go, we have just begun to scratch the surface of some markets but there is a long, long way to go, but now it is getting reasonable." (Informant R)

"Interesting enough I do not think this [global policy] has influenced FE as such but definitely has influenced the growing participation

[21] In this subsection words have been put in bold to indicate the determinant of the socio-landscape level and specifically global issues, and national and international policies which have contributed, in the opinion of key informants, to the innovation dynamics.

> of other businesses in FE, even the announcement this week of ABB joining the formula, is definitely influenced by **industry trends**." (Informant O)

Expanding on the reasons behind their perception of a direct influence of the landscape level in this transition, interviewees pointed out that there is a direct connection between the FIA and some of the actors sitting and influencing the socio-landscape level. The quote below offers an example of this direct relation.

> "FIA FE has a different approach, but this is also due to the FIA having a role in **mobility and society.**" (Informant AF)

The role of the FIA in mobility and society was uncovered further by the help of an institutional map of FIA (Figure 14), which was developed for the purposes of this research. Specifically, this map shows that FIA has two departments directly involved with national and international policy: FIA campaigns and FIA mobility. While the first department engages with global challenges such as pollution and education, the latter, promotes accessible, sustainable and safe mobility for all. From this map, FIA mobility is linked to the FIA councils for automobiles, mobility and tourism, which deal with automotive and social campaigns in different nations. The members of these two departments are generally leaders in public policy at a national or international level, an example of this direct relationship between the policy regime and the socio-economic landscape:

> "Defining global public policy positions, concluding reciprocal agreements on service exchange, and issuing international documents […]. As a direct result of this work, the FIA is officially recognised by the United Nations, where it has special consultative status and sits on several of its transport-related working parties." (FIA n.d.).

Additionally, an accurate analysis of other non-institutional actors that sit at the patchwork of regimes level identifies direct relations between those actors and organisations or policymakers which sit at the socio-economic landscape level. Some examples of this direct link are: Agag, CEO of FEH was MEP at the European Parliament between 1999 and 2002; Longo, Deputy CEO of FEH is an international lawyer; Lord Drayson is a UK politician and former Minister of State in the Department for Business, Innovation and Skills; and Qualcomm

Technology Inc. which was directly involved in the UN Framework Convention on Climate Change meetings in 2009.

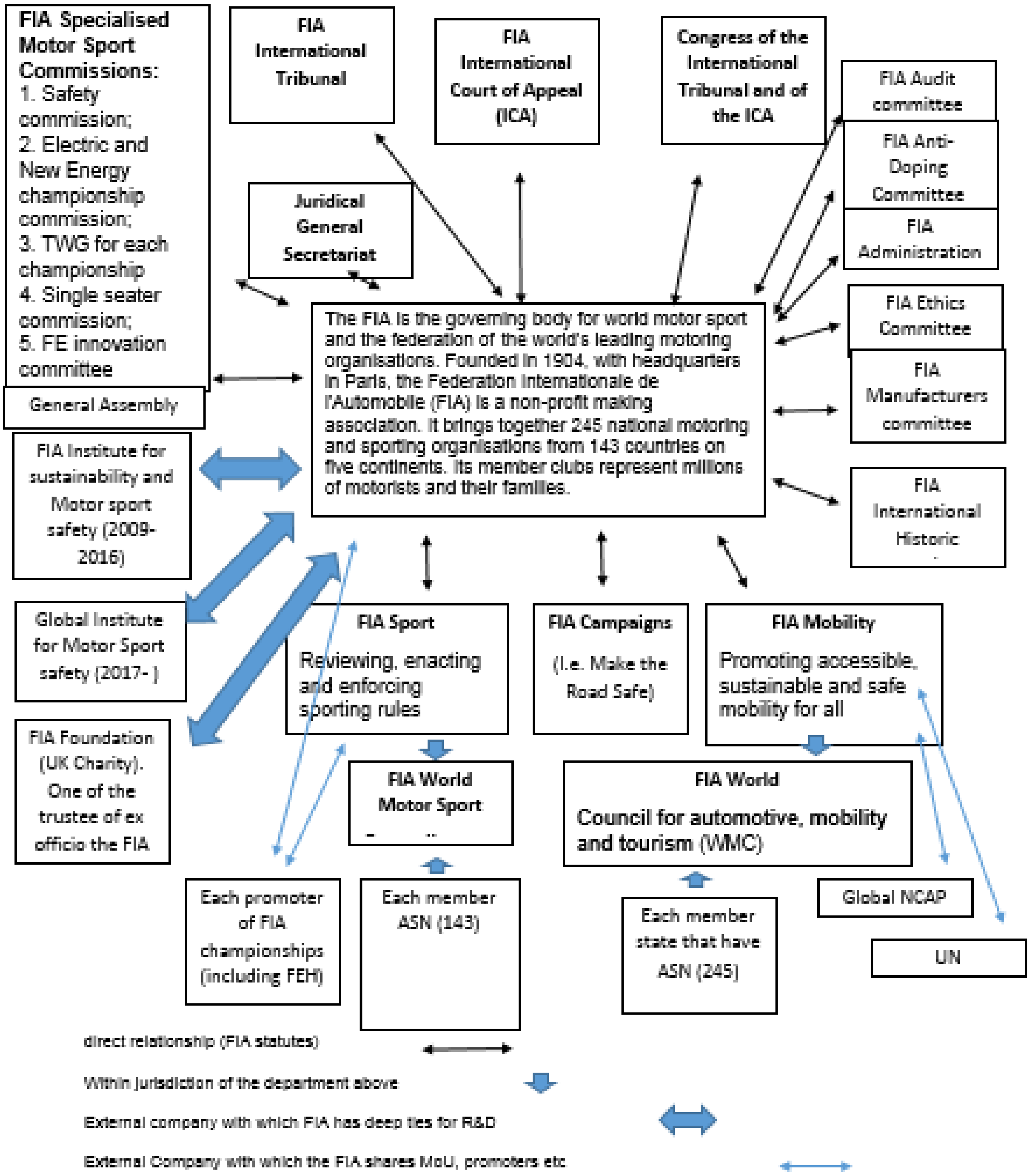

Figure 14 Institutional map of the FIA (author's compilation)

Hence, the socio-economic landscape level has direct agency within this transitioning system, influencing the patchwork of regimes level directly and shaping this low-carbon socio-technical transition by putting its pressure to fruition and triggering changes in the traditional system (i.e. FIA).

> "I think the FIA was influential both in the sporting side of the championship but also in a political sense, helping the championship to race in the places they have been". (Informant AC)

> "I think it all started from the FIA back in 2012 - I do not know why, but the word is that the European Commission went to the FIA and they say look, it is not a secret this will happen, and the FIA wanted to have a championship as a way to promote this technology. You cannot have motorsport that is going one direction and the world is going to the other direction." (Informant Y)

This direct agency of the socio-economic landscape level and its implications, which key informants have identified as paramount in helping to overcome lock-in mechanisms of established regimes which "make difficult to dislodge existing systems" (Geels 2011: 25), will be discussed further in chapter 7.

6.3.2 Patchwork of regimes level

Geels (2011) defines the patchwork of regimes level as the space where technological regimes, socio-cultural regimes, policy regimes, science regimes and the user and market regimes co-exist (chapter 2). These actors were first identified by the interim flow charts (section 6.2), and then, those data were triangulated by additional semi-structured interviews to build MLP schematics. These interviews have underlined that the composition of these regimes is dynamic, changing with time when the system develops, as the following quote confirms:

> "I think there have been significant changes in stakeholders very quickly and very significantly in just a few short years. It has evolved from a racing series with just one or two corporately backed teams, to a grid that primarily comprised of OEMs or OEMs backed teams." (Informant AD)

The sub-sections below proposes quotes that contribute to the operationalisation of the patchwork of regimes level.

6.3.2.1 Technological regime

Based on Rip and Kemp's (1998) definition of the technical regime, Geels (2001) includes different firms that shared similar routines, and which produce a technological trajectory (Geels 2001: 6). The following quotes, from senior managers of companies 14, 12 and 13, are significant in identifying firms to include in this regime.

> "Agag appointed Fred Vasseur to set up a company to design the car. So Fred had big contact in motorsport, and we selected every single subcontractor to achieve the target set by Agag. Basically, he comes to us, and he said: design an electric single seater, it must run 20 minutes at the pace of a Formula 3. There were these three requirements. Design to be innovative." (Informant K)

> "The key players in the early days were **FE**[22], **Spark**, **McLaren** and **Williams**." (Informant X)

> "If you talk about technical level, there were some **manufacturers** changing the focus and working with different **suppliers**; I guess just becoming more and more competitive. […] So I think in **S1 there were a set of series partners**, **S2 the focus has changed** in terms of **manufacturers** and any **technical partners** they were working with, and as the season keeps growing with the manufactures, they will take more and more of that work in-house." (Informant P)

> "So there was a lot of changes at the last minute. After that point it became very steady and to be fair we stuck to the road map, the main difference was that in S4 and S5 - opening the battery- **we** [**Teams**] discussed it when the series started, but this had not happened." (Informant Y)

[22] Words have been put in bold to underline actors and/or groups of actors who are included in this regime.

The extracts below were provided by three different categories of informants (chapter 4), and all suggest that this regime is dynamic and changing with the unfolding of FIA Formula E.

> “The name of the companies changed too from the beginning, **DHL**, **Renault**, **QUALCOMM**, **Michelin**. Before the first race basically there was a long preparation of the project, certain parts like, for example, the safety protocol, were followed by all and all the companies were involved […]. The **FIA**, **FEO** and the **teams**… the teams were not involved from the real beginning […] they were involved, let’s say, one year before the first race only. Before that, they were a lot of companies all under the leadership of the FIA.” (Informant Q)

> “So there were big changes right at the beginning, before going racing, Lord Drayson give up on his teams, and so did a very well-known Italian F1 racer in S1. They [Trulli] had a very difficult season, did not work out for S2.” (Informant J)

In the extract below, the CTO of company X correlated this change of actors in the technological regime during seasons to changes in both technical regulations and vision of the championship.

> “The original concept was perhaps a lot wider than what we had today, it had the vision that maybe other car manufacturers will come along and design another Formula E car, to be competitive, so in the old days you had a **Lola** and a **Reynard** and a **Dallara**, compared with the **Spark** guys and I remember **Wirth** research was very interested in producing a car and I am sure there was someone else like **Mygale** or other **race constructors** that would have been interested.” (Informant X)

Although the inclusion of the FIA within the technological regimes could be argued, informants have highlighted that the role of the FIA during the infancy stage of innovation was only on safety grounds, mainly at a regulatory level.

> “In season 1, FIA was only involved in the safety aspect as it was all new, they were only involved with this and FEH sporting rules.” (Informant K)

> “In a way the FE ecosystem is becoming more traditional from S5 and the then FIA role is increasing as all the manufacturers are coming in and the level of competition is increasing very fast the FIA need to be more and more rigorous in the way they manage the championship because you don’t want any big dispute and issue around performance for the manufacturers.” (Informant X)

Table 6-B presents a summary of the changes in the technological regime during each season, outlining the status/involvement of the different actors.

Table 6-B Summary of changes in actors and groups of actors between S0 and S3 (author's compilation)

Actors/groups of actor	S0	S1	S2	S3
FEH	Involved	Involved	Involved	Involved
Spark Racing Technologies	Involved	Involved	Involved	Involved
McLaren Applied Technologies	Involved as a single supplier for e-motors, sensors and ECU	Not involved as a supplier to the teams only	Not involved as a supplier to the teams only	Not involved as a supplier to the teams only
Williams Advanced Engineering	Involved as a single supplier of Battery System	Involved as a single supplier of Battery System	Involved as a single supplier of Battery System but also as a single provider to one Team	Involved as a single supplier of Battery System but also as a single provider to one Team
Manufacturers	Not involved	Involved	Involved	Involved
Technical Partners	Not involved	Marginally involved	Involved	Involved
DHL	Involved	Not actively involved	Not actively involved	Not actively involved

Actors/groups of actor	S0	S1	S2	S3
Renault	Involved (safety partners for the championship)	Not involved (Involved as a sponsor of the championship)	Involved as a Team	Involved as a Team
QUALCOMM	Involved	Not involved	Not involved	Not involved
Michelin	Involved	Involved	Not involved actively	Not involved actively
FIA	Involved	Involved	Involved	Involved
Teams	Not involved	Marginally involved	Involved	Involved
Race Constructors (Lola, Mygale, Drayson, Wirth)	Involved	Not involved	Not involved	Not involved
Dallara	Involved	Involved	Involved	Involved

This table identifies two critical findings:

- Reading across the rows, the position of these actors change within this regime, as the dichotomy involved/not involved underlines (i.e. Teams were not involved in the technological regime initially, and from season two they became marginally involved to being involved in season three). Additionally, it emerges that actors migrate across different regimes and amongst different levels. Specifically, whilst DHL was actively involved in season zero in shaping the technology of the championship, in season one, the analysis of the data shows how the involvement of this actor has changed.

- Similarly, reading across the columns of table 6B, it emerges that the composition of the technological regime for each season changes, confirming previous data about the changing dynamics of this regime.

6.3.2.2 Policy regime

Within the FIA Formula E system, informants have illustrated the role and composition of the FIA, its committees and working groups (Figure 14) as playing an active part without causing inequalities (Fischer and Newig 2016) and offering support not only from a financial point of view but also, and most importantly, in assisting with technical and sporting regulations.

> "I think the FIA was influential both in the sporting side of the championship but also in a political sense, helping the championship to race in the places they have been." (Informant AC)

> "We certainly have relied a huge amount on the FIA in terms of creating the rules, the regulations that have allowed the championship to flourished, to develop." (Informant H)

> "My immediate experience of the FIA in season 1, FIA was [involved with] the drivers, the technology [rules], steering the championship as FE did not know what they needed." (Informant L)

Other informants have pointed out also the active role that FEH, which is referred below as FE, has played within the policy regime.

> "**FE** comes up with something to start with, and then the **FIA** and **Spark** were the ones that come out with the regulation and technical side of things […], so it was the case of making a car and making the rules." (Informant J)

> "We cannot say this is **FIA** or FEH, this is cooperation, we are all in the same boat and this is what is making it happen. [We] can build it together, in a long term vision." (Informant V)

While the policy regime has included FEH during the infancy phase of FIA Formula E, the role of this organisation and consequently its position in the MLP schematics has changed with the unfolding of innovation (Figure 12 and Figure 13), as key-informants have pointed out.

> "Formula E, both FEH and FEO are now the promoters of the sport, and FIA is the governing body in the sporting and technical

> regulation as much they are in other motorsport championships". (Informant P)

During the growth phase of FIA Formula E, informants have uncovered traditional (for the motorsport industry) and non-traditional (taken from the business industry) ways of governance which were put in place to account for the different actors involved in the championship, as quotes below confirm.

> "Because you have now the manufacturers coming in this has gone from one make in S1 to multi-make in S2 which was very quick and then the FIA by definition become much more involved" (Informant Y)

> "I am pushing for different working groups, technical working group, sporting working group, marketing working group and the financial working group and we have an FE innovation commission. Moreover, what I ask for, is to have something like a project, every request should be handled like a project, which is totally unusual for the FIA. All the information is coming together on the desk of XX. He has to collect information, to handle the project, it has to be done by an FIA person because this is an FIA series and so in order to push discussion forwards [we need to] bring together all the information together and to give them to all the parties, and then we read them and make a decision." [AF]

While the Technical Working Group is implemented from season one, the Innovation Committees and other working groups start to be fully functional only by the second half of season 2 onwards, as previously summarised in Figures 12 and 13. Those committees represent the vested interests of the growing number of actors entering FIA Formula E and the need to accommodate those different interests. A full description of the committees and groups will be given in section 6.4.

6.3.2.3 Science regime

Schot and Geels (2007) present the science regime as including R&D infrastructures and universities (chapter 2).

Only 7% of key-informants have addressed universities being involved in FIA Formula E, mostly during the infancy phase of innovation. The extract below underlines that advisors from universities were used in season zero and one, to assess the feasibility and state of technologies and to advise on regulations.

> "We used technical experts for the technology to value where we are, and to decide technical advancement and solutions to incorporate into the battery tender." (Informant AF)

> "XX, working at the technical university in Lausanne, he is our technical expert of where we are and how we should go there, and for example, it was different technology in the other tender, but I cannot name the other expert as everything is so secret." (Informant AF)

Data have suggested that the Innovation Committee and the Electric and New Energy Committee (part of the FIA as shown in Figure 14), both sitting at the policy regime, still retain some of those links with academia in the growth phase of FIA Formula E. However those links have a reduced capability compared to the infancy phase of Formula E. Contrarily, teams have explained that they have made very little use of universities during the infancy stage of FIA Formula E, relying on well-known companies and in-house capabilities to develop their technologies. Though, the COO of company 15, forecasts changes to this non-engagement in the future.

> "In terms of the bigger science community involvement, academia, I would say there has not been so much traction until now, but this is definitely going to change - for example, I can say […] we are going to work with universities to develop programs so for sure we are all doing the same. More OEMs are starting to work closely with local universities." (Informant Y)

6.3.2.4 Socio-Cultural Regime

Acknowledging that technological trajectories are not generated by technology only, Geels (2011) introduces the socio-cultural regime to account for the cultural dimension of transition. This regime "interpenetrates and co-evolves" (Geels 2011: 27) with the other regimes. Differently, to other regimes, the building blocks of this regime are factors embedded in society such as popular culture, responsibilities, society belief, shared value, environmental concerns, etc. The following quotes identify factors that are included in the socio-cultural regime for FIA Formula E.

> "I think it is important as it is in tune with popular culture, the development in society, the development of environmental responsibilities and sustainability." (Informant AE)

> "The thing about electric mobility that is a very key point is that e-mobility is not just about technology, it is about range anxiety, it is about racing, it is about performance of cars and what we know is that if you could portray electric vehicles in a cool, innovative way, driving at speed, having fun, having competition, you change the perception of EV being a boring utilitarian car, with something cool, sexy, amazing, people will start to go out and buy an electric car which then fosters the amount of money that is needed for the development of electric vehicle. Formula 1 does not give you the performance for your engine, but people buy them anyway, so that is what we want to see, breaking down the cultural barriers." (Informant H)

> "Mr Agag was all time pointing out that it is real, the global warming is not a show, it is a reality, and we serve with our exposure to show that sport and motor racing in that way, leads the way." (Informant Q)

The analysis of the data suggests that the factors which sit at the socio-cultural regime are the same global challenges that emerged from the scoping phase of this research (chapter 5) confirming that, in line with theories of technological change, it is not just technology that shapes technological transitions, but also society and macro-events (chapter 2). Data outlines that these factors remain very much the same in the short and medium terms, contrary to the speed of change of other regimes. This finding confirms that the concept of time within the MLP regimes is not linear (Geels and Schot 2007).

6.3.2.5 User and market regime

Within this context, the motorsport value chain framework (Henry et al. 2007) has offered a definition of users and markets for the motorsport industry (chapter 3). The MLP approach brings those two concepts together under one regime (chapter 2).

Key informants' interviews have highlighted how, in this context, users and markets have multiple connotations, and concluding that two separate regimes are more appropriate (as presented in Figures 10, 11, 12 and 13). As discussed in section 4.6, users and consumers were not directly interviewed, due to the sudden unavailability of the first group (drivers) during the time at which the interviews were carried out and the difficulties of providing an adequate sample for customers in the designated timeframe of the PhD (section 4.6). Whist a questionnaire distributed to spectators during the race could have been considered most suitable, if time would have allowed, experts and journalist appropriateness as a proxy for users and customers in the FIA Formula E system was investigated. In other word, from an initial analysis of the data collected from these two typologies for actors, were correlated to users' and customers' opinions identified in the scoping phase of this research, and specifically from documentary data. The results showed a good conformance between the users and customers' data and the one collected from journalists and experts. Hence, it was decided to use journalists' and experts' interviews as suitable proxy respondents for this particular viewpoint on the system, as their access resulted far more viable and less time consuming.

The quote below confirms this richness of the data offered by experts' interviews and highlight the need to differentiate between the user and market regime.

> "Users: is a user the person who drives an FEV car or the fan? […] I think this is a 2 way thing - the sport needs the fan, growing the reach is a priority and also from what I see the fans are very close and we understand they are quite sophisticated, they just don't want to watch a video and forget, but they want to have their say. […] The second pillar has to be marketing promotion and FE is here to promote these technologies, all the things we are developing we

> have to put them on the track and make sure the fans say oh these are amazing, these cars have really good technologies." (Informant Y)

Recently, Schot, Kanger and Verbong have explored the role of users in shaping transitions, recognising that "a core focus in the transitions literature is on how to nurture the introduction of potentially disruptive technologies that are already available" (2016: 2). The analysis of the data from the main phase of this research confirms that users are important for this low-carbon socio-technical transition. As the quotes below argue, users were responsible for changing the demand of the innovation proposition (Schot, Kanger and Verbong 2016) and shaping new routines which are not necessarily in line with traditional motorsport.

> "In sport, you very need to get involved them [users] in setting up the rules, very much like fanboost where the more voted driver get an extra boost of energy which allows [them] to defend or to attack. […] In many ways, it is making the relationship between the sport and the people far closer. It is not only watching a race in your house, now we can all watch in your house, in buses, on your mobile phone, and you can participate in the outcome, influencing the outcome through your vote." (Informant H)

> "[They] build something that is all about fan connection, to an audience that does not understand motor racing in the middle of capital cities." (Informant AB)

> "It is waking people up on the fact that motorsport is losing its fans, most motorsport fans are 40-50, [the] younger generation teenager does not have much interest in motor racing maybe do not have much interest in driving cars. So what FE is trying to do is to appeal to that generation and show that motorsport is interesting because it is relevant." (Informant H)

As discussed in chapter 3, Henry et al. (2007) suggest that there are two markets that motor racing is targeting: the market of the motor industry (automotive) and the market of the racing industry. The analysis of the data suggests that FIA Formula E actively targets a new market: the entertainment market. Recognising that entertainment is the main feature of each sport, interviewees have underlined that fan boost, digital platforms and the racing format of this fully electric championship were introduced to target the entertainment market directly.

> "It is new, different, entertaining, exciting, we are clearly a very much digital driven championship or sport, and we are of interest for a young generation than the one watching F1, we are appealing to a different audience although there is some transfer of people across [from traditional motorsport] which are starting to look at what we do." (Informant H)

> "What Alejandro and his team recognised [is that] motorsport, actually is not the right word, motor racing is entertaining, its sport and engineering it is a factual product of what we are doing. At the end of the day people have to enjoy it, they are excited, that is what makes me realise that sometime fanboost which all seems a gimmick to an engineer why we should be doing that should all be aerodynamics, does not really matter what makes people excited in the stand." (Informant X)

It is the richness of the data on the role of users and the different markets that FIA Formula E engages with, that is the reason behind this research decision to split Geels' (2011) users and market regime into users' regime and market regimes.

6.3.3 Niche Level

As seen in chapter 2, Geels defines niches as "individuals or small group of actors, with local practices which differ from the regimes" (2011: 27). He includes R&D laboratories ("protected space", Geels 2011: 27), start-ups, spin-offs and any actor who could potentially carry seeds for transformation, technologically, commercially, or culturally. Informants have addressed tier 1 and tier 2 incumbent suppliers of the motorsport industry (Dallara, Williams Advanced Engineering) as the micro level, the niche level, pointing out that the technology development at this level could not have been successful in destabilising the traditional motorsport, as there is no rules and alliance at this level, and every company pursuit their own development and financial goals.

Geels defines niches as being crucial for triggering socio-technical transition, as they provide the seeds for change. Once a technological innovation, which substantially deviates from the existing technology, has developed within the niche and diffused into the mainstream market, this can destabilise existing regimes creating windows of opportunities for the technological innovation to be adopted. Niches are the protected space for technological innovation, an incubation room protecting novelties from the mainstream market, with few and rather abstract and generic rules (Genus and Cole 2008).

As some of the key informants have pointed out, FIA Formula E was not triggered by a novel technology emerging from a single company, but from the pressure of the landscape level together with a business opportunity which the policy regime and the socio-technical regime decided to enforced, at the patchwork of regime level. The electric battery technology used for the first electric racing car, was, in fact, one of the already available technologies in the mainstream market of adjacent sectors, such as the automotive sector. Hence the traditional bottom-up approach of the MLP where a radical technological innovation diffuses into the mainstream market, does not mirror the story of FIA Formula E which the interviewees have narrated, which has instead emerged as a business model innovation at the start.

Recognising that early works have been specifically focusing on this bottom up approach, Geels calls for a more specific attention to regime and landscape levels, to address processes that “operate downwards from general feature of the socio-technical landscape” (2012: 32).

As regimes are the same actors involved at a niche level but with more structure and with formal rules, following Geels (2018) recommendation to research further the patchwork of regimes level and landscape level to identify other mechanism rather than bottom up which could enabled transitions, this PhD concentrates its efforts in investigating regimes and landscape levels, disregarding the niche level. Data has shown, in fact, that a business opportunity within the existing system (traditional motorsport) and institutional (FIA) and socio-political factors (national and international policy and global challenges) were the main triggers for this low-carbon sustainable transition and not a radical niche innovation.

6.4 Temporal understanding of the interaction across and between actors in this system: intra-system dynamic

Chapter 5 has shown that FIA Formula E involves a complex interaction of factors within three main themes, which together with global trends interact in time and combination when innovation unfolds. The strict relationships between technology, business, regulation and global challenges have been confirmed from the majority of the main phase interviews. A former director of company 8 and the CCO of company 6 summarised it in the below extracts:

> "I don't think FIA is in charge of technical matters in the broad sense, the **strategic policy** of where FE is going, and should go, must be a strategic decision made by the owners of FE in the future, when we switch from the one-stop battery, when there will be free chassis, when there will be free aero development. Those are **commercial** questions first, and **regulatory** questions second. […] The FIA might develop a set of very clever **regulations** but the drive for the future development of FE will come from the owners of FE, and they will be informed by the Teams and the manufacturers involved in FE." (Informant AB)

> "[…] What we wanted to do, was to ensure we had a **business model**[23] to allow them [car manufacturers] to nest and give a return in terms of **IP** and **technology**, which enhances people's adoption of these [EV] vehicles. Now, this was very important! What we wanted to do is to make sure we create real cost control in the championship, so we do not allow aerodynamics, competition between teams, because that is out of scope, this is money that should be spent **to create value** on the areas **of technology** that the world needs **to move on**." (Informant H)

[23] The words in bold highlight how the dimensions, which were identified in chapter 6, from documentary data and scoping interviews, recur in data gathered during the main phase interviews. These dimensions (business, technology, regulatory and landscape) are interconnected (Freeman 1989; Perez 2009; Pinch and Bijker 2007).

The following quotes reinforce further the concept that it is not just technology that enables transition (chapter 2).

> "You can say that if the best **technology** has been used and no one is interested the model has no sense." (Informant H)
>
> "The problem is that **technology was only one side of it** and some packages were not good enough on the technical or on the organisation side so at the end *we* decided, and some technical proposals were a bit crazy - overoptimistic let's say." (Informant U)

This interaction amongst different factors (chapter 5), which is a result of the complexity of our world, is reinterpreted through the lens of the MLP as interactions amongst regimes or intra-system dynamics. The analysis of the data suggests that the intra-system dynamics can be explored further by understanding several working groups and committees that are involved with shaping the FIA Formula E technological trajectory. Specifically:

- **Technical Working Group (TWG)**

  The TWG focuses on the technology that is allowed within the championship, what materials are allowed to be used in the car, which areas are open, which are closed, the roadmap going forward. The TWG is a forum where only manufacturers' technical representatives can take part, as extracts below underline.

  > "The TWG meetings are forums where manufacturers' technical representatives can steer the future of the sport from a technical point of view." (Informant P)
  >
  > "Initially, in S1, there was not a TWG because, just because, the cars were all the same, so in year one no TWG but there were meetings we could have gone to. Then, with the arrival of manufacturers, the TWG was formed." (Informant I)
  >
  > "In S1 teams and suppliers were participating in the TWG […] but there was always mostly a representative from FE that would keep the quality amongst the teams' proposals." (Informant X)

- **Sporting Working Group (SWG):**

The SWG allows one person for each team (entrant) to take part in the meeting, together with representatives from FIA and FEO. It focuses on the sporting regulation as the quote below reiterates.

> "It has team principals, FIA and FE; we are talking about the sporting regulation, so how long is a race, the pit stop time, what is the weight of the car – sorry, no - Sporting is more about the show itself." (Informant H)

- **Commercial Working Group (CWG):**

The CWG was introduced at the end of 2017, and it is considered at the same level of TWG and SWG. It is mainly made of heads of marketing from teams and manufacturers and FEO and FIA.

> "The CWG is at the same level of TWG and SWG. It started later than those groups, only starting in 2017 whereas TWG is in operation since 2014. It is mainly made of heads of marketing from Teams and Manufacturers and FEO and FIA, the commercial people. The idea is that **technical people** will have their say on where **technology** is going, **sporting people** will have their say on **race format** and **commercial people**, in the CWG, will have their say for **marketing**. For example, if the technical group would say we should have 4-wheel drive, double powertrain cars because this is technically advanced, it could be that the CWG will say hold on a second, we have to consider the cost or could say this is not in line with the manufacturers' strategy. So, the idea is that the three working groups collect their thoughts, put them together, and the decision is made based on very good information." (Informant R)

> "The commercial working group […] is to look at the long term market that teams want to be in, how we market the ecosystem, instead of the motor vehicles market, as we use the teams and drivers, as an extension of our family, so we have a family far more holistically together, the relationships are very close." (Informant H)

- **Innovation committee** (or also known as FE committee)

The Innovation Committee is in charge of approving or rejecting all the decisions taken from the working groups. This committee, which comprises of 20 people, discusses how decisions will affect the championship and its roadmap from a technical, sporting and commercial point of view, in order to make recommendations for the World Motorsport Council (WMSC).

> “Then, what they [working groups] decide, goes to the committee and the committee will discuss how that technology decision will affect the championship and its roadmap from a sporting point of view and a commercial point of view, so they make a decision on what is right for FE.” (Informant H)

> “There are 20 people within the Innovation committee, but only 6 or 7 can vote. All in all, it is so nice an environment that we never had to come to a vote. We take decisions collectively, between FE and FIA.” (Informant T)

> “Final decisions are always made by the innovation commission, which comprises of various different people from FE, FIA, outside experts, which have the final decision making. Well, I say that, but they can only make recommendations for the World Motorsport Council to decide. So the WMSC will decide on the ultimate technical regs and sporting regs but what we are doing here is to work closely with them to decide that good technical and sporting decisions are made because it is no good to produce technical regs and sporting regs when manufacturers do not want to be part of it.” (Informant R)

> “There is the president of the ENEC (Electric and New Energy championships committee), he was the former president of BMW, he is the one who is getting it [electrification]. From FE, you have Agag, Alessandro Longo, there is someone from the juridical side, marketing and TV, Benoit, for the sporting side, Carlos Nunes, logistic and technical. From the FIA side, you have the technical director, Niclot before and Simon now, Frederic Bertrand, from the marketing side, myself as manager of the project and the secretary of ENEC and at the beginning, we had someone from SPARK and communication from FIA.” (Informant V)

- **Formula E Team Association** (FETA)

  FETA was set up in 2014 as a teams' forum to discuss and cooperate supporting the championship to grow. It has now evolved to incorporate manufacturers, and the idea behind this association is to work with the promoter and the FIA to bring the series forward, chairman of FETA underlined below:

  > "What FETA has done over the last 3 seasons and hopefully continuing after that, is tackling issues and making sure when we go to FEO or FIA we have a common voice, we are already in agreement because the FIA doesn't want to listen to us if 6 out of 10 are interested in something, it has to be everybody or nobody." (Informant X)
  >
  > "[…] for sure Alejandro has the vision, but he cannot do without us [teams], and we are trying to guide him, as we have OEM partners and experience and we are trying to say yes we agree with that, no we don't agree with that, yes we could agree with that if you make these modifications." (Informant X)

These working groups and committees were put into place at different times of FIA Formula E, as outlined from Figures 10, 11, 12 and 13. Notably, the TWG and SWG, two groups already existing in traditional motorsport, made their appearance respectively halfway through and at the end of S1. The FE Innovation committee and the FE Team Association are active in the growth phase of FIA Formula E. However, the CWG emerged as a new concept in motorsport, which only appeared at the end of S3 when the championship was well in its growth phase.

The different time at which each group was originated highlights the changing dynamics of the championship. Whilst technology was the main focus during the infancy stage followed by sport to enhance the interest of the show when the championship reached the end of the growth phase, the sustainability of the championship versus the business resources of new entrants, mainly OEMs, became the main focus. The analysis of the data suggests that this is the reason for the CWG, which ultimately provides feedback on costing for any sportive and technical amendments proposed.

Data has also uncovered that during the early stage of the infancy phase of FIA Formula E, the absence of these groups and committees was filled by the FIA and FEH, as also observed in section 6.3. Interviewees have addressed how the two leaders of these organisations and their shared vision have been instrumental towards shaping and enabling the championship, confirming previous findings on cross-contamination of actors between regimes.

> “I think Alejandro Agag has been visionary, often, in respect of creating this championship, really working alongside Jean Todt […] I think it is all about having a vision of the future, where is the vision going, where is the future of motorsport, where leads the future of road transportation” (Informant P)

> “I think Jean Todt was very much the driving force behind all this thing, and this is the reason why Alejandro was able to succeed with this as he had at the back Jean Todt, if you’ve got the backing of the head of the FIA the rest of the FIA has to fall into line and follow. It will have been a much difficult process if Jean Todt has not been supportive of this if he would have been as sceptical as most of the motorsport world it would have been a much harder process.” (Informant AC)

> “They [Agag and Todt] both drove each other as I think the initial idea was tendered by Jean Todt and no one entered the tender when he did it. That is the history - there was a tender sent out, and nobody entered and then when Alejandro found out about the idea, starting to think about it he was the one that had the vision that matches what they were after.” (Informant J)

Finally, the extract below is an interesting example of the interplay between the socio-economic landscape level and the patchwork of regimes level already discussed in sub-section 6.3.2:

> “[Formula E] has come about at the right time because of the number of aspects which converge at once, you know, **legislation**, **climate change**, and continuing climate change messaging, and **emission concerns**.” (Informant O)

This intra-system dynamic shapes and enacts the transition pathway of FIA Formula E (chapter 7).

6.5 The nexus of interconnected systems and the changing dynamics of the FIA Formula E: inter-system dynamics

As discussed in section 2.4.2, Papachristos et al. have focused systems' interactions in socio-technical transition:

> "In the majority of published studies to date, the MLP considers system transitions as standalone processes, i.e. as a result of interactions taking place internally in a single focal sociotechnical system, with additional system elements situated in external landscape, regimes, or niches, external to the innovatory system. However […] it is very rare to find societal and sociotechnical system transitions which are not influenced at any stage of the transition by processes taking place in other interrelated systems" (2013: 1).

Coherently with this study, this PhD investigates the nexus of interconnected or interrelated systems with the changing dynamics of FIA Formula E as inter-system dynamics. Similarly to Papachristos et al. (2013) and Papachristos 2014, senior managers have in fact stressed how low-carbon sustainable transition in motorsport is not a standalone process, but it has been influenced by other adjacent[24] interrelated systems, most precisely the automobility, entertainment and electronic sectors. The quote below explains:

> "So when the decision came to enter FE the question was what platforms are out there which can give our brand as manufacturers an exciting and engaging platform to develop our [electric] brand, which will be the brand under which we will compete in FE, and FE offers itself a very logical and sensible opportunity to do that because, through this technology, which is an important future technology for the OEM industry and mobility industry, it brings

[24] The word adjacent is used to identify systems which share some of the expertise and knowledge of the FIA FE system.

> excitement, emotions, competition all these things that effectively motorsport can do.” (Informant AE)

However, as this informant has pointed out and differently from Papachristos et al. (2013) third pathway to transitions (section 2.4.2), FIA Formula E was not a new system emerging, at a niche level, from the contribution of technologies developed in existing antecedent socio-technical systems, neither arises from the combination of resources, technologies and competences of two parents system, acting as an outsiders from both systems. Rather, FIA Formula E develops as a well-structured patchwork of regimes, who come about as a business needs in the motorsport system, mirroring the evolution of the technological trajectory of adjacent sectors (particularly automotive) and fulfilling a different societal need within the motorsport system of systems (chapter 1).

This interaction between the innovatory system of FIA Formula E and the automotive sector is reinforced by a former senior engineer from company 16, whose interview has unveiled the existence of an informal group composed only by automotive manufacturers, during the infancy phase of FIA Formula E.

> “They also have another group which they call like a potential future manufacturers group, BMW, VW (Joe Capito) were in it, they had a separate group as FE was trying to attract manufacturers and what they did yes, you had the TWG which in theory was giving you the road map, but they had this future group behind it which was also trying to dictate the road map because basically what they didn’t want was to say is this is the road map because this is what the teams agree, and if they then had 4 manufactures say well, we didn’t want to sign up for that. Mercedes could be, no Renault, Audi (Domenicali). This group liaises with FIA.” (Informant AA)

During the growth phase of innovation, data shows that many automotive manufacturers start to take part in the Technical Working Group including BMW, Mercedes, Jaguar, Mahindra, and so on.

6.6 A disruptive innovation in the motorsport system: what is it that FIA Formula E is disrupting?

Aside from being addressed from the press as disruptive innovation, FIA Formula E was awarded the disruption prize from Prof Christensen (Disruptor award 2018), in 2015. This prize is awarded to the company which fulfils all the requirements of Christensen and Raynor's litmus test (2013) and can be then considered disruptive in the meaning of the theory of disruptive innovation (chapter 2). In order to investigate the level of disruption awareness (Vriens and Solberg 2014) of the 26 senior managers and experts and to understand the factors behind their answers (Christensen and Raynor 2013), all interviewees were asked if FIA Formula E was a disruptive innovation and what made it disruptive. The question was posed openly ('Is Formula E a disruptive innovation?'), which resulted in open answers and multiple replies. This section presents the outcomes of the analysis of these data, organised by the framework used during the process of coding (chapter 4) in line with the theory of disruptive innovation (Christensen and Raynor 2013).

6.6.1 Technology disruption

When questioned if FIA FE is a disruptive innovation, only 10% of key-informants addressed technology disruption, all with a negative connotation (not disruptive).

> "**Electric powertrain is not disruptive**; it is an innovation but I mean the unfortunate thing is to get the right message across we have to be in the inner city". (Informant J)

> "No, it is more difficult to confirm that technology is disruptive in that way, development has definitely accelerated the technology, but whether it is disruptive, **I do not think it is** but is certainly leading the acceleration of electric powertrain performance." (Informant O)

> "**It is not disruptive for the technology at all**; I think it is driving technology. Forcing people to develop much quicker, I think it is pushing to do this. If I am honest, it is really focusing on the e-mobility." (Informant L)

> "FE is following what is going to happen in road cars. What I heard from manufacturers is that some part of the development they do from motorsport can come from road cars and this is the first time in years I hear this. I was sceptical about track-to-road, but it looks like that some manufacturers really think this is the way it works in FE. Basically, the main part is all about software; they work a lot for efficiency, and they find a lot of small strategies that can be used for a normal road car." (Informant U)

6.6.2 Business model disruption

Eighty per cent of the interviewees addressed business disruption as the reason why FIA Formula E caused great grief to incumbents. The academic literature defines business model disruption as a rapid displacement of an existing business model (Hwang and Christensen, 2008). The business model displaced, in this research context, was addressed as the business model of Formula One, by the majority of key informants.

> "It is disruptive to the global sport, and I will even go as far as saying it is disruptive for entertainment, I do not think we are sports, we are an entertainment part, it only happens that our actors are drivers, are team principals, mechanics and engineers, female drivers. We believe that society will be different in the future and if we constrain ourselves in motorsport, we will not achieve our objective. We need to grow, motorsport fans are important, but we need to be much more to have a true impact in society." (Informant H)

> "I think it has done more not because of the product but because of the way they have done it. It is a social media led strategy, good use of highlighting, leveraging the film content, the track context not being as restrictive as F1 has been in the past, that, I think, has been the key to reaching a new audience rather than the racing product itself. F1 is now employing people to do the same." (Informant AE)

> "Yes [FE is] most definitely disruptive. F1 is now doing a lot of things that FE started to do years ago probably because they realised that

this is the way to do things, the modern media the digital media way to do things. 100% it is disruptive. The fact that manufacturers are moving to FE from other formula means that it has been disruptive." (Informant AC)

"What is disruption? Is it to change people minds on how motorsport is considered? I do not know if it is just FE which has changed people's minds or if it is the way to see motorsport that has changed. In 2012 you could not see motorsport on Facebook, now you have a lot of content there. Like in every social media." (Informant K)

6.6.3 New-market disruption

Amongst the subthemes which have emerged during the data analysis, the creation of a new market was pointed out as one of the disruption opportunities of FIA FE (Gilbert, 2003). The following quotes from senior managers provide an adequate account.

"If you want to know what is going on in FE don't read the car magazines and their websites, they will be still going on about the car squealing and you can't hear the engine, talk to people who actually go who haven't been to a motor race before but it has arrived in Chile, Marrakesh and they are interested in different forms of spectacles which relate to modern technology, uses fanboost which is great fun, you know, you can do that from your telephone, it has a lot of this that young people want to interact with." (Informant R)

"I think some elements are really different, the format, the way we go about promoting ourselves, fanboost it is all unique, but in other aspects, there are similarities with F1 or other series, it is natural. I think we are in many areas pioneering, and the latest example of that is ABB coming on board as the overall sponsor of the series, it is the first time that that is happening in an FIA series, this is an example of how we are pioneering." (Informant R)

"Disruptive is the latest thing of which people want to talk. Disruptive, yes you know I would say from the traditional noise of a V8 the smell of ethanol or gasoline, yes it is disruptive, and it has made people think about motor racing in a different way. You can do it all in 1 day, bring the race to the people rather than force people to come to the race; it is trying to find new races, I do not think that we care particularly about the traditional fan base." (Informant X)

"Yes, I do [think FE is disruptive], for motorsport yes, for several reasons really, one for the ecological story that I think it is important especially for road cars, but more than that from my personal perspective, I think what is relevant is that they are doing some quite significant steps in changing things such as running the season the way they are doing it, running in street circuits that I think it is bringing motorsport to much younger audience. The fanboost, personally I do not like it, I do not think it is particularly sporty, but it is changing the way a driver relates to his fans which is for a long time been the problem of F1." (Informant G)

"I think it depends on which side you look at, if you take it at face value, Audi withdrawing from WEC to enter FE, I think you would have to say that at that level it is disruptive, as they had a more appropriate outcome to have and a place to go and they went on that way, it is disruptive with Jaguar, Jaguar would not have entered motorsport if not because of the fact that there was an electric championship that had so many synergies with their future plans." (Informant O)

6.6.4 Lower end product disruption

Christensen and Raynor (2013) define a lower end product as a product of inferior quality or lower technological finesse than the existing one. This new product appeals to some users, who are not able to afford the existing product, and gradually evolves, also capturing customers from the existing product. The quotes below show how people actively involved in this championship describe Formula E as lower in technological finesse than existing motorsport.

> “What I think it is disruptive; it is at the start point of Formula E the technology that was presented was at a much lower point than what it could have been. The innovation is not disruptive, but the start point of that innovation probably is.” (Informant G)

> “To motorsport in general, I think disruptive is not the word, they have done a very good commercial operation, tracks are very narrow with a lot of walls and a lot of fencing and the reason they do that it is because it creates the sensation of speed. Because cars are not actually that fast. They went to Monaco, and it looks very fast. They are manufacturing collisions or incidents and overtaking as they make the track so narrow and they end up with some good action with someone making something out of the ordinary to make a pass. I think it is trying to fulfil and entertain but not achieving much at the minute as the figures are low.” (Informant AA)

6.7 Conclusion

This chapter has reinterpreted the innovatory system of FIA Formula E through the lens of the Multi-Level Perspective approach (MLP) by the use of twenty-six additional interviews with senior managers and experts directly involved in the FIA Formula E championship between S0 and S3. The outcome of this process brings an understanding of FIA Formula E as a complex, multi-actor system where actors are dynamic and changing levels and regimes as the transition unfolds. In order to understand those changes and to answer RO3 of this study, this chapter has acknowledged that an explicit in-depth integration of time dimension within the MLP approach is needed. This operationalisation of time allows for a broader analysis of micro-changes, which are most useful to understand temporal system dynamics of transformation processes. Hence this chapter has operationalised this time dimension by producing four MLP schematics (section 6.2). Acknowledging criticisms on the robustness and accuracy of the operationalisation of the regimes and levels within the MLP framework (chapter 2), this chapter has proposed a process to identify actors and groups of actors and place them into MLP schematics. This process draws from the visual map presented in chapter 5 and uses flow charts as interim tools to extrapolate actors and groups of actors from events and activities (section 6.2).

Section 6.3 has offered a narrative on the composition and agency of each MLP levels and regimes. Specifically, this section has shown that some of the actors, which sit at the patchwork of regimes, are also embedded in the socio-technical landscape level. Although previous studies have revealed some crossovers between actors at the socio-economic landscape and the policy level in the patchwork of regimes (Rogge and Reichard 2016), additional data have uncovered that, in this context, relations with the landscape level also exist amongst actors of the technological regime.

Confirming what was already found in chapter 5, the analysis of the new data set has shown that regimes are dynamic, changing across the temporal dimension of this transition. Contrary to Geels (2011), this practical example has shown these micro changes (intra-system dynamics) are paramount to explore patterns which shape and enable transitions. Analysing intra-system dynamics, TWG, SWG, CWG and the Innovation Committee were identified as playing a crucial role to convey different interests in the roadmap of FIA Formula E (section 6.4). This intra-system dynamic, which the literature has recently addressed as policy mixes or ways of governance (Kivimaa and Martiskainen 2018; Raven and Walrave 2018; Rogge, Pfluger and Geels 2018), is in this transition not confined only to actors sitting at the policy regime, but has included actors from the technological, science and market regime. These actors, organised in working groups and committees shape successfully this low-carbon sustainable transition in the motorsport industry which will be discussed further in chapter 7.

Drawing from key informant interviews, this chapter has also confirmed that the FIA Formula E socio-technical system is not per se', but adjacent interrelated systems, across industry boundaries, have influenced its dynamic. Specifically, in this empirical case, section 6.5 has discussed how the automotive sector and the electronic goods sector have affected the technological trajectory and target market of FIA Formula E. This inter-system dynamic is vital to position FIA Formula E within broader contextual changes in order to contribute to the transition literature.

Finally, as FIA Formula E has been often addressed in newspapers as a disruptive innovation (The Telegraph, The Independent), section 6.6 investigates if this fully electric championship is disruptive (Christensen and Raynor 2013) and what it is that FIA Formula E is disrupting. Three significant findings have emerged from those data: (a) the interviewees defined FIA Formula E disruptive due this championship initially targeting a new market (non-consumption) with a low-performance product, compared to the existing product (where for the product the informant mainly refers to a Formula One car); (b) the technology used in FIA Formula E in S0 and S1 is defined as well-known technology and (c) key informants addressed the business model of FIA Formula E as the main element to define this electric championship disruptive.

The next chapter will discuss these findings further connecting them to the literature presented in chapter 2.

7 Discussion

7.1 Introduction

The analysis of the data gathered in the scoping phase (chapter 5) and the main phase (chapter 6) of this research has shown how FIA Formula E, in the motorsport industry, can be considered a suitable example of low-carbon sustainable socio-technical transition to depict and explain some of the literature gaps of the MLP approach (chapter 2).

Specifically, in the scoping phase of this research, documentary data and key-informants' interviews have supplied the basis to build the innovatory system of FIA Formula E, confirming that, in this high-tech industry, triggers and enablers of change include socio-economic and political factors (chapter 5). Mindful of the complexity of this multi-actor system, where actors and their relationships change amongst levels, and across regimes with time, the main phase of this research has presented the socio-technical system of this fully electric formula bracketing the time of this transition and using four MLP schematics. A variety of findings have emerged from those schematics (chapter 6). These findings are summarised and explained in table 7-A.

Table 7-A Summary of the findings (author's compilation)

FINDINGS	
Temporal system's dynamics	Actors and relations change with time. Hence to understand in depth the dynamics of a system in transition it is necessary to look at micro-change during its temporal dimension.
Operationalisation of MLP regimes: strengthening up the rigour using business and management strategies	In order to enhance the robustness of the operationalisation of MLP regimes, strategies from business and management studies can be used. This study has used strategies from business and change management theories to refine the concept of time and visualise events and activities, and theories from management and engineering studies to translate the visual map of the innovatory system into MLP schematics

Composition and agency of the socio-economic landscape level	The refinement of the time dimension within the MLP has uncovered the composition and agency of the socio-economic landscape in this socio-technical transition.
Adjacent and interrelated systems influenced the dynamic of this system	Data suggest that socio-technical systems are not 'per se', but they are affected by adjacent systems which influence and shape its technology trajectory.
Intra-system dynamics	TWG, CWG, SWG FE innovation committee, FETA were addressed as a way to enable and shape this low-carbon transition and maintain the interest of actors' involved
Regime-led socio-technical transitions	Data have shown that this low-carbon sustainable socio-technical transition is enabled by the interaction of different actors which sit at the patchwork of regimes level. The window of opportunity generated from the pressure of the landscape level to the existing system, is harvested from and enabled by a new system, at the patchwork of regime levels.
The theory of disruptive innovation as a way to understand the patchwork of regimes level shifts	Documentary data and key-informants have defined FIA Formula E as disruptive innovation. The word disruptive assumes different connotations which, for FIA Formula E, have not included the technology; defined as known and lower-end if compared with other series. Rather, the business model and a different non-market target were considered as discriminants for its success.

This chapter discusses the combination of these findings on a broader level, connecting them to the literature of socio-technical transition (chapter 2) in an attempt to shed light on existing gaps (section 2.5). It is organised as follows:

- Section 7.2 discusses the dynamic of this low carbon socio-technical transition, connecting findings with the literature gaps highlighted in sub-section 2.4.5 and their contributions within:
    (a) the literature of the Multi-Level Perspective approach (Geels 2011; Geels 2018; Smith, Voß and Grin 2010; Truffer, Schippl and Fleischer 2017);

(b) the general literature of transition management and system transformation (Baden-Fuller and Haefliger 2013; Berkhout, Angel and Wieczorek 2009; Coenen and López 2010; Foxon, Reed and Stringer 2009; Geels et al. 2017; Geels 2018; Hekkert et al. 2007; Loorbach 2010; Markard and Truffer 2008),

(c) the debate around new pathways to innovation;

(d) how the theory of disruptive innovation (Raynor and Christensen 2003) could help in explaining this system change reconfiguration if mobilised within the MLP approach (Pinkse, Bohnsack and Kolk 2014; Rotheram-Borus, Swendeman and Chorpita 2012; Wilson and Tyfield 2018).

- Section 7.4 concludes this chapter and introduces the next one.

7.2 A dynamic approach to disruptive innovation-led low-carbon socio-technical transitions

Findings have shown how the structure of the FIA Formula E system is both socially constructed and highly structured. This structure is dynamic and transforms along the temporal dimension of the transition as FIA Formula E develops. This transformation does not imply exclusively the change of actors and relations amongst levels and between regimes but includes exogenous factors, one-time events and shifts to the technological trajectories of adjacent interrelated sectors. The sub-sections below uncover each of these findings.

7.2.1 Refining the MLP concept of time: how understanding the temporal dynamics of a system can shed light on how and when to intervene

The language of low-carbon socio-technical transitions is populated by terms such as changes, transformations and long-term vision, which implicitly assume that time is a contextual condition for sustainable transitions to occur. However, in the operationalisation of the MLP approach, micro-changes are disregarded in favour of the overall dynamic of the socio-technical shift (Geels 2011) and a time dimension is not explicitly considered.

By contrast, theories of innovation and technological changes (Utterback and Abernathy 1975; Nelson and Winter 1982; Foster 1986; Clark and Stauton 1989), which have been extensively mobilised within the MLP approach have considered time paramount to understanding the dynamics of innovations, studying phases or periods within the overall cycle of innovations. Similarly, theories of evolutionary economics (Nelson and Winter 1982, Dosi1988, Freeman 1989, Perez 2010) have studied changes of phenomena over time, “explain[ing] why that something it is at a moment in time in terms of how it got there” (Dosi and Nelson 1994: 154), and considering the social dimension of innovation embedded in a specific ‘spatial milieu’ (Latour 1990). As the MLP approach draws from evolutionary theory, studies have proposed the refinement of the spatial dimension of the MLP approach (Coenen, Benneworth and Truffer 2012; Smith, Voß and Grin 2010) to account for various aspects of country and regional diversities. This leads to a better explanation of why low-carbon sustainable transitions can result in different outcomes in different countries, in particular in the mobility sector (Marx et al. 2015). This refinement of the spatial dimension has not yet translated into a refinement of the temporal dimension of the MLP approach.

Contrary to Geels (2011) suggestion to disregard micro-changes for understanding low-carbon transitions, data in chapter 5 and chapter 6 have outlined several micro-changes over time, in actors and groups, which allowed a more in-depth reinterpretation of the story of FIA Formula E. However, this would not have been possible using the conventional MLP approach which uses one schematic only where the dimension of time is the overall time of the transition. Rather, a granular refinement of the temporal dimension of the phenomenon was acknowledged and implemented producing four MLP schematics, one for each season of FIA Formula E. These four schematics allow a better understanding of the drastic changes of this system in actors, relations and networks, during the time of this low-carbon socio-technical transition.

The theoretical justification to this granular refinement of the temporal dimension is offered from theories of technological change and evolutionary economics (chapter 2), which have translated in the ability to bracket time into a plurality of instants, key moments, or, in the motorsport context, seasons (chapter 3, chapter 5 and chapter 6).

This plurality of times or seasons collated together are the absolute time of Newton[25], the overall temporal dimension of the transition of the MLP approach. This study has proposed and tested a way to operationalise this refinement of time through an array of MLP schematics (Figure 15) for a better understanding of patterns of changes and therefore actors and groups of actor roles (chapter 6).

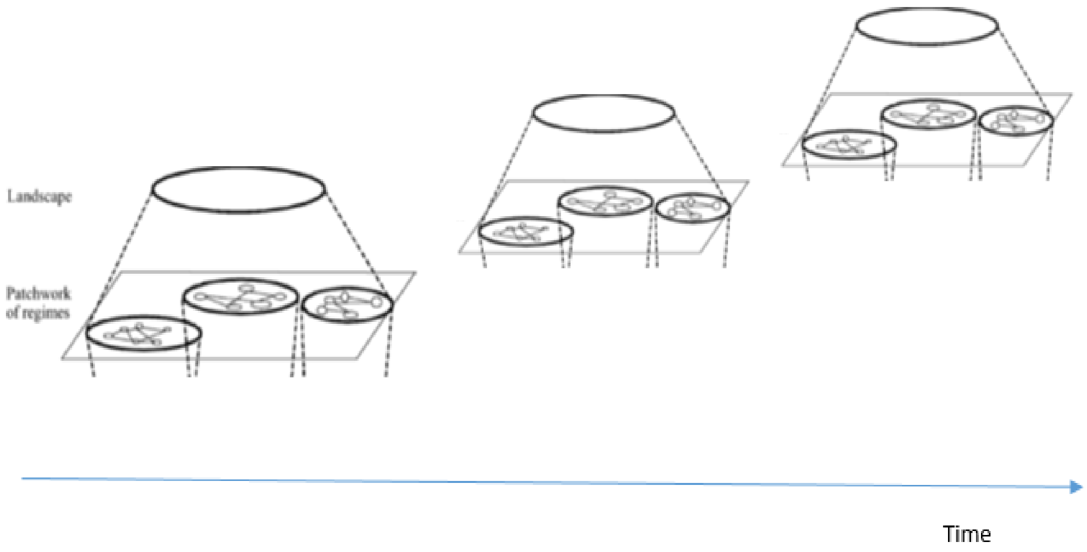

Figure 15 Suggested enhancement to the temporal dimension of the MLP approach (author's compilation)

The temporal dimension was bracketed using strategies for processing data from process theory, which was explained in detail in chapter 4 (Langley 1999).

7.2.2 Mobilising management and industrial engineering techniques within the MLP approach: assuring robustness to MLP regimes and levels

Responding to critiques on the robustness of regimes in the MLP schematics (Genus and Cloe 2008; Smith, Voß and Grin 2010; Fisher and Newig 2016), this research has shown that some steps could be developed in order to make these schematics as free as possible from biases. Specifically, the approach in chapter 5 has used strategies for processing data (Langley 1999) to bracketing the time of this low-carbon socio-technical transition and to re-arrange events and activities in a visual map. This visual map is the innovatory system of FIA Formula

[25] Newton believed that the concept of time is absolute and could only be understood mathematically. Though humans could only perceive and understand the concept of relative time, which was described by this author as the time between sunrise and sunset.

E, from which actors, actors' groups, their relationships and their change in the system are extrapolated by the use of flow-charts (chapter 6). The use of flow charts identifies changes and is a practice well established in business, management and engineering disciplines. In industrial engineering, an inter-disciplinary profession which overlaps with operational research, system engineering and operation management, flow charts are used to study and optimise complex processes involving people, organisations, knowledge, information, equipment, material and energy (Badiru 2005).

Hence, mobilising business and industrial engineering techniques within the MLP approach, this research has proposed a way to allow a more robust definition of regimes and a better operationalisation of levels during the temporal dynamic of socio-technical transition.

7.2.3 Composition and agency of the socio-economic landscape level: opening the "garbage can"

Geels (2011) suggests that the landscape level has often been treated in most empirical studies as a residual analytical category, "a kind of garbage can" (Geels 2011:37), and it is therefore in need of a revision to include "not only the technical and material backdrop that sustains society, but also demographical trends, political ideologies, societal values, and macro-economic patterns" (Geels 2011:28). However, empirical studies have not yet given to the socio-economic landscape level any direct roles on transition, which reinforces Mark and Truffer's critique on this level lacking a well-defined agency (Markard and Truffer 2008).

This empirical study has offered a detailed definition of the socio-economic landscape level (chapter 6), exploring its direct agency in triggering and shaping this low-carbon sustainable socio-technical transition in the motorsport industry. More precisely, the robust and novel way to operationalise MLP levels has enabled the inclusion of several well-known factors in the socio-economic level, amongst which are international and national policy, macro-economic patterns and one-time events. The analysis of the data has also shown that this level is not populated by any technical and material trend, but mainly from "popular culture, the development of environmental responsibilities and sustainability" (informant AE), which are not only a backdrop to transitions, but are an active force that trigger, drive and shape the ‘modus operandi’ of the patchwork of regimes level (chapter 6). This direct agency of the socio-economic landscape is dynamic and changes with the unfolding of the transition. Specifically, during the infancy phase of FIA Formula E, documentary data and semi-structured interviews have confirmed how this socio-economic landscape, together with a business opportunity in the existing system, is the trigger for the electrification of motorsport. Senior managers (A, C, E, F, O, H, AB) describe FIA Formula E as another attempt of the motorsport industry to respond to the pressure of national and international policy towards more sustainable motorsport and its alignment with the global automobility strategy.

The very first interviews of both Agag and Todt, given in chapter 1 and chapter 5, illustrate this direct agency of the socio-economic landscape level with the patchwork of regimes level, suggesting that the idea of FIA Formula E was shaped, in 2012, at a dinner party involving Todt, president of the FIA, Agag, businessman, former politician and team owner and Tajani, president of the European Union. Reinterpreting these interviews using narrative analysis and symbolic interaction theories (Loseke 2016), a multifaceted bond is revealed amongst international policy, the traditional motorsport system and a business opportunity, the alignment of which resulted in FIA Formula E.

This direct interaction of the socio-economic landscape level with the patchwork of regimes level is not limited to the infancy stage of this socio-technical transition. At the end of season 1, in fact, one-time events, which in the MLP sits at a socio-economic landscape level (Geels et al. 2017), started to accelerate the transition and direct the interests of automotive stakeholders in this fully electric championship. These one-time exogenous events, which informants identified with Fukushima and Dieselgate (“I think they [global issues] have contributed to the championship, so has the diesel emission issue” –Informant Q), triggered a new phase of FIA Formula E. In this new phase, the agency of the landscape level is still direct, shaping business strategy and the technological roadmap of this fully electric championship, as key-informants confirmed (chapter 6).

The direct agency of the international policies and macro-economic patterns is not new to the literature of technological change (chapter 2). Specifically, TT (Dosi 1982) and TEP theories (Freeman 1982; Perez 2010) have extensively argued that technological trajectory and socio-economic factors have an active role in shaping technological change.

7.2.4 The influence of interrelated systems on the temporal dynamics of this low-carbon sustainable transition

In the majority of the studies on the MLP approach, researchers have considered transitions stand-alone processes, concentrating in studying inter-system dynamic between niches and patchwork of regimes level as triggers to shifts (Geels and Schot 2007; Geels 2011). Contrarily, coherently with findings from Papachristos et al (2015) (section 2.4.2), this empirical study has unveiled that the low-carbon socio-technical transition of the motorsport system is widely influenced by other adjacent or interrelated systems (chapter 6). Specifically, rather than using the Papachristos et al (2013) framework for identifying the involvement of external entities in transitions (regimes and niches), This study have used information from senior managers, which suggested that the automotive sector, the entertainment and electronic goods sectors have directly shaped (but not created) the technological and strategy trajectory of FIA Formula E.

Senior managers have, in fact, addressed the technology used in this fully electric championship as “not really new” (Informant AB), “already existing in other sectors [automotive]” (informant O), explaining that the technological trajectory of FIA Formula E is “aligned with wider automotive sector developments” (informant AE) and “built upon the global challenges which the automotive sector presents” (informant AC). If the influence of the automobility sector was almost expected, as the motorsport industry historically holds connections with car manufacturers (chapter 3) in terms of technologies (turbo, use of light materials, R&D on fuel efficiency) and business models (as a marketing platform from some automotive companies), the impact of sectors such as entertainment, mainly the video game and virtual reality industry, and electronic goods is new to the value-chain of the motor racing industry (Henry et al. 2007 cited in chapter 3).

Specifically, the analysis of the data has shown how both these sectors play a crucial role in the definition of users’ regimes and market regime since the infancy phase of FIA Formula E, including video-game players (gamers) and younger generations (Chapter 6). Some key-informants have addressed two compelling examples to clarify this nexus between electric motorsport and the entertainment and electronic goods sectors: a) FIA Formula E attending the Consumer Electronics Show in Las Vegas, in 2017, bringing racing drivers and e-gamers to virtually race together, and b) FIA Formula E introducing the fanboost (a social media vote which allowed the winning driver to have more energy –kW- during the race), a way for the young generation and digital media users to interact directly with the championship.

Differently from Papachristos et al. (2015) fifth pathway (section 2.4.2), this empirical example of interaction amongst interrelated system do not imply any niche interactions that led to a new system emergence substitution pathway, rather it suggests an alignment at regimes and landscape levels with interrelated sectors for FIA Formula E to become relevant for those sector and, at the same time, in the motorsport industry.

This nexus amongst interrelated systems and the transitioning system, which does not reside at niche level, needs consideration in order to assess, analyse and propose ways to intervene within the system for accelerating and guiding this scope oriented transition.

7.2.5 Intra-system dynamics and governance: an effective way to successfully shape and enact low-carbon socio-technical transition?

Recent studies (Rogge and Reichardt 2016; Geels et al. 2017; Kivimaa and Martiskainen 2018; Rogge, Pfluger and Geels 2018) have highlighted how, within sustainable transitions, an understanding of the influence of policy represents one of the main items on the agenda (chapter 2). Techniques of governance and policy mixes, in fact, play key roles in the "redirection and acceleration of technology" (Rogge and Reichardt 2016: 1620). Rogge and Reichardt (2016) have suggested a definition of policy mixes to include processes, dimensions and characteristics of the relevant innovation, which is most useful to make recommendations and advice more substantial and impactful for policymakers. Contrarily, Howlett and Rayner (2009) include policy and policy mixes within the technique of governance, underlining the need for more empirical research on governance strategies. These policy mixes are often proposed as solutions to complex problems such as low-carbon sustainable technological transitions or environmental issues (Howlett 2009; Rogge and Reichardt 2016; Rogge, Pfluger and Geels 2018).

Recognising motorsport as green innovation, Huber (2012) suggests that framing motorsport within the broader shift to clean-tech exemplifies how motorsport can contribute to a low carbon transformation pathway. Huber considers regulatory changes in Formula One, enforced by the FIA, and government-funded consortia being the policy instruments for triggering a sustainable transition within the motorsport industry.

This research has explained that the FIA is not able, alone, to enable or inhibit technological transition within the FIA titled championships (Huber 2012; Papachristos 2014). Instead, key-informants agreed that the FIA does so in combination with other actors belonging to the technological, business and sporting spheres. This interaction between, in the language of the MLP, the policy regime, the science regime and the technological regime, all sitting at the patchwork of regimes level, can be linked to what the literature has addressed as techniques of governance (Florini and Sovacool 2009; Meadowcroft 2007). Specifically, drawing from Meadowcroft (2007), which applies the notion of governance to sustainable development, referring to the interaction of policy, private businesses and society towards the achievement of sustainable development, the main phase of this research has offered evidence on how working groups and committees exemplify this concept of governance (section 6.2). The narrative in chapter 6 has further validated Fischer and Newig's (2016) research for which "taking the perspective of governing transitions towards sustainability introduces two further actor typologies. Governance is understood as public decision-making beyond, but also including, the state. Actors who participate in governance are commonly divided into state (government), private sector (business) and civil society actors" (2016: 479). Working groups and committees (chapter 6) represent the influence of policy, technology and business within the development of this championship, encompassing concepts of techniques of governance (Howlett 2009; Meadowcroft 2007) and policy-mixes (Rogge and Reichardt 2019).

Data have also shown these ways of governance deployed in FIA Formula E are dynamic, changing with the technological trajectory of the championship and the invested interests of incumbent and new actors. An explanation of this change can be found in the composition of the Technical Working Group. In S0 and S1, this group included: a representative for each team taking part in the championship, other important technical actors (SRT, WAE, MAT, and Renault Sport), members of the FIA technical department, the FIA Electric and New Energy committee, the scientific community, stakeholders from FEH and a number of informal actors (automotive manufacturers interested in the championship but not yet involved). After the announcement of the opening of the development of the electric powertrain, the TWG configuration changed drastically. Data from chapter 6 has shown how, from S2, only FIA, FEH, SRT, and one member of each homologated manufacturer were included in the TWG.

Additionally, FE Innovation committee (section 6.4) has emerged as the instrument for mitigating different and diverse invested interests from a multitude of actors directly or indirectly involved in FIA Formula E. This committee has been defined from informant H as built upon existing models of business and strategic management already implemented for firms and corporations. Further research on this committee could shed light on best practice for policy-mixes and governance when confronted with low-carbon sustainable socio-technical transitions.

7.2.6 A regime-led socio-technical change: transition pathway

The dynamics approach to low-carbon socio-technical transition developed in this thesis has allowed for a detailed reconstruction of the transition pathway of FIA Formula E in the motorsport industry. By focusing on the concept of time and analysing micro-changes of actors and relations for each season, a transition pathway led by regimes and triggered and shaped by the overarching socio-economic landscape level was uncovered.

This pathway is different from both the traditional transition pathways developed in the realm of the MLP (Geels and Schot 2007) and the fifth transition pathways developed by Papachristos, Sofianos and Adamides (2013) (section 2.4.2).

For ease of comparison, the dynamic of transition pathways discussed from the MLP approach (chapter 2) is summarised in Figure 16 below.

Figure 16 Dynamics of socio-technical transition within the MLP approach (Geels 2001: 8)

As already explained in chapter 2, the MLP approach argues that the locus of innovation resides at niches level where radical innovation starts and “only breaks through under particular circumstances when multiple processes link up and accumulate” (Geels 2001: 7). Contrarily, this research has unveiled that in the case of FIA Formula E the low-carbon transition is triggered by the pressure and the direct influence of the socio-economic landscape level and enacted by the patchwork of regime level (section 7.3.3). Within this patchwork of regime level, the technological and policy regimes are the ones that initially have allowed FIA Formula E to take shape (chapter 6). Both these regimes are incumbent to traditional motorsport and driven, amongst other things, by a business opportunity in the traditional system. This business opportunity in the established system is referred to, in the MLP approach, as a window of opportunities, which is created by internal problems of existing regimes intensified by the landscape pressure (Schot, Kanger and Verbong 2016). However, the opportunity for FIA Formula E to break through was not caused by internal problems of the existing system, but from the pressure and the direct agency of the socio-economic landscape level and the need for traditional motorsport to be aligned with the technological trajectory of interrelated system, amongst which the automotive sectors, as documentary data outlined (chapter 5).

Papachristos, Sofiano and Admides (2013) have suggested a fifth transition pathway, namely a new emergence substitution pathway (section 2.4.2). The seeds for change in their new pathways are exogenous as the researchers observe that "outsiders are involved in the majority of transition cases. Nevertheless, their involvement in transitions has not attracted much interest so far, neither has the extent to which niches and regimes of external systems influence transitions" (2013: 56). Although the study suggests that those interactions might happen both at regime and niche level, the study only show empirical cases in which niches of interrelated system have triggered a new emergence substitution pathway (i.e. functional food), generating a new system to replace the old one. Differently, in this thesis, data have shown that FIA Formula E does not substitute existing motorsport championships, and its momentum is not linked to technological innovation emerging from niches of exogenous systems with a different societal needs to fulfil. Data have shown that in the case of FIA Formula E destabilisation is not driven by niches, and new set of rules are not created or introduced in the existing regimes as a result of niche innovation (Geels 2012).   Additionally, as sustainable transition are purpose driven, the societal needs to fulfil are the same in the automotive industry as in FIA Formula E, contrary with the way Papachristos set the boundaries for the definition of exogenous systems.

Rather, this research argues that, initially, the new system, which share the landscape level and in same degree part of the niche level with the old traditional system (motorsport), co-exists with the traditional one, positioning itself in a parallel non-consumption market. Although initially, the two don't compete for the same market and value network, once the new patchwork of regimes (FIA Formula E) has gained enough momentum, FIA Formula E takes customers away from the traditional system (as seen from season 2 onwards) until rules are created to reorganise the whole system to include the new one.

This finding is in line with the novel regime shift framework discussed by Ghosh and Schot (2019) and confirms that this new transition pathway does not belong solely to non-western culture (section 2.4.5). Bracketing the overall socio-technical transition time into seasons has also shown how one-time events have played an essential role in accelerating the momentum of this low-carbon sustainable transition of the motorsport industry.

The dynamics of this unconventional transition pathway (sixth transition pathways) can only be fully explained using the language of the theory of disruptive innovation (Christensen and Raynor 2013) and its main concepts such as non-consumption market and value network (section 2.2.2). The section below will further explain the transition pathway uncovered by this research and will contribute to the recent debate on disruption and the MLP approach.

7.2.7 Mobilising the theory of disruptive innovation within the MLP approach to understand the regime-led low-carbon socio-technical transition

This research has shown how FIA Formula E can be interpreted as regimes led, low-carbon socio-technical transition in the motorsport industry. In order to explain further the dynamic of this socio-technical change, it is necessary to mobilise the theory of disruptive innovation within the enhanced MLP approach that this research has presented (section 7.2.1).

As pointed out in section 2.4.4, scholars have started a debate around the benefit of using the theory of disruptive innovation (Christensen and Raynor 2013) to study energy transformations (Dijk, Wells and Kemp 2016; Geels 2018; Kramer 2018; Wilson and Tyfield 2018). Specifically, Dijk, Wells and Kemp (2016) have sought to define to what extent FEV is disrupting the ICE market giving "special attention to consumer product frames of salient product characteristics and government regulation as important determinants of demand" (Dijk, Wells and Kemp 2016: 77). Understanding that the level of analysis of Christensen's theory is firms and not systems, they propose a way for testing the hypothesis of this theory within systems' regime evolution, considering "an evolution framework base on changes of technology and institutional context" (Dijk, Wells and Kemp 2016: 78). Though, Dijk, Wells and Kempt's (2016) research does not account for changes of social and cultural context, or macro-economic patterns as a way to explain changes to the system.

Acknowledging the different unit of analysis, Geels (2018) has argued that the disruptive innovation theory is not able to explain transitions. He considered the theory of disruptive innovation (Christensen and Raynor 2013) as an alternative framework to explain changes within the overall system, rather than an innovation or business theory. In academia, these two terms are not equivalent as theory is referred to as a rational conceptualisation of phenomenon either physical, biological, sociological or from any other scientific domain which includes an inductive and deductive phase (Christensen, Raynor and Mcdonald 2015), while framework does assign a contextual value to theories. Hence, addressing an innovation as disruptive in Christensen's terms is not the same as asking if the whole system is disruptive, as earlier pointed out by Dijk, Wells and Kemp (2016). Rather, mobilising the theory of disruptive innovation (Christensen and Raynor 2003) within the MLP approach in the same way that other theories of innovation and technological changes were previously mobilised could provide a useful insight to identifying patterns in gradual system reconfiguration, and causal mechanisms of business, political, consumer and cultural processes (refer to section 2.4.2).

Within the theory of Disruptive Innovation (Christensen and Raynor 2013) two mechanism for disruption are addressed: new-market disruption and lower end product disruption. If examples of lower-end disruption are products with lower technological appealing and lower price competing in the existing market (i.e. Kia in the automotive industry or Toyota in the luxury vehicle market), the personal computer and the Sony's first transistor radio have often been used as exemplification of new-market disruption. In both cases, lays Christensen's remark that technology is not per se' disruptive, but that disruption is a relative term, relative to the business model it is disrupting. Coherently with this theory, data in chapter 6 has shown that FIA Formula E technology was not consider a disruptive, new technology. Experts have in fact defined the battery and powertrain used in the first all-electric championship a well-established technology in adjacent sectors, such as the automotive sector (section 6.1). To reinforce that, a negative category for technology disruption was added to the coding framework (chapter 4), to reflect as the technology used in FIA Formula E was not disruptive per se' (6.6.1), but it was one of the technologies from the known array of technical developments available (Dosi, 1982).

The data have confirmed that the business model that FIA Formula E embraced from Season 1 to Season 3 was disruptive, as this was a new business model compare with the one from traditional motorsport industry which lowered barrier to entry and allow for entrepreneur and incumbent to compete at the same level (section 6.2). Additionally, Section 6.6.3 and 6.6.4 have shown that, although initially perceived as a lower technological and much cheaper product, FIA Formula E did not compete in the existing market, but it developed 'per se', in an initially non-consumption market. From interviews from senior managers, electric motorsport emerged as a non-consumption market, where new users, entrepreneurs and incumbent actors were interacting in a coordinate way and with a well-defined set of shared rules without initially interfering with the traditional motorsport industry (informants B, D, N, H, AD, AE, and AF).

If during the infancy phase, FIA Formula E have emerged as a system per se', not competing directly with the existing market, attracting mostly entrepreneurs and new entrants (e.g. Dragon Racing, Mahindra, and NIO) due to low-barrier to entry (chapter 5) and basing his value proposition on the ecological message and entertainment, when the championship globalised, data reveals that incumbent actors from traditional motorsport (Boss, HP, Microsoft, Mmm Champagne, Mercedes, Porsche, Audi, and Renault) started to be "pulled out" from the existing traditional championships, to move to this electric championship.

The migration of incumbents to this new system, which data has shown was facilitated from one-time events (chapter 5), and international and national policies (landscape pressure) can find an explanation from Christensen and Raynor's theory.

> "Although new market disruption initially competes against non-consumption in their unique value network, as their performance improves they ultimately become good enough to pull customers out of the original value network into the new one". (2013: 45)

Hence, as sees in chapter 6, during S2, FIA Formula E start to compete for the same customers and market of other motorsport championships, without leading to a displacement of one system over the other one, as only a few cases of disruptive innovation have caused a complete technological shift, where the new market has displaced the old market King and Baatartogtokh (2015). Rather, gradually with time, systems (championships) within the traditional system of motorsport (see chapter 1) reconfigures to include this new system, and responding to business, political, cultural and social demands this new system has created (section 6.6).

This idea of gradual reconfiguration (sixth pathways to transition), which is beyond the time horizon of this study, is confirmed by some of the expert and senior managers interviewed in this research (informants B, C, AF) which have pointed out as the sustainability piece and the alignment with the automotive sector are now necessary pieces for the reconfiguration of the motorsport system.

Figure 17 outlines the process describe above.

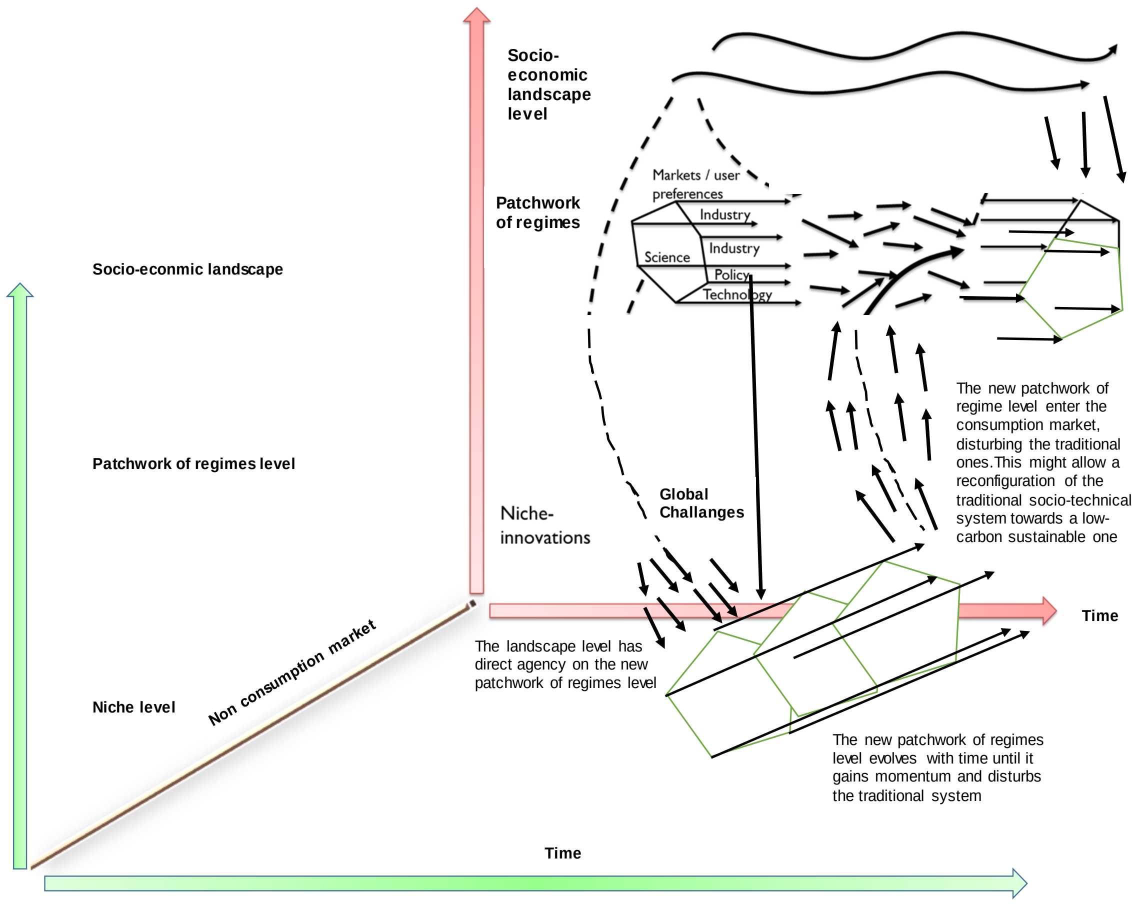

Figure 17 Mobilising the theory of disruptive innovation to explain regime-led low-carbon socio-technical transitions (author's compilation)

Responding to Kramer's call on "the challenges ahead of us" (2018: 248), the model above (fig. 17) embraces Kramer's suggestion to break apart the term disruptive innovation arguing that considering business and technical innovation is almost too narrow to describe the wide transformation in the mobility and energy sector to sustainability and that institutional innovation and behavioural change needs to be included in order to acquire a full understanding of the dynamic of these shifts. Embracing the idea that "disruptive innovation in Christensen's theory is a driving force in the corner of a scenario space" (Kramer 2018: 250), data from the main phase of this research (chapter 6) has shown how the disruptiveness of FIA Formula E was not in the technologies deployed (section 6.6.1), rather in its business model and its target non-consumption market (section 6.6.2 and 6.6.4), underlining how valuable is to mobilised this theories within the MLP approach in order to unveil a new transition pathways.

7.3 Conclusion

This chapter has discussed the empirical findings presented in chapter 6 (summarised in table 7-A) connecting them to the literature of chapter 2 and identifying how these contribute to the broader debate on the dynamics of low-carbon socio-technical transitions (section 2.4.5). From this discussion, FIA Formula E has resulted in a useful example of a regimes-led transition pathway which is enabled by the patchwork of regimes and triggered and shaped by the socio-economic landscape level.

Drawing on empirical data and from key-concepts of theories of technological changes (chapter 2), section 7.2.1 has proposed a refinement of the temporal dimension of the MLP approach to better understand the dynamics of the system for socio-technical transitions. Mobilising management and industrial engineering techniques, this research has proposed ways to operationalise robustly regimes and levels (7.2.2). These techniques offer a way to limit biases when placing actors in levels and regimes, enhancing the repeatability and the validity of the outcomes of the research.

Filling other MLP literature gaps (section 2.4.5), this chapter has contributed to developing further the composition and agency of the socio-economic landscape level. It is from this rationalisation of the socio-economic landscape level through which the direct relations between this level and the patchwork of regimes level have emerged, unveiling that this direct agency changes with the unfolding of the socio-technical transition (7.2.3). The influence of adjacent interrelated systems on this transition was also discussed (7.2.4), together with techniques of governance and policy-mixes (7.2.5).

Finally, in order to explain this transition pathway fully, section 7.2.7 has mobilised the theory of disruptive innovation (Bower and Christensen 1995; Christensen 1997; Christensen 2006; Raynor and Christensen 2003) within the MLP approach. Benefitting in full from concepts of this theory, the transition pathways of FIA Formula E has been discussed by conceptualising a regimes-led shift triggered and shaped by the direct agency of the socio-economic landscape, one-time events and other adjacent interrelated systems. Figure 17 has outlined this transition pathway, in which this parallel patchwork of regime level co-exists initially in a non-consumption market. When this new system gains momentum, the disruptive system pulls customers away from the traditional system, causing its destabilisation and entering the traditional consumption market. It is at this point that a reconfiguration of rules to include the new system is needed.

The next chapter concludes this thesis, discussing contributions, limitations, and further research, and providing a personal statement on this journey.

8 Conclusion

This PhD has addressed gaps in low-carbon sustainable socio-technical transitions literature, pointing out several problems of the Multi-Level Perspective approach (Geels and Schot 2007; Geels 2012). Those gaps have included the structure of the socio-economic landscape level, its direct agency in influencing, facilitating and shaping transitions and any cross-fertilisation of the transitioning system with adjacent interrelated systems (Geels, 2018). The MLP literature has also neglected alternative transition pathways where other sources of innovation, rather than radical innovations at niche level, trigger system shifts (Ghosh and Schot 2019; Schot, Kanger and Verbong 2016; Verbong and Loorbach 2012). Although Ghosh and Schot (2019) have proposed a regime-led shift in mobility, they have concluded that non-Westerner culture plays an essential role in enabling this novel pathway, calling for further empirical studies.

This thesis set out to make a contribution to those gaps using motorsport as a context to explore low-carbon sustainable socio-technical transition.

Since 2007, the motorsport industry has started the process of decarbonisation, introducing low-carbon, energy efficient technological innovations such as KERS and ERS in existing motorsport championships. This process culminated in 2012 with the announcement of the first fully electric championship called FIA Formula E. This electric championship, which raced for the first time in Beijing in 2014, has grown and globalised and attracted many sponsors and manufacturers, new and incumbent to traditional motorsport and has made the headlines of many well-known magazines. Those magazines have addressed FIA Formula E as a disruptive innovation (The Telegraph; The Independent) for the motorsport industry and, in 2015, the championship was presented with the Christensen's disruptive innovation award (Disruptor award 2018).

Lately FIA Formula E has also been of interest in academia, being referred to as an innovation based transition toward sustainability (Huber 2012, Robeers 2019), R&D test bed for low-carbon energy efficient innovations with significant contribution to the automotive sector (Skeete 2019).

This chapter provides a summary of this research and discusses contributions to theory, methodology, motorsport literature and practice. It also details limitations, and suggests avenues for further research. Finally, a reflective section on my PhD journey is presented which concludes this chapter.

8.1 Summary of the thesis

This section offers a brief summary of this thesis.

Chapter 1 has presented the rationale of this thesis, setting out the aim to understand FIA Formula E as an example of a potentially disruptive innovation which has triggered a low-carbon sustainable socio-technical transition within the motorsport industry. Drawing from gaps in the academic literature of the MLP approach, this chapter identifies an overarching research question:

How do actors and institutions successfully facilitate, shape, drive and enact the dynamics of a disruption-led, low-carbon socio-technical transition?

Chapter 2 has expanded on the theoretical background used to answer the research question. Specifically, this chapter shows that understanding technological transition through innovation is a major arena of study, but one which recognises that technological change is not caused solely by a shift in technology (Abernathy and Utterback 1978; Abernathy and Clark 1985; Utterback and Abernathy 1975). These shifts must be understood as a process entailing technical, political, economic and social factors (Dosi and Nelson 2010; Dosi and Nelson 2013; Freeman and Perez 1988; Perez 2010). As a radical or disruptive innovation triggers most socio-technical transitions (Geels and Schot 2007; Geels 2010; Geels 2012), space and time dimension, impact on and of economy and society, ability to build new markets, to modify the existing value network of the existing system, need consideration within the complex process of change. Hence, this chapter has reviewed theories about the socio-construction of technology and techno-economic paradigm in an attempt to identify factors which contribute to this process. Those factors are the same factors which system innovation and transition theories take into consideration when analysing low-carbon shifts. Amongst other approaches, this chapter has given particular attention to the Multi-Level Perspective approach, detailing its theoretical foundation. In the last decade, this approach has been extensively used to empirically understand low-carbon shifts as a multi-level, multi-actor process (Geels and Schot 2007; Geels 2012; Geels et al. 2017). This approach is useful for analysing socio-technical transitions and “for informing intervention related to the policy and management of technological change in practice” (Genus and Coles 2008: 1436). Current research gaps and intended empirical improvements are presented to answer calls for further empirical studies on the composition and the agency of the socio-landscape level and on empirical examples of different transition pathways (Geels 2011; Geels 2004; Genus and Cole 2008; Papachristos et al. 2013; Verbong, Schot and Kanger 2017; Geels et al. 2016; Schot and Kanger 2018). Finally, this chapter presents recent papers on disruption and low-carbon transformation (Geels 2018; Kramer 2018; Wilson and Tyfield 2018), assessing gaps and avenue for advancing the understanding of the dynamics of low-carbon transition when triggered by disruptive innovation.

Chapter 3 has introduced the research context, detailing the value of motorsport for low-carbon sustainable or energy efficient transitions, its value chain framework (Henry et al. 2007) and the dynamic of the motorsport innovatory system. It discussed at length the relevance of the motorsport industry as an exploratory context for vehiculating low-carbon transition to the broader audience unveiling how this industry has the unique connotation of enacting changes very quickly, within 5 to 10 years, contrary to other systems where the length of the low-carbon transition has been estimated at 50-70 years. It is the fast pace of innovation which makes the motorsport context most suitable for exploring low-carbon sustainable transitions and making useful predictions for systems’ reconfiguration. This chapter has also explained the value framework of the motorsport industry (Henry et al. 2007), detailing actors and institutions which are involved in the business of motorsport. Additionally, it has offered examples of innovations which have triggered changes to the motorsport system through different transition’s pathways. The introduction of composite materials is, in fact, a valid example of innovation driven by the niche level, whilst the Cosworth DVF8 engine and the changes that its dominance has inflicted on the motorsport system presents a change driven from new technical regulation, or in the language of the MLP, by the patchwork of regimes level. Finally, this chapter introduced the story of FIA Formula E, in the motorsport industry, the context of this research.

The research question and objectives in Table 8-A have emerged from chapter 2 and 3.

Table 8-A Research question and objectives of this thesis

RQ	**How do actors and institutions successfully facilitate, shape, drive and enact the dynamics of a disruption-led, low-carbon socio-technical transition?**
RO1	Understand the temporal dynamics of FIA Formula E, defining key moments, events and activities.
RO2	Identify the main factors that drive changes in this innovatory system.
RO3	Identify actors and institutions, through the lens of the multi-level perspective to understand how these and their relations facilitate, shape and enact this disruptive-led low-carbon socio-technical transition in the motorsport industry, over time.
RO4	Consider implications for policy and management for informing strategy-building towards coherent low-carbon transformations in other sectors than motorsport

Given these research objectives, chapter 4 has discussed the research design and methodology of this study, touching on philosophy and personal stance. It detailed the research design of this study, which consisted of two phases: a scoping phase and the main phase. Overall, a mix of documentary data, from primary and secondary sources, and semi-structured interviews with key informants and senior managers of the motorsport industry was used to gather information. Whilst the five interviews in the scoping phase of this research were coded by hand, the additional twenty-six semi-structured interviews to senior management in the main phase were coded using N-Vivo software. Those additional interviewees were all directly involved within the FIA Formula E. The ability to access this elite motorsport community and the coding framework used was also discussed within this chapter.

Drawing from the data collected during the scoping phase of this research, chapter 5 has presented the innovatory system of FIA Formula E. Specifically this chapter answered research objectives 1 and 2. Through the analysis of 920 documents and five semi-structured interviews, this chapter identifies different factors that were part of this innovatory system. These factors were clustered initially around technology, regulatory and business themes. A visual map (Figure 8) of events and activities was built in order to understand the complexity of the phenomenon, within the temporal dimension considered (August 2012- August 2017). From this map, other factors emerged as playing a role in the dynamics of this low-carbon transition. These factors were addressed under the name of global challenges. Specifically, national and international policies, environmental issues and social perception of environmental and technological issues were instrumental in triggering and facilitating this first all-electric championship, FIA Formula E. The chapter also validated the concept of seasons, as the temporal unit of measure of the motorsport system. This concept is widely used to refer to critical events during a championship life cycle within new and traditional motorsport. Finally, drawing from theories of innovation and particularly from the S-Curve (Foster 1984), section 5.3 has explored the dynamics of this first fully electric championship, narrating the infancy phase and growth phase of FIA Formula E through the lens of the primary and secondary data gathered in the scoping phase of this study. This data analysis led to a compilation of a list of interviewees for the main phase of this study, which was instrumental in exploring actors and actors' group dynamics within the FE innovatory system.

Using twenty-six additional semi-structured interviews, chapter 6 has reinterpreted the innovatory system of FIA Formula E within the lens of the MLP. Four MLP schematics were presented, one for each FIA Formula E season, in order to understand deeply the micro-changes amongst actors and levels. Aside from building a comprehensive picture of actors which facilitate and drive this sustainable shift, the chapter also unveiled that other adjacent interrelated systems have influenced the transition pathways of this low-carbon change in the motorsport industry, particularly the automotive sector. Finally, key-informants' thoughts on whether FIA Formula E is disruptive and what it is that FIA Formula E is disrupting were provided at the end of the chapter.

Chapter 7 returned to the literature to discuss the empirical analysis regarding the MLP framework and research question (How do actors and institutions successfully facilitate, shape, drive and enact the dynamics of a disruption-led low carbon socio-technical transition?). Important messages have included:

- How FIA Formula E has emerged as a useful example for understanding the composition and role of the socio-economic landscape level and its interaction with the patchwork or regimes level;
- How this low-carbon transition pathway is dissimilar from the one which most empirical MLP studies have investigated including the latest finding of Papachristos et al. (2013);
- How exogenous factors in adjacent systems have influenced the transition pathway and the speed at which this transition has taken place;
- How analysing micro-changes can be of help in building a comprehensive and robust picture of the overall system change;
- How mobilising the theory of disruptive innovation (Raynor and Christensen 2003) within the MLP approach could enhance the understanding of this new transition pathway, mainly when disruptive innovation triggers this shift.

To conclude, chapter 8 has summarised this thesis, highlighting the contribution to knowledge and the originality of this study, and outlining limitations and avenues for further research.

8.2 Answering the research question

This thesis presented an interesting example of a regime-led transition pathway for low-carbon sustainable socio-technical changes in the motorsport industry. By exploring this example, it has answered this research question:

How do actors and institutions successfully facilitate, shape, drive and enact the dynamics of a disruption-led, low-carbon socio-technical transition?

Historically, in the MLP literature, the majority of empirical studies have explained that these changes are triggered by technological innovations at the niche level (Geels 2002; Schot 2005; Raven 2004; Geels 2012; Kivimaa and Martiskainen 2018; Schot and Kanger 2018). After building up enough momentum, this innovation destabilises the existing patchwork of regime level (Geels et al. 2016) causing cracks to appear in the traditional system (chapter 2). Geel and Schot (2007) have suggested four transition pathways for system reconfiguration which section 2.4. 2 has explained. In order to broaden the MLP framework, Papachristos et al. (2013) have suggested a fifth transition pathway, namely a new system emergence substitution pathway, taking into account the influence of exogenous system and regimes within sustainable transitions. However this study only presented empirical examples where niches have driven the change and substitute existing system.

Regime-led transitions have been recently discussed in non-Western culture (Ghosh and Schot 2019) as ways to enact low-carbon sustainable transition in mobility without the needs of niche innovation. Similarly, scholars have considered the pressure of the landscape level on low-carbon transition as possible causes for accelerating sustainable shifts, drawing from empirical cases in specific projects in geographically confined areas (Marletto 2015; Moradi and Vagnoni 2018). However, the understanding of the system dynamics of alternative transition pathways remains, to date, limited.

FIA Formula E has emerged as a low-carbon shift in the motorsport industry, driven and shaped from the pressure of the socio-economic landscape level on the policy regime of the existing system and a business opportunity, and enacted by a new the patchwork of regimes level.

By introducing a refinement of the temporal dimension in the MLP (chapter 6), bracketing the overall time of transition into seasons to help a deeper understanding of the micro-change of the system, this study has shown that initially, in the infancy phase of FIA Formula E, only the policy (FIA) and technology (FEH) regimes, sitting at the patchwork of regimes level, enable this sustainable transition, initially in a non-consumption market (electric motorsport), responding to the demand for the motorsport industry to reflect broader global challenges (chapter 5 and chapter 6).

During the growth phase of innovation, one-time events such as Dieselgate and Fukushima and the change of direction from adjacent interrelated sectors (chapter 5 and chapter 6) caused FIA Formula E to gain momentum and disturb incumbent FIA championships. In this phase its trajectory was shaped by several working groups (chapter 6) which represented the vested interest of different actors, at different times, in this fully electric championship. These working groups have been defined in chapter 7 as techniques for governance.

Drawing a parallel with business and management theories, the dynamics of this low-carbon sustainable transition can be fully explained through mobilising the theory of disruptive innovation within the MLP approach. In doing so, this research has shown that the story of FIA Formula E can be reinterpreted as a novel parallel patchwork of regimes in the traditional motorsport system, created by new and incumbent actors of the existing motorsport systems in response to the landscape pressure (international and national policy) and adjacent interrelated systems (automotive). In its early days, in fact, FIA Formula E was a non-consumption market with a value network and a value proposition different from traditional motorsport championships. With time, with the pressure of the landscape level and the help of exogenous events in adjacent sectors, such Dieselgate and Fukushima, FIA Formula E started attracting incumbent actors, pulling those away from the traditional system until the new system gained enough momentum to change the old value network and to destabilise the existing patchwork of regimes level (Figure 17). Contrarily to most of the empirical studies this momentum is not only dictated by the technological advancement of the innovation but mainly by socio-economic factors. It is this further integration with business and innovation theories which enable practical recommendations for policy and practitioners for informing strategy-building towards coherent low-carbon transformations in other sectors than motorsport.

8.3 Contributions to knowledge and originality of this research

This thesis makes contributions to theories, methodology, motorsport literature and practice as follows.

8.3.1 Contribution to theories:

The study of low-carbon socio-technical changes has gained momentum in the last decade, specifically in investigating concepts and frameworks for understanding and enabling low carbon transition. The literature has increasingly offered methods and frameworks to analyse those complex system shifts as a mixture of changes in science, technology and society, suggesting potential strategies for policy-makers to influence those changes and for practitioners to formulate companies' strategies.

This thesis contributes to the debate around the use of the Multi-Level Perspective approach to understand the dynamics of low-carbon socio-technical transition (Berkeley et al. 2017; Geels 2011; Geels 2018; Rogge, Pfluger and Geels 2018; Smith, Voß and Grin 2010; Truffer, Schippl and Fleischer 2017). Specifically, by introducing insights from theories of technological change and innovation, this thesis contributes to the debate around a new transition's pathway within the MLP approach (Geels, 2011; Verbong, Schot and Kanger, 2017), offering an example of how changes may not be just triggered by niche level innovation as most scholars have explained (Schot 2005; Geels and Schot 2007; Geels 2012) but, instead from the patchwork of regime level (Ghosh and Schot 2019) under the pressure of the landscape level. Specifically, this study fills the existing gap in allowing for "different routes in system innovation and transitions. These routes may consist of different kinds of interaction between the three levels" (Geels 2004: 916). As opposed to other empirical studies, FIA Formula E has shown that system changes are not driven by niches, product or process innovation, but are triggered by socio-technical needs of the existing system to be aligned with international and national policy and socio and cultural changes. Hence, this low-carbon change in the motorsport industry is triggered by socio-economic factors at a landscape level and is actuated and shaped by the interaction of different actors and actors' groups within the patchwork of regimes level.

Secondly, this research opens the "garbage can" (Geels 2011:34) of the socio-economic landscape level, answering Schot's call for a better definition of this level (Schot, Kanger and Verbong 2018) and defining its compositions, its dynamics and uncovering its direct agency on transition. The agency of this level and the direct relationships with the patchwork of regimes level have emerged, unveiling how the pressure from the socio-economic landscape facilitates and triggers this low-carbon shift. The extent of this direct agency changes over time, as the innovation unfolds.

By mobilising theory of technological change to assess the structuration of levels and regimes, space and time have emerged as two important dimensions against which the context should be explored. Specifically, although the concept of time is implicit within the MLP, as this approach implies changes to the system, this empirical study has shown how uncovering micro-changes to actors and group of actors is paramount to understand the dynamics of the transition. As such, when the new innovation enters in the window of opportunities created in the old system, a grain-refinement of the temporal dimension in which the phenomenon is observed should be considered. This refinement is operationalised in chapter 6 by defining an MLP schematic for each season, including season 0, the years approaching the first racing season of FIA Formula E. Drawing from the insight of Foster S-Curve theory (1986), phases of this low-carbon transition were identified. Exploring the phenomenon throughout these phases, when innovation unfolds, was essential to identify patterns of change in actors and actors' group.

Additionally, since the context of each MLP is defined for each season and the phases of the transition are structured for this transition, it is possible to detect implication on the inter-system dynamics. Specifically, the direction of this system transformation results are influenced by the technological trajectory of interrelated systems confirming what Papachristos (2014) has observed in his studies. However, differently from the fifth pathways which Papachristos et al. (2013) have described (section 2.4.2), FIA Formula E does not emerge from technology developed at niche level in other systems, nor as a new system, emerging outside existing systems, which incorporate features of all its 'parents systems'.

Finally, this study contributes to the recent debate of disruption in socio-technical transition (Geels 2018; Wilson and Tyfield 2018). Specifically, as socio-technical theories represent transformative changes in the organisational field, mobilising theories of business innovation and specifically the theory of disruptive innovation (Christensen and Raynor 2013) has contributed to providing insight on the process transformation and reconfiguration of the system. This empirical study has offered grounds for a much broader and richer understanding of disruptive innovation in systems (Pinkse, Bohnsack and Kolk 2014; Rotheram-Borus, Swendeman and Chorpita 2012; Wilson and Tyfield 2018). Precisely, drawing from the theory of disruptive innovation, which identifies, alongside the techno-economic mechanism, a social and business mechanism playing an important role for technological changes, this thesis suggests that mobilising this theory of business innovation within the MLP approach could shed interesting findings on the dynamics of the transition. Utilising concepts of relativeness to the business model which the new system is disrupting, new value network, customers' culture, socio-landscape pressure and costumer's preferences at a system level has been helpful for understanding the dynamic of this low-carbon transition, generating an important recommendation for practitioners. Data gathered has shown how the FIA Formula E patchwork of regimes level developed per se', in response to a business opportunity and a request from the socio-economic landscape level, in a non-consumption market, where new users, new market, entrepreneurs and some incumbents were initially interacting without interfering with the traditional patchwork of regimes. With time, and with the pressure of the socio-economic landscape level and disastrous events, this new system gained enough momentum to draw the attention of incumbents to the well-established traditional system, destabilising the existing system. The dynamics of this transition are therefore very different to those investigated by many MLP scholars, as the new system, which a disruptive innovation has triggered, resulted in a non-consumption system initially, with the very different business model and value network from the old traditional systems. Whilst the infancy stage of FIA Formula E coincides with the above phase in which both systems (new and traditional) live parallel lives, data have shown that when the new system gains enough momentum it invades the traditional system market, drawing away users, sponsors, teams and manufacturers, as shown in the growth phase. It is at this point that there is a need for a reconfiguration of the system which accounts for both systems. Hence, this research suggests that mobilising the theory of disruptive innovation (Christensen and Raynor 2013) can supply recommendation for this reconfiguration process.

This empirical study has also supplied an example of how mobilising business innovation theories within the MLP approach and specifically the theory of disruptive innovation goes beyond the limitations of the unit of analysis of those theories, which is firms. In doing so, this thesis has contributed to the mismatch from Geels' paper (2018), which was one of the gaps that emerged in chapter 2. Specifically, Geels' article from 2011 endorsed the practice of mobilising theories of innovation, technological change, institutional theories within the MLP approach, remarking that the unit of analysis of these theories is not relevant when mobilised within an MLP approach. Later, in 2018, the scholar dismisses the possibility of using the theory of disruptive innovation to understand disruption in low-carbon transitions. This thesis has shown that this incompatibility was due to considering the theory of disruptive innovation as a different framework to explain system changes, rather than mobilising this theory of innovation within the MLP approach to explore the dynamics of alternative transition's pathways.

In summary, this thesis has provided many inputs and suggestions for the refinement of levels of the MLP approach and the exploration of alternative transition pathways. Those enhancements are based on a socio-technical understanding of low-carbon system changes but also account for theories of business and management being mobilised within this approach.

8.3.2 Contribution to methodology

FIA Formula E is an empirical study of low-carbon socio-technical transition. As such this research also brings methodological contribution to the MLP approach. Specifically, answering Genus and Cole's (2008) call for a more robust operationalisation of the MLP regimes, this research has proposed a way to build regimes and levels as free as possible from biases using strategies for processing data from business studies (Langley 1999) and techniques from operational research and change management from strategic management and engineering disciplines. Chapter 5 has explained how using temporal bracketing, narrative and visual mapping could result in building a robust innovatory system of the phenomena which can then be translated by the use of these techniques into MLP schematics (chapter 6). Those strategies and techniques conferred to the study robustness, external validity and enhanced its replicability.

Additionally, this study acknowledges the temporal system dynamics in low-carbon socio-technical transition within the MLP approach, proposing a way to operationalise it, in order to allow for a more comprehensive understanding of actors and their relationship within the different phases of the transition.

8.3.3 Contribution to motorsport literature

One contribution of this study to the motorsport literature has been to explore the dynamics of low carbon transitions using the context of FIA Formula E. Electric motorsport has been briefly touched on from Huber (2012) who debated that the use of electric motorsport would increase the uptake of electric vehicles and accelerate the low-carbon transition within the automotive sector. Whilst it is not the priority of this study to add to this debate, data has shown that the rapid growth of this formula has responded to the automotive sector's need for a technology incubator and a R&D department, together with representing a marketing and commercial platform for the transformation of the automotive system. Most recently scholars have used the context of FIA Formula E to explore environmental sustainability in motorsport (Robeers and Van Den Bulk 2018; Robeers 2019) responding to previous studies on greenwashing in FIA Formula One and FIFA (Miller 2016). These studies have concluded that FIA Formula E is the first attempt to raise environmental sustainability in motorsport and, "from a macro-prospective on motor sport as a whole, […] a first step in profound changes in motorsport governing behaviour" (Robeers and Van Den Bulk 2019: 348). Rather, FIA Formula E has been used in this thesis as an example of low-carbon system transformation bringing contribution to the motorsport literature on exploring the way this change was enacted and the dynamics of these shifts.

The second area of contribution to the motorsport literature is to unveil how decisions are taken in motorsport and precisely the significance of non-institutional actors in changing the rules and drive technology and business roadmaps. Contrarily to previous studies (Papachristos 2014), which identify the FIA as having powers to change any regulation within the motorsport industry, this study has shown that changes in regulation are decided collectively between the FIA and other actors, which play an essential role in driving and enacting changes. Those actors are included in the Technical Working Group (TWG), Commercial Working Group (CWG) and Sportive Working Groups (SWG) and collectively drive the direction of technical, business and sporting changes. Those committees do not exist exclusively for the FIA Formula E championship but are partly or entirely deployed in all other championships under the FIA umbrella. Exploring FIA Formula E has also uncovered that, within this process of road mapping, informal actors (the new manufacturer's group) were involved too, and they belong to the interrelated system.

Finally, this study contributes to motorsport literature showing that changes in this system are not just driven by radical technologies (Jarvenpaa and Standaert

2017) but from socio-economic and political factors. Chapter 6 has unveiled that the technology used in FIA Formula E from season 0 to season 3 was just the best technology available on the market in 2012. Rather, socio-economic, political and societal factors were successfully combined to fulfil an interrelated business need. It is the awareness of those other factors over technological excellence of which the motorsport literature should be most mindful when considering changes.

8.3.4 Practical implication

By mobilising the theory of disruptive innovation (Christensen and Raynor 2013) with the approach of Geels and Schot (2007), this thesis creates a novel explanation for disruption-led socio-technical transition discussed in chapter 7. This explanation could be of interest to practitioners for informing strategy building towards low-carbon sustainable transitions. This framework is explained in figure 17 and includes a parallel system which initially is in a non-consumption market to test, define and aggregate invested interests from different actors involved, implicitly and explicitly, in the transition. This parallel system shares the socio-economic landscape with the traditional system and includes new and incumbent actors at the patchwork of regime level. This is possible as this low-carbon sustainable transitions are purpose-oriented (chapter 2) where their ultimate purpose is to solve the Global Challenge (chapter 1) and specifically climate change (Geels et al. 2017). Once the parallel system enters in the consumption market, as values are transformed, it shakes up the traditional motorsport system, calling for a reconfiguration where both systems co-exist. The terms of this reconfiguration will be part of the recommendations for further research in section 8.4.

This thesis also contributes to the debate around the scope of motorsport on public discourse, and specifically the use of motorsport as a vehicle that may enable societal changes (Huber 2012).

8.3.4 Originality of this research

The originality of this research is twofold.

Firstly this research brings new empirical work on low-carbon transition using motorsport as a context to explore the dynamics of sustainable socio-technical change. Specifically, in this thesis, the motorsport industry has served as a useful context to explore factors and actors extensively within a low carbon, sustainable, technological change, in what the management literature would typically define as a short term horizon, between a 5 to 10 year span. The peculiarity of this industry, discussed in chapter 3, is in fact to be a super-fast, ever-changing world, where a fast-paced innovation, rapid production culture and a 'can do' attitude are the primary factors for success. In this context, FIA Formula E has progressed from its infancy phase to the end of the growth phase in five years, whilst, in other sectors, this would have taken from ten to fifteen years per phase (automotive sector) or even more (space and defence sectors). It is this ability to explore and observe technological changes as they are happening which has made the motorsport industry appealing and useful for answering the research question and objectives of this study and to solve key challenges addressed in chapters 2.

Secondly, this thesis introduces a cross-disciplinary interpretation of this transition pathway, mobilising the theory of disruptive innovation (Christensen and Raynor 2013) within the MLP approach in the same way in which theories of innovation and technological change were mobilised within other empirical research (Fischer and Newig 2016, Johnstone and Kivimaa 2018, Loorbach 2010, Rogge, Pfluger and Geels 2018, Verbong and Loorbach 2012, Verbong and Geels 2007).

8.4 Limitations and avenues for further research

This section addresses two specific limitations, which generated four ideas.

The first limitation is the timeframe of this study. The data collected referred from season 0 to season 3, which this thesis has found coinciding with the infancy and growth phase of the life cycle of FIA Formula E. As the overarching design of this thesis was to explore the dynamics of low carbon transition, those data were enough to discover actors and institutions which have driven, shaped and enacted this championship. However, the data collected have shown that the time frame considered did not include the maturity phase of FIA Formula E. Hence further research should include an investigation into seasons 4, 5 and 6. This further data might shed light into the maturity phase of innovation (Foster 1986), which corresponds, in the theory of disruptive innovation (Raynor and

Christensen 2003), to the phase where the new product enters the existing market, causing a reconfiguration of the system, supplying insight on the co-evolution and reconfiguration of systems in transition (Geels 2018).

The other limitation of this study is the type of innovation system selected. Motorsport has been historically an industry where the innovatory system has allowed for innovation to come through different ways, either with changes in regulation (top-down approach) or with potentially disruptive innovation being developed and accepted into the system (bottom-up approach). This peculiarity allows for a potential diversity of transition pathways compared to other more conventional industries. Further research in other industries should be encouraged to look for similar transition pathways. One limitation of researching other industries is the time scale of low-carbon transition which, after 18 years are just at the end of their infancy stage. As seen in chapter 2, in fact, academic theories estimate the time scale of low-carbon technological transition in the energy and automotive industry to be 50-70 years, making it difficult to study the reconfiguration processes.

Recommendations for further studies in other industries could also include some methodological guidance, such as selecting appropriately the sample of semi-structured interviews, which need to include a diversity of actors belonging to all the different regimes, sitting at the patchwork of regime level. The use of a visual map to display events and activities, as used in this study and discussed in chapter 4 is highly recommended to select interviewees robustly. However, this is a time-consuming operation which, in a more structured industry, might be replaced by the use of institutional and stakeholder’s maps detailing actors and actors’ groups. Those maps can be used to identify actors in each regime robustly. Stakeholder mapping is a widely used method in policy-making and has been recently introduced in geography and social science, although “its legitimacy is yet to be fully granted by the academic community” (Aligica 2006: 80). The institutional and stakeholder mapping is a cognitive process that identifies the stakeholder involvement in the project in order to map out actors (the stakeholders) but also processes such as relative power, influence or interests.

8.5 Personal reflection

In this last section, I reflect on my journey in conducting this PhD.

My personal stance has been already discussed in section 5.2 in order to offer the reader a clear understanding of my positionality, background and reflexivity to fully appreciate the reasons behind the methodological approach chosen; hence this last section will offer the reader some insights on expectations, aspiration and changes to my inner self during the overall process of this research.

When I started this journey into my PhD, I was not sure how the journey would change me. Many influential people in the motorsport industry thought that this decision was equivalent to taking a sabbatical year, or more than one, whilst deciding if returning to the engineering side of the industry or progressing on the business and strategy side. Personally, undertaking a PhD was a case of rebalancing my life and continuing the process of learning and being intellectually challenged. Having observed first-hand changes to the motorsport industry, I was very keen to investigate these changes further. What I was not aware of when I started was how this journey would have changed my understanding of the world. Looking back, this does not surprise me now, as I, an engineer, was doing my PhD within the business school research Centre for Business in Society.

I do not recollect having reflected much on the title of the centre until perhaps in the second year of my PhD someone made a silly joke that the name of the centre was influencing the way I was "seeing" the reality. The most important and probably deeper change that occurred to me, a 40 something female engineer, was to understand that technology is not per se', but is made of multiple factors which all contribute, in time and combinations, to change. Although this could sound like a cliché, this was personally the most unexpected finding, especially within the motorsport industry where academic and industry studies have focused mainly on technology and business factors.

Whilst my initial expectation of my PhD was narrating the story of FIA Formula E, which I knew by heart as I contributed to writing it, by my second year at the Centre for Business in Society (CBiS) I understood that a story is not only made of what we know or what we see, but from hidden insights, discoveries, lost and found information which was part of my extended journey. This information needed a clear methodological approach, structured around repeatability and robustness, where existing and well-travelled research methods would have been applied for gathering and analysing the data. This part of the journey was hard, but when this was understood, almost everything fell into place.

Almost at the same time, I was selected to attend the first summer school at the University of Sussex, in the Centre for Innovation and Energy Demand. This was an enlightening opportunity which helped me to understand the level at which my study could contribute to current debates, having had the privilege to speak and socialise with transition scholars such as Geels, Schot, Rogge, and Reichardt. Being able to use the motorsport industry as a context for contributing to the transition literature was a significant part of my journey, which I am planning to translate in journal articles once my PhD journey is finished.

Although I have some pressure from the industry to go back, I am reticent to go back full-time within a role which I feel will not do much justice on how I have changed in those years. My understanding of the world, in fact, has been transformed, and I would rather find a way to finish the journey I started, studying further hypotheses concerning system reconfiguration or transferring my findings to the automotive and energy sector. This could bring some interesting implications for policy and industry looking at new pathways to innovation.

Within the motorsport industry, there is also a hidden need for system reconfigurations which can include the traditional motorsport system and new ones, but which are also able to take into account societal and business changes. Although single actors deny the need for reconfiguration, namely FEH and F1, other stakeholders of the system such as FIA, Liberty Media and OEMs are starting to become more aware of this need.

A personal reflection section should also include a section on what I could have done differently in this journey. Suggestions concerning different methodological avenues and the use of stakeholder and institutional maps have been already supplied in section 8.4 and could be of use in other industries.

I hope that this understanding has also been transferred to you, the reader of this PhD and that you have enjoyed the journey.

References

Abernathy, W. J. and Utterback, J. M. (1978) 'Patterns of Industrial Innovation'. Technology Review 64, 254-228

Abernathy, W. J. and Clark, K. B. (1985) 'Innovation: Mapping the Winds of Creative Destruction'. Research Policy 14 (1), 3-22

Abernathy, W. J., Clark, K. B., and Kantrow, A. M. (1983) Industrial Renaissance: Producing a Competitive Future for America: Basic Books (AZ)

Aligica, P. D. (2006) 'Institutional and Stakeholder Mapping: Frameworks for Policy Analysis and Institutional Change'. Public Organization Review 6 (1), 79-90

Anderson, P. and Tushman, M. L. (1990) 'Technological Discontinuities and Dominant Designs: A Cyclical Model of Technological Change'. Administrative Science Quarterly, 604-633

Anthony Giddens (1984) The Constitution of Society: Outline of the Theory of Structuration. Univ of California Press

Associated Press (2013) Leonardo DiCaprio Partners with Venturi for FIA Formula E Team [online] available from <http://www.foxnews.com/sports/2013/12/09/leonardo-dicaprio-partners-with-venturi-for-fia-formula-e-team.html> [01/08 2017]

Atkinson, P. and Delamont, S., 2006. Rescuing narrative from qualitative research. *Narrative inquiry*, *16*(1), pp.164-172.

Audi Mediacenter (2016) Audi with New Motorsport Strategy: FE Instead of WEC [online] available from <https://www.audi-mediacenter.com/en/press-releases/audi-with-new-motorsport-strategy-formula-e-instead-of-wec-6980> [28/07 2017]

Automotive World (2013) Spark Racing Technology (SPARK) FIA Formula E Consortium Launched [online] available from <https://www.automotiveworld.com/news-releases/spark-racing-technology-spark-fia-formula-e-consortium-launched> [08/08 2017]

Baden-Fuller, C. and Haefliger, S. (2013) 'Business Models and Technological Innovation'. Long Range Planning

Badiru, A. B. (2005) *Handbook of Industrial and Systems Engineering*.: CRC Press

Beard, C. A. (1927) 'Time, Technology, and the Creative Spirit in Political Science'. The American Political Science Review 21 (1), 1-11

Beecroft, N. (2017) Global Sport and Sustainability Leaders Elected to Board at Inaugural Congress in Paris [online] available from <http://www.marketwired.com/press-release/global-sports-sustainability-leaders-elected-board-inaugural-congress-paris-2219863.htm> [08/08 2017]

Belson, K., (2012) Formula E Goes Racing Hunting for Respect, and a Market. [02/10/2012 2012] available from <https://wheels.blogs.nytimes.com/2012/10/02/formula-e-racing-goes-hunting-for-respect-and-a-market/> [01/08/2017]

Berggren, C., Magnusson, T., and Sushandoyo, D. (2015) Transition Pathways Revisited: Established Firms as Multi-Level Actors in the Heavy Vehicle Industry [online]. available from <http://www.sciencedirect.com/science/article/pii/S0048733314002005>

Berkeley, N., Bailey, D., Jones, A., and Jarvis, D. (2017) 'Assessing the Transition towards Battery Electric Vehicles: A Multi-Level Perspective on Drivers of, and Barriers to, Take Up'. Transportation Research Part A; Transportation Research Part A 106, 320-332

Berkhout, F., Angel, D., and Wieczorek, A. J. (2009) 'Asian Development Pathways and Sustainable Socio-Technical Regimes'. Technological Forecasting and Social Change 76 (2), 218-228

Biesbrouk, T. (2013) Dragon Racing Joins FIA Formula E Championship [online] available from <in http://www.electricautosport.com/2013/09/dragon-racing-joins-fia-formula-e-championship/> [05/08 2017]

Biesbrouk, T. (2014) ***Q&A with FIA President Jean Todt about Formula E***. https://www.electricautosport.com/2014/09/qa-fia-president-jean-todt-formula-e/ edn: Electric Autosport

Bijker, W. E. (1997) Of Bicycles, Bakelites, and Bulbs: Toward a Theory of Sociotechnical Change.: MIT press

Bijker, W. E., Hughes, T. P., and Pinch, T. J. (1987) The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology.: MIT press

Bijker, W. E., Hughes, T. P., and Pinch, T. (2012) Social Construction of Technological Systems: The MIT Press

BMW group (2017) BMW Confirms FIA Formula E Championship Entry as an Official Manufacturer in Season 5 – Formula E a Platform for the Mobility of the Future and a Technological Laboratory for BMW iNEXT and Other Future Generations of BMW i Models.. [11/07 2017] available from <https://www.press.bmwgroup.com/global/article/detail/T0272584EN/bmw-confirms-fia-formula-e-championship-entry-as-an-official-manufacturer-in-season-5-%E2%80%93-formula-e-a-platform-for-the-mobility-of-the-future-

and-a-technological-laboratory-for-bmw-inext-and-other-future-generations-of-bmw-i-models?language=en> [01/08/2017]

Bochner, A.P., Ellis, C. and Tillmann-Healy, L., 2000. Relationships as stories: Accounts, storied lives, evocative narratives.

Bohnsack, R., Kolk, A., and Pinkse, J. (2015) 'Catching Recurring Waves: Low-Emission Vehicles, International Policy Developments and Firm Innovation Strategies'. Technological Forecasting and Social Change 98, 71-87

Bohnsack, R., Pinkse, J., and Kolk, A. (2014) 'Business Models for Sustainable Technologies: Exploring Business Model Evolution in the Case of Electric Vehicles'. Research Policy 43 (2), 284-300

Bower, J. L. and Christensen, C. M. (1995) 'Disruptive Technologies: Catching the Wave'. Harvard Business Review 73 (1), 43-53

Bruland, K. and Mowery, D. C. (eds.) (2004). 'Innovation through Time': Georgia Institute of Technology

Bryman, A. (2015) Social Research Methods.: Oxford university press

Bryman, A. and Bell, E. (2015) Business Research Methods: Oxford University Press, USA

Bruner, J. and Kalmar, D.A., 1998. Narrative and metanarrative in the construction of self. *Self-awareness: Its nature and development*, pp.308-331.

Carlsson, B. and Stankiewicz, R. (1991) 'On the Nature, Function and Composition of Technological Systems'. Journal of Evolutionary Economics 1 (2), 93-118

Chackraborty, A. (2013) Mahindra Steps Up for Formula E [online] available from <http://www.wheels24.co.za/News/Mahindra-steps-up-for-Formula-E-20131129> [01/08 2017]

Champions (2014) Donningthon Park Chosen as World Base by Formula E Championship in Motorsport [online] available from <https://champions-speakers.co.uk/news/donington-park-chosen-world-base-formula-e-motorsport-series> [01/08 2017]

Chandy, R. K. and Tellis, G. J. (1998) 'Organizing for Radical Product Innovation: The Overlooked Role of Willingness to Cannibalize'. Journal of Marketing Research 35 (4), 474-487

Christensen, C. (1993) 'The Rigid Disk Drive Industry: A History of Commercial and Technological Turbulence'. Business History Review 67 (4), 531

Christensen, C. M. (1997) 'The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail'. Harvard Business School Press Books, 1

Christensen, C. M. (2000) The Innovator's Dilemma. Boston, MA: Boston, MA. : Harper

Christensen, C. M. (2006) 'The Ongoing Process of Building a Theory of Disruption'. Journal of Product Innovation Management 23 (1), 39-55

Christensen, C. M., Horn, M. B., and Staker, H. (2013) 'Is K-12 Blended Learning Disruptive? An Introduction to the Theory of Hybrids.' Clayton Christensen Institute for Disruptive Innovation

Christensen, C. and Overdorf, M. (2000) 'Meeting the Challenge of Disruptive Change'. Harvard Business Review 78 (2), 66-76

Christensen, C. and Raynor, M. (2013) The Innovator's Solution: Creating and Sustaining Successful Growth: Harvard Business Review Press

Christensen, C., Raynor, M., and Mcdonald, R. (2015) 'What is Disruptive Innovation?' Harvard Business Review, 1

Clark, P. and Staunton, N. (1989) Innovation in Technology and Organization.

Coenen, L. and López, F. J. D. (2010) 'Comparing Systems Approaches to Innovation and Technological Change for Sustainable and Competitive Economies: An Explorative Study into Conceptual Commonalities, Differences and Complementarities'. Journal of Cleaner Production 18 (12), 1149-1160

Coenen, L., Benneworth, P., and Truffer, B. (2012) 'Toward a Spatial Perspective on Sustainability Transitions'. Research Policy 41 (6), 968-979

Connelly, G. (2014) *Sustainability for all* [online] available from <www.fia.com> [2017]

Corbin, J., Strauss, A., and Strauss, A. L. (2014) Basics of Qualitative Research.: sage

Crossan, M. and Apaydin, M. (2010) A Multi-Dimensional Framework of Organizational Innovation: A Systematic Review of the Literature. Oxford: Blackwell Publishing Ltd

Defilippi, R. and Wikstrom, P.,: (2014) International Perspectives on Business Innovation and Disruption in the Creative Industries.: Edward Elgar Publishing

Delbridge, R. and Mariotti, F. (2009) Racing for Radical Innovation: How Motorsport Companies Harness Network Diversity for Discontinuous Innovation: Advanced Institute of Management Research (AIM)

Dewar, R. D. and Dutton, J. E. (1986) 'The Adoption of Radical and Incremental Innovations: An Empirical Analysis'. Management Science 32 (11), 1422-1433

Dijk, M., Orsato, R. J., and Kemp, R. (2013) 'The Emergence of an Electric Mobility Trajectory'. Energy Policy 52, 135-145

Dijk, M., Wells, P., and Kemp, R. (2016) 'Will the Momentum of the Electric Car Last? Testing an Hypothesis on Disruptive Innovation'. Technological Forecasting & Social Change 105, 77-88

Disruptor award (2018) [online] available from <https://www.disruptorawards.com/new-gallery-1/2017/1/26/formula-e-racing-tribeca-disruptive-innovation-awards-2015> [01/07 2018]

Dosi, G. (1982) 'Technological Paradigms and Technological Trajectories: A Suggested Interpretation of the Determinants and Directions of Technical Change'. Research Policy 11 (3), 147-162

Dosi, G., Freeman, C., and Fabiani, S. (1994) 'The Process of Economic Development: Introducing some Stylized Facts and Theories on Technologies, Firms and Institutions'. Industrial and Corporate Change 3 (1), 1-45

Dosi, G. and Nelson, R. R. (1994) 'An Introduction to Evolutionary Theories in Economics'. Journal of Evolutionary Economics 4 (3), 153-172

Dosi, G. and Nelson, R. R. (2010) 'Technical Change and Industrial Dynamics as Evolutionary Processes'. Handbook of the Economics of Innovation 1, 51-127

Dosi, G. and Nelson, R. R. (2013) 'The Evolution of Technologies: An Assessment of the State-of-the-Art'. Eurasian Business Review 3 (1), 3-46

Dosi, G. and Winter, S. (2002) 'Interpreting Economic Change: Evolution, Structures and Games'. The Economics of Choice, Change, and Organizations.Cheltenham, Edward Elgar Publishers

Easton, G. (2010) 'Critical Realism in Case Study Research'. Industrial Marketing Management 39 (1), 118-128

Easton, G., Lundgren, A., Axelsson, B., and Easton, G. (1992) 'Changes in Industrial Networks as Flow-through Nodes'

Electric Race News (2013) ***China Racing is Second Race Team to Join FIA's Formula E Electric Car Racing Series***. http://www.electricracenews.com/2013/03/china-racing-is-second-race-team-to.html edn: Electric race news

Ellul, J. and Juriste, P. (1954) La Technique Ou l'Enjeu Du Siècle.: A. Colin Paris

Elwood, S. A. and Martin, D. G. (2000) '"Placing" Interviews: Location and Scales of Power in Qualitative Research'. The Professional Geographer 52 (4), 649-657

Enel (2016) Formula E Makes History in Marrakech [online] available from <https://www.enel.com/en/media/news/d201611-FormulaE-makes-history-in-Marrakech.html> [01/08 2017]

European Commission (2012) The Grand Challenge — the Design and Societal Impact of Horizon 2020 [green/white paper] Luxembourg: Publications Office of the European Union

Evans, J. and Jones, P. (2011) 'The Walking Interview: Methodology, Mobility and Place'. Applied Geography 31 (2), 849-858

Farla, J., Markard, J., Raven, R., and Coenen, L. (2012) 'Sustainability Transitions in the Making: A Closer Look at Actors, Strategies and Resources'. Technological Forecasting and Social Change 79 (6), 991-998

Federation International De l'Automobile Anon (2018a) [online] available from <www.fia.com> [n.d. 2012]

FIA (2012a) *REGISTRATION PROCEDURE FOR THE SUPPLY OF CARS IN THE 2014 and 2015 FIA FORMULA E CHAMPIONSHIP*. [2012 2012] available from <https://www.the-mia.com/assets/FIA_FORMULA_E.pdf> [01/06/2018]

FIA (2016) FE: All that's New in Formula E [online] available from <https://www.fia.com/news/fe-all-thats-new-formula-e> [06/06 2017]

FIA (2017) FIA Smart Cities: Heping Cities to Define New Models for Sustainable Urban Mobility [online] available from <https://www.fia.com/fia-smart-cities-0> [10/01 2017]

Finnegan, R. H., Salaman, G., Thompson, K., 1937-, and University, O. (1987) Information Technology: Social Issues: A Reader. Sevenoaks: Sevenoaks: Hodder and Stoughton in association with the Open University

Fischer, L. and Newig, J. (2016) Importance of Actors and Agency in Sustainability Transitions: A Systematic Exploration of the Literature. Basel: MDPI AG

Flick, U., 1956- author (2014) An Introduction to Qualitative Research. Edition 5. edn

Florini, A. and Sovacool, B. K. (2009) 'Who Governs Energy? the Challenges Facing Global Energy Governance'. Energy Policy 37 (12), 5239-5248

Formula E (2013a) ABT Sportline to Compete in Formula E Under Audi Sport Banner [online] []

Formula E (2013b) Fox Sport Confirms International Multi-Years Deal with FIA Formula E Championship [online] available from <http://www.fiaformulae.com/en/news/2013/august/fox-sports-confirms-international-multi-media-deal-with-fia-formula-e-championship/> [07/01 2017]

Formula E (2013c) Causeway Media Partners to Take Multi-Million Investment in Formula E [online] available from <http://www.fiaformulae.com/en/news/2013/december/causeway-media-partners-to-make-multi-million-investment-in-formula-e.aspx> [07/01 2017]

Formula E (2014a) The Road Map of Formula E [online] available from <http://www.fiaformulae.com> [01/06 2017]

Formula E (2014b) New Investors Raise Capital Totalling 50 Million Euros for Formula E Series [online] available from <http://www.fiaformulae.com/en/news/2014/may/new-investors-raise-capital-totalling-50-million-euros-for-formula-e-series.aspx> [08/01 2017]

Formula E (2015) FIA Homologates Manufacturers for Second Season [online] available from <http://www.fiaformulae.com/en/news/2015/august/fia-homologates-manufacturers-for-second-formula-e-season.aspx> [07/01 2017]

Formula E (2017) Boss Talk [online] available from <http://www.fiaformulae.com/en/news/2017/january/boss-talk/> [06/15 2017]

Formula E (2018b) Anon [online] available from <www.fiaformulae.com> [07/07 2017]

Formula E Holdings (2012) New FIA Formula E Championship Powered by Electric Energy [online] available from <http://news.cision.com/formula-e-holdings/r/new-fia-formula-e-championship-powered-by-electric-energy,c9296748> [01/08 2017]

Formula E Operations Ltd (2015) *Sustainability Report Season One*. London: Formula E Holding

Formula E Operations Ltd (2016) *Sustainability Report Season Two*. London: Formula E Holding

Foster, R. N. (1986) 'Working the S-Curve: Assessing Technological Threats'. Research Management 29 (4), 17-20

Fox News (2013) Andretti to Run Electric Car Series [online] available from <http://www.foxnews.com/auto/2013/07/17/andretti-to-run-electric-car-series.html> [01/08 2017]

Foxall, G. R. and Johnston, B. R. (1991) 'Innovation in Grand Prix Motor Racing: The Evolution of Technology, Organization and Strategy'. Technovation 11 (7), 387-402

Foxon, T. J., Hammond, G. P., and Pearson, P. J. G. (2010) Developing Transition Pathways for a Low Carbon Electricity System in the UK [online]. available from <http://www.sciencedirect.com/science/article/pii/S0040162510000697>

Foxon, T. J., Reed, M. S., and Stringer, L. C. (2009) 'Governing Long-Term Social-Ecological Change: What can the Adaptive Management and Transition Management Approaches Learn from each Other?'. Environmental Policy and Governance 19 (1), 3-20

Freeman, C. (1982) 'The Economics of Industrial Innovation'

Freeman, C. (1989) Technology Policy and Economic Performance: Pinter Publishers Great Britain

Freeman, C. (1991) 'Networks of Innovators: A Synthesis of Research Issues'. Research Policy [online] 20 (5), 499-514. available from <http://www.sciencedirect.com/science/article/pii/004873339190072X>

Freeman, C. and Perez, C. (1988) Structural Crises of Adjustment, Business Cycles and Investment Behaviour: Pinter

Fuenfschilling, L. and Truffer, B. (2016) 'The Interplay of Institutions, Actors and Technologies in Socio-Technical Systems - an Analysis of Transformations in the Australian Urban Water Sector'. Technological Forecasting and Social Change 103, 298-312

Gadde, L., Huemer, L., and Håkansson, H. (2003) 'Strategizing in Industrial Networks'. Industrial Marketing Management 32 (5), 357-364

Gaignault, G. (2010) *L'Electric Formula EF01 Est Nee* [online] available from <http://www.autonewsinfo.com/2010/09/29/l%E2%80%99electric-formula-ef01-est-nee%E2%80%A6-1380.html> [22/07 2017]

Garcia, R. and Calantone, R. (2002) 'A Critical Look at Technological Innovation Typology and Innovativeness Terminology: A Literature Review'. The Journal of Product Innovation Management 19 (2), 110-132

Garud, R. (2012) Path Dependence and Creation. New York: New York: Psychology Press

Gatignon, H., Tushman, M. L., Smith, W., and Anderson, P. (2002) 'A Structural Approach to Assessing Innovation: Construct Development of Innovation Locus, Type, and Characteristics'. Management Science 48 (9), 1103

Geels, F. W. (2002) 'Technological Transitions as Evolutionary Reconfiguration Processes: A Multi-Level Perspective and a Case-Study'. Research Policy 31 (8), 1257-1274

Geels, F. W. (2004) 'From Sectoral Systems of Innovation to Socio-Technical Systems: Insights about Dynamics and Change from Sociology and Institutional Theory'. Research Policy 33 (6), 897-920

Geels, F. W. (2010) 'Ontologies, Socio-Technical Transitions (to Sustainability), and the Multi-Level Perspective'. Research Policy 39 (4), 495-510

Geels, F. W. (2011) 'The Multi-Level Perspective on Sustainability Transitions: Responses to Seven Criticisms'. Environmental Innovation and Societal Transitions 1 (1), 24-40

Geels, F. W. (2012) 'A Socio-Technical Analysis of Low-Carbon Transitions: Introducing the Multi-Level Perspective into Transport Studies'. Journal of Transport Geography 24, 471-482

Geels, F. W. (2018) 'Disruption and Low-Carbon System Transformation: Progress and New Challenges in Socio-Technical Transitions Research and the Multi-Level Perspective'. Energy Research & Social Science 37, 224-231

Geels, F. W. (2018) 'Low-Carbon Transition Via System Reconfiguration? A Socio-Technical Whole System Analysis of Passenger Mobility in Great Britain (1990–2016)'. Energy Research & Social Science; Energy Research & Social Science 46, 86-102

Geels, F. W., Kern, F., Fuchs, G., Hinderer, N., Kungl, G., Mylan, J., Neukirch, M., and Wassermann, S. (2016) 'The Enactment of Socio-Technical Transition Pathways: A Reformulated Typology and a Comparative Multi-Level Analysis of the German and UK Low-Carbon Electricity Transitions (1990-2014)'. Research Policy 45 (4), 896-913

Geels, F. W. and Schot, J. (2007) 'Typology of Sociotechnical Transition Pathways'. Research Policy 36 (3), 399-417

Geels, F. W. and Schot, J. (2010) 'The Dynamics of Transitions: A Socio-Technical Perspective'

Geels, F. W., Sovacool, B. K., Schwanen, T., and Sorrell, S. (2017) 'The Socio-Technical Dynamics of Low-Carbon Transitions'. Joule; Joule 1 (3), 463-479

Geels, F. W. and Verhees, B. (2011) 'Cultural Legitimacy and Framing Struggles in Innovation Journeys: A Cultural-Performative Perspective and a Case Study of Dutch Nuclear Energy (1945–1986)'. Technological Forecasting & Social Change 78 (6), 910-930

Genus, A. and Coles, A. (2008) 'Rethinking the Multi-Level Perspective of Technological Transitions'. Research Policy 37 (9), 1436-1445

Ghosh, B. and Schot, J. (2019) Towards a Novel Regime Change Framework: Studying Mobility Transitions in Public Transport Regimes in an Indian Megacity [online]. Available from <http://www.sciencedirect.com/science/article/pii/S2214629618304547>

Glaser, B. G. and Strauss, A. L. (1967) 'The Discovery of Grounded Theory: Strategies for Qualitative Theory'. New Brunswick: Aldine Transaction

Gort, M. and Klepper, S. (1982) 'Time Paths in the Diffusion of Product Innovations'. Economic Journal 92 (367), 630-653

Griffiths, M. (1998) Educational Research for Social Justice: Open University Press

Grin, J., Rotmans, J., and Schot, J. (2010) Transitions to Sustainable Development: New Directions in the Study of Long Term Transformative Change: Taylor & Francis

Håkansson, H. and Ford, D. (2002) 'How should Companies Interact in Business Networks?' Journal of Business Research 55 (2), 133-139

Hekkert, M. P., Suurs, R. A. A., Negro, S. O., Kuhlmann, S., and Smits, R. E. H. M. (2007) 'Functions of Innovation Systems: A New Approach for Analysing Technological Change'. Technological Forecasting & Social Change 74 (4), 413-432

Henry, N., Angus, T., Jenkins, M., and Aylett, C. (2007) 'Motorsport Going Global'. in Motorsport Going Global. Ed. by Anon: Springer, 132-156

Henry, N. and Pinch, S. (2000) 'Spatialising Knowledge: Placing the Knowledge Community of Motor Sport Valley'. Geoforum 31 (2), 191-208

Herrero, L. J. (2011) 'Transport and Mobility: The Keys to Sustainability'. Fund.Gen.CSIC.Lychnos (4)

Howlett, M. (2009) 'Governance Modes, Policy Regimes and Operational Plans: A Multi-Level Nested Model of Policy Instrument Choice and Policy Design. (Report)'. Policy Sciences 42 (1), 73

Howlett, M. and Rayner, J. (2007) 'Design Principles for Policy Mixes: Cohesion and Coherence in ‘new Governance Arrangements’'. Policy and Society 26 (4), 1-18

Huber, F. (2012) 'Can Motorsport Valley Drive Us Green?'

Hwang, J. and Christensen, C. M. (2008) 'Disruptive Innovation in Health Care Delivery: A Framework for Business-Model Innovation'. Health Affairs 27 (5), 1329-1335

Jarvenpaa, S. and Standaert, W. (eds.) (2017) *Proceedings of the 50th Hawaii International Conference on System Sciences*. 'Emergent Ecosystem for Radical Innovation: Entrepreneurial Probing at Formula E'

Jarvis, D. and Dunham, P. (2003) 'Conceptualising the 'competitive' strategies of Rural Manufacturing SMEs'. Tijdschrift Voor Economische En Sociale Geografie 94 (2), 246-257

Jenkins, K., McCauley, D., and Forman, A. (2017) 'Energy Justice: A Policy Approach'. Energy Policy 105, 631-634

Jenkins, M. (2010) 'Technological Discontinuities and Competitive Advantage: A Historical Perspective on Formula 1 Motor Racing 1950–2006'. Journal of Management Studies 47 (5), 884-910

Jenkins, M. (2014) 'Innovate Or Imitate? The Role of Collective Beliefs in Competences in Competing Firms'. Long Range Planning 47 (4), 173-185

Jenkins, M. and Floyd, S. (2001) 'Trajectories in the Evolution of Technology: A Multi-Level Study of Competition in Formula 1 Racing'. Organization Studies (Walter De Gruyter GmbH & Co.KG.) 22 (6), 945

Jenkins, M., Pasternak, K., and West, R. (2009) Performance at the Limit: Business Lessons from Formula 1 Motor Racing. Cambridge: Cambridge: Cambridge University Press

Jenkins, M. and Tallman, S. (2010) 'The Shifting Geography of Competitive Advantage: Clusters, Networks and Firms'. Journal of Economic Geography 10 (4), 599-618

Johnstone, P. and Kivimaa, P. (2018) 'Multiple Dimensions of Disruption, Energy Transitions and Industrial Policy'. Energy Research & Social Science 37, 260-265

Kemp, R. and Rotmans, J. (2005) 'The Management of the Co-Evolution of Technical, Environmental and Social Systems'. In Towards Environmental Innovation Systems. ed. by Anon: Springer, 33-55

Kemp, R., Schot, J., and Hoogma, R. (1998) 'Regime Shifts to Sustainability through Processes of Niche Formation: The Approach of Strategic Niche Management'. Technology Analysis & Strategic Management 10 (2), 175-198

Kivimaa, P. and Martiskainen, M. (2018) 'Dynamics of Policy Change and Intermediation: The Arduous Transition towards Low-Energy Homes in the United Kingdom'. Energy Research & Social Science 44, 83-99

Klein, H. K. and Kleinman, D. L. (2002) 'The Social Construction of Technology: Structural Considerations'. Science, Technology, & Human Values 27 (1), 28-52

Kondratieff, N. D. (1979) 'The Long Waves in Economic Life'. Review (Fernand Braudel Center), 519-562

Kramer, G. J. (2018) 'Energy scenarios—Exploring Disruption and Innovation'. Energy Research & Social Science 37, 247-250

Krivevski, B. (2013) *Drayson Racing is First on Grid for 2014 FIA Formula E Championship* [online] available from <http://electriccarsreport.com/2013/01/drayson-racing-is-first-on-grid-for-2014-fia-formula-e-championship/> [23/07 2017]

Langley, A. (1999) 'Strategies for Theorizing from Process Data'. The Academy of Management Review 24 (4), 691-710

Langley, A., Smallman, C., Tsoukas, H., and Ven, V. D. (2013) 'Process Studies of Change in Organization and Management: Unveiling Temporality, Activity, and Flow'. Academy of Management Journal 56 (1), 1-13

Latour, B. (2005) Reassembling the Social: An Introduction to Actor-Network-Theory.: Oxford university press

Law, J. and Callon, M. (1988) 'Engineering and Sociology in a Military Aircraft Project: A Network Analysis of Technological Change'. Social Problems 35 (3), 284-297

Leggett, T. (2012) Formula E Electric Car Racing Series in Launched by the FIA [online] available from <http://www.bbc.com/news/business-19402383> [07/08/2017 2017]

Loorbach, D. (2010) 'Transition Management for Sustainable Development: A Prescriptive, Complexity-Based Governance Framework'. Governance 23 (1), 161-183

Loorbach, D., Frantzeskaki, N., and Thissen, W. (2010) 'Introduction to the Special Section: Infrastructures and Transitions'. Technological Forecasting and Social Change 77 (8), 1195-1202

Loseke, D. R. (2016) 'Symbolic Interaction and Narrative Productions of Meaning in Public Spaces'. in *The Structural Bias Charge: Myth Or Reality?*. ed. by Anon: Emerald Group Publishing Limited, 123-144

MacKenzie, D. and Wajcman, J. (1999) The Social Shaping of Technology.: Open University press

Maclaurin, W. R. (1953) 'The Sequence from Invention to Innovation and its Relation to Economic Growth'. The Quarterly Journal of Economics 67 (1), 97-111

Markard, J., Raven, R., and Truffer, B. (2012) 'Sustainability Transitions: An Emerging Field of Research and its Prospects'. Research Policy 41 (6), 955-967

Markard, J. and Truffer, B. (2008) 'Technological Innovation Systems and the Multi-Level Perspective: Towards an Integrated Framework'. Research Policy 37 (4), 596-615

Marletto, G. (2014) Car and the City: Socio-Technical Transition Pathways to 2030 [online]. available from <http://www.sciencedirect.com/science/article/pii/S004016251300320X>

Marx, K., 1818-1883 (1967) The Communist Manifesto. Harmondsworth: Harmondsworth: Penguin

Maskell, P., Bathelt, H., and Malmberg, A. (2004) 'Temporary Clusters and Knowledge Creation: The Effects of International Trade Fairs, Conventions and Other Professional Gatherings'

Mauthner, N. S. and Doucet, A. (2003) 'Reflexive Accounts and Accounts of Reflexivity in Qualitative Data Analysis'. Sociology 37 (3), 413-431

McBeath, S. (2009) Competition Car Composites: A Practical Handbook. 2nd ed. edn. Sparkford: Sparkford: Haynes

Meadows, D. H., Meadows, D. L., and Randers, J. (1992) Beyond the Limits: Confronting Global Collapse, Envisioning a Sustainable Future: Post Mills, Vt.: Chelsea Green Pub. Co.,

Meadowcroft, J. (2007) 'Who is in Charge here? Governance for Sustainable Development in a Complex World*'. Journal of Environmental Policy & Planning 9 (3-4), 299-314

Miles, M. B., Huberman, A. M., Huberman, M. A., and Huberman, M. (1994) Qualitative Data Analysis: An Expanded Sourcebook.: sage

Miller, T. (2016) 'Greenwashed Sports and Environmental Activism: Formula 1 and FIFA'. *Environmental Communication* 10 (6), 719-733

Mirani, L. (2014a) How to make Electric Cars Sexy: Race them on the Streets of the World's Biggest Cities [online] available from <https://qz.com/214350/how-to-make-electric-cars-sexy-race-them-on-the-streets-of-the-worlds-biggest-cities/> [01/08 2017]

Mirani, L. (2014b) Cars in this New Racing Championship are Fueled by Electricity -and Tweets [online] available from <https://qz.com/215774/cars-in-this-new-racing-championship-are-fueled-by-electricity-and-tweets/> [02/08 2017]

Misa, T. J. (1998) 'Theories of Technological Change'. Bulletin of Science, Technology & Society 18 (4), 312-312

Moradi, A. and Vagnoni, E. (2018) A Multi-Level Perspective Analysis of Urban Mobility System Dynamics: What are the Future Transition Pathways? [online]. Available from <http://www.sciencedirect.com/science/article/pii/S0040162516308010>

Motorcycle news (2009) TTX GP Launch Zero Carbon Road Race Series [online] available from <https://www.motorcyclenews.com/sport/tt-road-races/2009/july/jul0609-ttxgp-launch-zero-carbon-road-race-series/> [08/16 2017]

Motorsport (2013) FIA WEC: LMP1 Regulation Announced [online] available from <https://www.motorsport.com/wec/news/fia-wec-lmp1-regulations-for-2014/444070/> [05/20 2017]

Mount, M. (2012) The Mechanisms that Drive Disruptive Innovation. [online] PhD thesis or dissertation: University of York

Mowery, D. C. and Rosenberg, N. (1999) Paths of Innovation: Technological Change in 20th-Century America: Cambridge University Press

Nathan, S. (2013) *Electric Formula: Inside the Formula E Racing Car* [online] available from <https://www.theengineer.co.uk/issues/october-2013-online/electric-formula-inside-the-formula-e-racing-car/> [08/08 2017]

Nelson, R. R. and Winter, S. G. (1977) 'In Search of a Useful Theory of Innovation'. In Innovation, Economic Change and Technology Policies. ed. by Anon: Springer, 215-245

Nelson, R. R. and Winter, S. G. (1982) 'The Schumpeterian Tradeoff Revisited'. The American Economic Review 72 (1), 114-132

Nichols, G. and Savage, M. (2017) 'A Social Analysis of an Elite Constellation: The Case of Formula 1'. Theory, Culture & Society 34 (5-6), 201-225

Nightingale, A. (2009) 'Warming Up the Climate Change Debate: A Challenge to Policy Based on Adaptation'. Journal of Forest and Livelihood 8 (1), 84-89

Ogburn, W. F. and Duncan, O. D. (1964) On Culture and Social Change: Selected Papers: University of Chicago Press Chicago.

Olsen, O. E. and Engen, O. A. (2007) 'Technological Change as a Trade-Off between Social Construction and Technological Paradigms'. Technology in Society 29 (4), 456-468

Oltra, V. and Saint Jean, M. (2009) 'Sectoral Systems of Environmental Innovation: An Application to the French Automotive Industry'. Technological Forecasting and Social Change 76 (4), 567-583

Painter, J., Rimmer, A., and Brown, A. (2002) A Feasibility Study into the Role Motorsport can play in the Development of Energy Efficient Automotive Technologies. England: MIA

Palmer, M., Medway, D., and Warnaby, G. (2017) 'Theorizing Temporary Spatial Clusters and Institutional Boundary-Work in Industrial Marketing'. Industrial Marketing Management 61, 104-113

Papachristos, G., Sofianos, A., Ademides, E. (2013) 'System Interactions in Socio-Technical Transitions: Extending the Multi-Level Perspective'. Environmental Innovation and Societal Transformation 7, 59-69

Papachristos, G. (ed.) (2014) 32nd International Conference of the System Dynamics Society, Delft, the Netherlands, 20-24 July 2014; Authors Version. 'Technology, Performance and Team Adaptation to Regulation in Formula 1'

Patton, M. Q. (1990) Qualitative Evaluation and Research Methods: SAGE Publications, Inc

Pentland, B. T. (1999) 'Building Process Theory with Narrative: From Description to Explanation'. Academy of Management Review 24 (4), 711-724

Perez, C. (2010) 'Technological Revolutions and Techno-Economic Paradigms'. Cambridge Journal of Economics 34 (1), 185

Pinkse, J., Bohnsack, R., and Kolk, A. (2014) 'The Role of Public and Private Protection in Disruptive Innovation: The Automotive Industry and the Emergence of Low-Emission Vehicles. (Report)(Author Abstract)'. Journal of Product Innovation Management 31 (1), 43

Porter, M. E. (2011) Competitive Advantage of Nations: Creating and Sustaining Superior Performance: Simon and Schuster

Punch, K. F. (2005) Introduction to Social Research: Quantitative and Qualitative Approaches. 2nd ed. edn. London: London: SAGE

Raven, R. P. J. M. (2004) 'Implementation of Manure Digestion and Co-Combustion in the Dutch Electricity Regime: A Multi-Level Analysis of Market Implementation in the Netherlands'. Energy Policy 32 (1), 29-39

Raven, R. and Walrave, B. (2018) 'Overcoming Transformational Failures through Policy Mixes in the Dynamics of Technological Innovation Systems'. Technological Forecasting and Social Change

Raynor, M. and Christensen, C. (2003) 'The Innovator's Solution'. Optimize, 64-74

Rinallo, D. and Golfetto, F. (2011) 'Exploring the Knowledge Strategies of Temporary Cluster Organizers: A Longitudinal Study of the EU Fabric Industry Trade shows (1986–2006)'. Economic Geography 87 (4), 453-476

Rip, A. and Kemp, R. (1998) 'Technological Change'. Human Choice and Climate Change 2 (2), 327-399

Robbins, A. (2015) 'DS Announces New Performance Arm'. The Telegraph 21/08

Robeers, T. (2019) *Driving the Sustainable Future? Media Representations of Environmental Sustainability in Motorsport: The Case of Formula E*

Robeers, T. and Van Den Bulck, H. (2018) 'Towards an Understanding of Side-Lining Environmental Sustainability in Formula E: Traditional Values and the Emergence of eSports'. *Athens Journal of Sports* 4, 331-350

Rogge, K. S., Pfluger, B., and Geels, F. W. (2018) 'Transformative Policy Mixes in Socio-Technical Scenarios: The Case of the Low-Carbon Transition of the German Electricity System (2010–2050)'. Technological Forecasting & Social Change; Technological Forecasting & Social Change

Rogge, K. S. and Reichardt, K. (2016) 'Policy Mixes for Sustainability Transitions: An Extended Concept and Framework for Analysis'. Research Policy 45 (8), 1620-1635

Rosenberg, N. (1974) 'Science, Invention and Economic Growth'. The Economic Journal 84 (333), 90-108

Rotheram-Borus, M., Swendeman, D., and Chorpita, B. F. (2012) 'Disruptive Innovations for Designing and Diffusing Evidence-Based Interventions'. American Psychologist 67 (6), 463-476

Sahal, D. (1981) 'Patterns of Technological Innovation'. Addison-Wesley

Sahal, D. (1985) 'Technological Guideposts and Innovation Avenues'. Research Policy 14 (2), 61-82

Savin-Baden, M. and Major, C. H. (2013) 'Qualitative Research: The Essential Guide to Theory and Practice'

Saward, J. (2012) 'An Electric World Championship'. [17/08/2012 2012] available from <https://joesaward.wordpress.com/2012/08/27/an-electric-world-championship/> [01/08/2017]

Schatzberg, E. (2006) 'Technik Comes to America: Changing Meanings of Technology before 1930'. Technology and Culture 47 (3), 486-512

Schmookler, J. (1965) 'Technological Change and Economic Theory'. The American Economic Review, 333-341

Schot, J. (2005) 'Radical Innovation as a Multilevel Process: Introducing Floating Grain Elevators in the Port of Rotterdam'. Technology and Culture 46 (1), 51-76

Schot, J., Kanger, L., and Verbong, G. (2016) 'The Roles of Users in Shaping Transitions to New Energy Systems'. Nature Energy 1 (5), 16054

Schot, J. and Kanger, L. (2018) Deep Transitions: Emergence, Acceleration, Stabilization and Directionality [online]. Available from <http://www.sciencedirect.com/science/article/pii/S0048733318300593>

Schumpeter, J. A. (1939a) Business Cycles, Vol. 1. New York; London: New York; London: McGraw-Hill

Schumpeter, J. A. (1939b) Business Cycles, Vol. 2. New York; London: New York; London: McGraw-Hill

Schumpeter, J. (1942) 'Creative Destruction'. Capitalism, Socialism and Democracy

Scoones, I., Leach, M., Smith, A., Stagl, S., Stirling, A., and Thompson, J. (2007) 'Dynamic Systems and the Challenge of Sustainability'

Shove, E. and Walker, G. (2007) 'CAUTION! Transitions Ahead: Politics, Practice and Sustainable Transition Management.(Implementation of Organizational Change)'. Environment & Planning A 39 (4), 763-770

Shubber, K. (2015) 'John Malone Back Formula E Motor Racing Championship'. Financial Times

Skeete, J. (2019) The Obscure Link between Motorsport and Energy Efficient, Low-Carbon Innovation: Evidence from the UK and European Union [online]

Smith, A. (2007) 'Translating Sustainabilities between Green Niches and Socio-Technical Regimes'. Technology Analysis & Strategic Management 19 (4), 427-450

Smith, A. and Kern, F. (2009) 'The Transitions Storyline in Dutch Environmental Policy'. Environmental Politics 18 (1), 78-98

Smith, A., Stirling, A., and Berkhout, F. (2005) 'The Governance of Sustainable Socio-Technical Transitions'. Research Policy 34 (10), 1491-1510

Smith, A., Voß, J., and Grin, J. (2010) 'Innovation Studies and Sustainability Transitions: The Allure of the Multi-Level Perspective and its Challenges'. Research Policy 39 (4), 435-448

Smith, D. J. (2012) 'Technological Discontinuities, Outsiders and Social Capital: A Case Study from Formula 1'. European Journal of Innovation Management 15 (3), 332-350

Smith, S. (2015) Schaeffler Becomes Technology Partners for Abt [online] available from <https://www.motorsport.com/formula-e/news/schaeffler-becomes-technology-partner-for-abt/607160/> [01/08 2017]

Smith, S. (2016) Red Bull Technology Bids for Formula E Battery Deal [online] available from <https://www.motorsport.com/formula-e/news/red-bull-technology-bids-for-formula-e-battery-deal-806696/> [01/08 2017]

Sorrell, S. (2018) 'Explaining Sociotechnical Transitions: A Critical Realist Perspective'. Research Policy 47 (7), 1267-1282

Steinhilber, S., Wells, P., and Thankappan, S. (2013) 'Socio-Technical Inertia: Understanding the Barriers to Electric Vehicles'. Energy Policy 60, 531-539

Sterrenberg, L., Andringa, J., Loorbach, D., Raven, R., and Wieczorek, A. (2010) 'Low-Carbon Transition through System Innovation: Theoretical Notions and Application'

Sylt, C. and Hewitt, K. (2015) 'Formula E is on Track for Stock Market Flotation'. Indipendent 19/06

Sylt, C. (2015b) Bright Spark behind Formula E Series [online] available from <https://www.raconteur.net/lifestyle/bright-spark-behind-formula-e-series> [08/08 2017]

Tallman, S., Jenkins, M., Henry, N., and Pinch, S. (2004) 'Knowledge, Clusters, and Competitive Advantage'. Academy of Management Review 29 (2), 258-271

Truffer, B., Schippl, J., and Fleischer, T. (2017) 'Decentering Technology in Technology Assessment: Prospects for Socio-Technical Transitions in Electric Mobility in Germany'. Technological Forecasting & Social Change; Technological Forecasting & Social Change 122, 34-48

Tsport100 (2013) Alain Prost Teams Up with Dams for Formula E Entry. [24/10 2013] available from <http://www.electric-vehiclenews.com/2013/10/alain-prost-teams-up-with-dams-for.html> [02/08]

Tushman, M. L. and Anderson, P. (1986) 'Technological Discontinuities and Organizational Environments'. Administrative Science Quarterly 31 (3), 439-465

Twomey, P. and Gaziulusoy, A. I. (2014) 'Review of System Innovation and Transitions Theories'. Melbourne, Australia

UN Enviroment (2017) Formula E Team Up with UN Environment in Race to Improve Inner-City Air Quality [online] available from <http://www.unep.org/newscentre/formula-e-team-un-environment-race-improve-inner-city-air-quality> [08/08 2017]

Utterback, J. M. and Abernathy, W. J. (1975) 'A Dynamic Model of Process and Product Innovation'. Omega 3 (6), 639-656

Van den Berg, H. (2008) 'Reanalyzing Qualitative Interviews from Different Angles: The Risk of Decontextualization and Other Problems of Sharing Qualitative Data'. Historical Social Research/Historische Sozialforschung, 179-192

Van den Bosch, S. (2010) Transition Experiments: Exploring Societal Changes Towards Sustainability.

Van Driel, H. and Schot, J. (2005) 'Radical Innovation as a Multilevel Process: Introducing Floating Grain Elevators in the Port of Rotterdam'. *Technology and Culture* 46 (1), 51-76

Verbong, G. and Geels, F. (2007) 'The Ongoing Energy Transition: Lessons from a Socio-Technical, Multi-Level Analysis of the Dutch Electricity System (1960–2004)'. Energy Policy 35 (2), 1025-1037

Verbong, G. and Loorbach, D. (2012) Governing the Energy Transition: Reality, Illusion Or Necessity: Routledge

Virgin (2013) Virgin Plug into Formula E [online] available from <https://www.virgin.com/news/virgin-plugs-formula-e> [2017]

Vriens, D. and Søilen, K. S. (2014) 'Disruptive Intelligence - how to Gather Information to Deal with Disruptive Innovations'. Journal of Intelligence Studies in Business 4 (3), 63-78

Watkins, G. (2016) Liberty F1 Take Over Good for Formula E -Alejandro Agag [online] available from <http://www.autosport.com/news/report.php/id/126123> [01/08 2017]

Watts, J. M. (2013) 'The Institutional Context for Temporary Staffing: A European Cross-National Comparative Approach'

Weitzman, E. and Miles, M. B. (1995) Computer Programs for Qualitative Data Analysis: Sage

Whitmarsh, L. (2012) 'How Useful is the Multi-Level Perspective for Transport and Sustainability Research?' Journal of Transport Geography 24, 483-487

Wikstrom, P. and Defilippi, R. (2016) Business Innovation and Disruption in the Music Industry: Edward Elgar Publishing

Williams F1 (2013) *Williams Partners with Spark Racing Technology to Provide Battery Expertise for the FIA Formula E Championship*. www.williamsf1.com/Advanced-Engineering/Media/News/WILLIAMS-PARTNERS-WITH-SPARK-RACING-TECHNOLOGY-TO-PROVIDE-BATTERY-EXPERTISE-FOR-THE-FIA-FORMULA-E-CHAMPIONSHIP/ edn

Wilson, C. and Tyfield, D. (2018) 'Critical Perspectives on Disruptive Innovation and Energy Transformation'. Energy Research & Social Science; Energy Research & Social Science 37, 211-215

Wright, P. (2001) Formula 1 Technology. Warrendale, PA.: Warrendale, PA.; Society of Automotive Engineers

Appendix 1 Full research ethics approval documentation

Coventry University ETHICS

Medium to High Risk Research Ethics Approval

Project Title

The dynamics of disruptive innovation: exploring the case of Formula E in motorsport

Record of Approval

Principal Investigator

I **request an ethics peer review** and confirm that I have answered all relevant questions in this checklist honestly.	X
I confirm that I will carry out the project in the ways described in this checklist. I will immediately suspend research and request new ethical approval if the project subsequently changes the information I have given in this checklist.	X
I confirm that I, and all members of my research team (if any), have read and agreed to abide by the Code of Research Ethics issued by the relevant national learned society.	X
I confirm that I, and all members of my research team (if any), have read and agreed to abide by the University's Research Ethics, Governance and Integrity Framework.	X

Name: Cristiana Pace ....

Date: 07/12/2017 ....

Student's Supervisor (if applicable)

I have read this checklist and confirm that it covers all the ethical issues raised by this project fully and frankly. I also confirm that these issues have been discussed with the student and will continue to be reviewed in the course of supervision.

Name: Nick Henry ....

Date: 07/12/2017 ....

Reviewer (if applicable)

Date of approval by anonymous reviewer: 11/12/2017

Medium to High Risk Research Ethics Approval Checklist

Project Information

Project Ref	P65407
Full name	Cristiana Pace
Faculty	Faculty of Business and Law
Department	Centre for Business in Society
Supervisor	Nick Henry
Module Code	FBL-PHD
EFAAF Number	
Project title	The dynamics of disruptive innovation: exploring the case of Formula E in motorsport
Date(s)	11/11/2017 - 27/07/2018
Created	07/12/2017 09:12

Project Summary

carry out semi-interview to people in the Motorsport sector, and specifically involved in Formula E, in order to gather data for the in depth phase of the research design.

Names of Co-Investigators and their organisational affiliation (place of study/employer)	
Is the project self-funded?	YES
Who is funding the project?	Coventry University
Has the funding been confirmed?	YES
Are you required to use a Professional Code of Ethical Practice appropriate to your discipline?	NO
Have you read the Code?	NO

Project Details

What is the purpose of the project?	Study how stakeholders shape, influence, facilitate and enact innovation, when innovation unfold. Specifically the in depth phase of the PhD evaluate the change of stakeholders across and among MLP's levels within the temporal dynamics of this disruptive/radical/revolutionary innovation in motor sport called Formula E.
What are the planned or desired outcomes?	gathered data to enhanced and validate the draft MLP's schematic and process map generated by the scoping phase (documentary data plus scoping interviews).
Explain your research design	The research design includes three phases: 1. a scoping phase, where data gathered from documentary sources (primary and secondary) and scoping interviews (6 to key-informants) were corroborated in order to produce a process map of the phenomenon (Formula E) and a draft MLP's schematic. 2. An in depth phase where qualitative semi structured interview to key informants were used to refine and validate the map and schematic of the scoping phase. 3. a confirmatory phase where 'elite' where policy-makers from the Motorsport and government organization will be asked to comments this PhD's findings.
Outline the principal methods you will use	In phase 2 and 3 (which is the part for which this ethic approval applies) qualitative semi-structured interviews will be used. Specifically, in the in depth phase, qualitative interviews will be used to capture individual experiences (Patton, 1990) of informants which were/are directly involved with the phenomenon. Data gathered from these interviews will be used to corroborate results from the scoping phase (Section 5.4). In order to guarantee robustness and validity of the data gathered, informants were selected amongst people who are and/or were directly involved in the FIA Formula E championships. Specifically, as the main purpose of these interviews was acquiring empirical data to provide an

	insight into stakeholders and stakeholders' dynamics, direct involvement was regarded as a discriminatory factor for the selection of representative sample groups. Some informants were identified from scoping interviews, and other interviewees were added to the list using snowballing sampling and respondent-driven sampling techniques. Senior management was interviewed in order to increase reliability of the data gathered. In order to guarantee that this selection was free from any biases arisen from situated knowledge, teams' websites, FIA and Formula E's websites were used to determine the level of seniority of informants. Journalists and technical experts were selected because of their influence and direct involvement with the FIA Formula E championship. The transcripts of these interviews will be coded by N-Vivo.
Are you proposing to use an external research instrument, validated scale or follow a published research method?	YES
If yes, please give details of what you are using	qualitative interviews are widely used in research. Attached to this form is the topic guidance. Additionally, acknowledging Elwood and Martin's (2000) view, the interview site itself embodies and constitutes multiple scales of spatial relations and meaning, which construct the power and positionality of participants in relation to the people, places, and interactions discussed in the interview' (Elwood and Martin 2000:649). Specifically I am planning to attended the Formula E race in Marrakesh, interviewing 20 informants in 4 days at their temporary offices. Recently, economic geographers have written a great deal on temporary space or temporary clusters and knowledge creation (Maskell, Bathlet and Malmberg, 2004). Specifically these studies have recognized the significance of temporal spatial cluster (TSC) for shaping and facilitating business creation, bringing together networks of actors. These TSCs' characteristic are the same of what this industry defines as race. Race are, in fact,

	temporary and temporally well defined, which co-locate in the same space a number of actors from the same network. Hence a race can be seen as an appropriate place to interview informants.	
Will your research involve consulting individuals who support, or literature, websites or similar material which advocates, any of the following: terrorism, armed struggles, or political, religious or other forms of activism considered illegal under UK law?		NO
Are you dealing with Secondary Data? (e.g. sourcing info from websites, historical documents)		NO
Are you dealing with Primary Data involving people? (e.g. interviews, questionnaires, observations)		YES
Are you dealing with personal or sensitive data?		NO
Is the project solely desk based? (e.g. involving no laboratory, workshop or off-campus work or other activities which pose significant risks to researchers or participants)		NO
Are there any other ethical issues or risks of harm raised by the study that have not been covered by previous questions?		NO
If yes, please give further details		

DBS (Disclosure & Barring Service) formerly CRB (Criminal Records Bureau)

Question			Yes	No
1	Does the study require DBS (Disclosure & Barring Service) checks?			X
	If YES, please give details of the serial number, date obtained and expiry date			
2	If NO, does the study involve direct contact by any member of the research team:			
	a)	with children or young people under 18 years of age?		X
	b)	with adults who have learning difficulties, brain injury, dementia, degenerative neurological disorders?		X
	c)	with adults who are frail or physically disabled?		X
	d)	with adults who are living in residential care, social care, nursing homes, re-ablement centres, hospitals or hospices?		X
	e)	with adults who are in prison, remanded on bail or in custody?		X
		If you have answered YES to any of the questions above please explain the nature of that contact and what you will be doing		

External Ethical Review

Question		Yes	No
1	Will this study be submitted for ethical review to an external organisation? (e.g. Another University, Social Care, National Health Service, Ministry of Defence, Police Service and Probation Office)		X
	If YES, name of external organisation		
2	Will this study be reviewed using the IRAS system?		X
3	Has this study previously been reviewed by an external organisation?		X

Confidentiality, security and retention of research data

Question			Yes	No
1	Are there any reasons why you cannot guarantee the full security and confidentiality of any personal or confidential data collected for the study?			X
	If YES, please give an explanation			
2	Is there a significant possibility that any of your participants, and associated persons, could be directly or indirectly identified in the outputs or findings from this study?			X
	If YES, please explain further why this is the case			
3	Is there a significant possibility that a specific organisation or agency or participants could have confidential information identified, as a result of the way you write up the results of the study?			X
	If YES, please explain further why this is the case			
4	Will any members of the research team retain any personal of confidential data at the end of the project, other than in fully anonymised form?			X
	If YES, please explain further why this is the case			
5	Will you or any member of the team intend to make use of any confidential information, knowledge, trade secrets obtained for any other purpose than the research project?			X
	If YES, please explain further why this is the case			
6	Will you be responsible for destroying the data after study completion?		X	
	If NO, please explain how data will be destroyed, when it will be destroyed and by whom			

Participant Information and Informed Consent

Question			Yes	No
1	Will all the participants be fully informed BEFORE the project begins why the study is being conducted and what their participation will involve?		X	
	If NO, please explain why			
2	Will every participant be asked to give written consent to participating in the study, before it begins?		X	
	If NO, please explain how you will get consent from your participants. If not written consent, explain how you will record consent			
3	Will all participants be fully informed about what data will be collected, and what will be done with this data during and after the study?		X	
	If NO, please specify			
4	Will there be audio, video or photographic recording of participants?		X	
	Will explicit consent be sought for recording of participants?		X	
	If NO to explicit consent, please explain how you will gain consent for recording participants			
5	Will every participant understand that they have the right not to take part at any time, and/or withdraw themselves and their data from the study if they wish?		X	
	If NO, please explain why			
6	Will every participant understand that there will be no reasons required or repercussions if they withdraw or remove their data from the study?		X	
	If NO, please explain why			
7	Does the study involve deceiving, or covert observation of, participants?			X
	Will you debrief them at the earliest possible opportunity?			
	If NO to debrief them, please explain why this is necessary			

Risk of harm, potential harm and disclosure of harm

Question			Yes	No
1	Is there any significant risk that the study may lead to physical harm to participants or researchers?			X
	If YES, please explain how you will take steps to reduce or address those risks			
2	Is there any significant risk that the study may lead to psychological or emotional distress to participants?			X
	If YES, please explain how you will take steps to reduce or address those risks			
3	Is there any risk that the study may lead to psychological or emotional distress to researchers?			X
	If YES, please explain how you will take steps to reduce or address those risks			
4	Is there any risk that your study may lead or result in harm to the reputation of participants, researchers, or their employees, or any associated persons or organisations?			X
	If YES, please explain how you will take steps to reduce or address those risks			
5	Is there a risk that the study will lead to participants to disclose evidence of previous criminal offences, or their intention to commit criminal offences?			X
	If YES, please explain how you will take steps to reduce or address those risks			
6	Is there a risk that the study will lead participants to disclose evidence that children or vulnerable adults are being harmed, or at risk or harm?			X
	If YES, please explain how you will take steps to reduce or address those risks			
7	Is there a risk that the study will lead participants to disclose evidence of serious risk of other types of harm?			X
	If YES, please explain how you will take steps to reduce or address those risks			
8	Are you aware of the CU Disclosure protocol?		X	

Payments to participants

Question			Yes	No
1	Do you intend to offer participants cash payments or any kind of inducements, or reward for taking part in your study?			X
	If YES, please explain what kind of payment you will be offering (e.g. prize draw or store vouchers)			
2	Is there any possibility that such payments or inducements will cause participants to consent to risks that they might not otherwise find acceptable?			
3	Is there any possibility that the prospect of payment or inducements will influence the data provided by participants in any way?			
4	Will you inform participants that accepting payments or inducements does not affect their right to withdraw from the study at any time?			

Capacity to give valid consent

Question		Yes	No
1	Do you propose to recruit any participants who are:		
	a) children or young people under 18 years of age?		X
	b) adults who have learning difficulties, mental health condition, brain injury, advanced dementia, degenerative neurological disorders?		X
	c) adults who are physically disabled?		X
	d) adults who are living in residential care, social care, nursing homes, re-ablement centres, hospitals or hospices?		X
	e) adults who are in prison, remanded on bail or in custody?		X
	If you answer YES to any of the questions please explain how you will overcome any challenges to gaining valid consent		
2	Do you propose to recruit any participants with possible communication difficulties, including difficulties arising from limited use of knowledge of the English language?		X
	If YES, please explain how you will overcome any challenges to gaining valid consent		
3	Do you propose to recruit any participants who may not be able to understand fully the nature of the study, research and the implications for them of participating in it or cannot provide consent themselves?		X
	If YES, please explain how you will overcome any challenges to gaining valid consent		

Recruiting Participants

Question			Yes	No
1	Do you propose to recruit any participants who are:			
	a)	students or employees of Coventry University or partnering organisation(s)?		X
		If YES, please explain if there is any conflict of interest and how this will be addressed		
	b)	employees/staff recruited through other businesses, voluntary or public sector organisations?		X
		If YES, please explain how permission will be gained		
	c)	pupils or students recruited through educational institutions (e.g. primary schools, secondary schools, colleges)?		X
		If YES, please explain how permission will be gained		
	d)	clients/volunteers/service users recruited through voluntary public services?		X
		If YES, please explain how permission will be gained		
	e)	participants living in residential care, social care, nursing homes, re-ablement centres hospitals or hospices?		X
		If YES, please explain how permission will be gained		
	f)	recruited by virtue of their employment in the police or armed forces?		X
		If YES, please explain how permission will be gained		
	g)	adults who are in prison, remanded on bail or in custody?		X
		If YES, please explain how permission will be gained		
	h)	who may not be able to refuse to participate in the research?		X
		If YES, please explain how permission will be gained		

Online and Internet Research

<table>
<tr><th colspan="3">Question</th><th>Yes</th><th>No</th></tr>
<tr><td rowspan="2">1</td><td colspan="2">Will any part of your study involve collecting data by means of electronic media (e.g. the Internet, e-mail, Facebook, Twitter, online forums, etc)?</td><td></td><td>X</td></tr>
<tr><td colspan="2">If YES, please explain how you will obtain permission to collect data by this means</td><td colspan="2"></td></tr>
<tr><td rowspan="2">2</td><td colspan="2">Is there a possibility that the study will encourage children under 18 to access inappropriate websites, or correspond with people who pose risk of harm?</td><td></td><td>X</td></tr>
<tr><td colspan="2">If YES, please explain further</td><td colspan="2"></td></tr>
<tr><td rowspan="2">3</td><td colspan="2">Will the study incur any other risks that arise specifically from the use of electronic media?</td><td></td><td>X</td></tr>
<tr><td colspan="2">If YES, please explain further</td><td colspan="2"></td></tr>
<tr><td rowspan="2">4</td><td colspan="2">Will you be using survey collection software (e.g. BoS, Filemaker)?</td><td></td><td>X</td></tr>
<tr><td colspan="2">If YES, please explain which software</td><td colspan="2"></td></tr>
<tr><td rowspan="6">5</td><td colspan="2">Have you taken necessary precautions for secure data management, in accordance with data protection and CU Policy?</td><td>X</td><td></td></tr>
<tr><td>If NO</td><td>please explain why not</td><td colspan="2"></td></tr>
<tr><td rowspan="4">If YES</td><td>Specify location where data will be stored</td><td colspan="2">the data will be stored in my hard disk and will be encrypted. They will be backed up with encryption to an external device.</td></tr>
<tr><td>Planned disposal date</td><td colspan="2">31/03/2019</td></tr>
<tr><td>If the research is funded by an external organisation, are there any requirements for storage and disposal?</td><td></td><td>X</td></tr>
<tr><td>If YES, please specify details</td><td colspan="2"></td></tr>
</table>

Languages

Question			Yes	No
1	Are all or some of the consent forms, information leaflets and research instruments associated with this project likely to be used in languages other than English?			X
	If YES, please specify the language[s] to be used			
2	Have some or all of the translations been undertaken by you or a member of the research team?			
	Are these translations in lay language and likely to be clearly understood by the research participants?			
	Please describe the procedures used when undertaking research instrument translation (e.g. forward and back translation), clarifying strategies for ensuring the validity and reliability or trustworthiness of the translation			
3	Have some or all of the translations been undertaken by a third party?			
	If YES, please specify the name[s] of the persons or agencies performing the translations			
	Please describe the procedures used when undertaking research instrument translation (e.g. forward and back translation), clarifying strategies for ensuring the validity and reliability of the translation			

Laboratory/Workshops

Question		Yes	No
1	Does any part of the project involve work in a laboratory or workshop which could pose risks to you, researchers or others?		X
	If YES: If you have risk assessments for laboratory or workshop activities you can refer to them here & upload them at the end, or explain in the text box how you will manage those risks		

Research with non-human vertebrates

Question			Yes	No
1	Will any part of the project involve animal habitats or tissues or non-human vertebrates?			X
	If YES, please give details			
2	Does the project involve any procedure to the protected animal whilst it is still alive?			
3	Will any part of your project involve the study of animals in their natural habitat?			
	If YES, please give details			
4	Will the project involve the recording of behaviour of animals in a non-natural setting that is outside the control of the researcher?			
	If YES, please give details			
5	Will your field work involve any direct intervention other than recording the behaviour of the animals available for observation?			
	If YES, please give details			
6	Is the species you plan to research endangered, locally rare or part of a sensitive ecosystem protected by legislation?			
	If YES, please give details			
7	Is there any significant possibility that the welfare of the target species of those sharing the local environment/habitat will be detrimentally affected?			
	If YES, please give details			
8	Is there any significant possibility that the habitat of the animals will be damaged by the project, such that their health and survival will be endangered?			
	If YES, please give details			
9	Will project work involve intervention work in a non-natural setting in relation to invertebrate species other than Octopus vulgaris?			
	If YES, please give details			

Blood Sampling / Human Tissue Analysis

Question			Yes	No
1	Does your study involve collecting or use of human tissues or fluids? (e.g. collecting urine, saliva, blood or use of cell lines, 'dead' blood)			X
	If YES, please give details			
2	If your study involves blood samples or body fluids (e.g. urine, saliva) have you clearly stated in your application that appropriate guidelines are to be followed (e.g. The British Association of Sport and Exercise Science Physiological Testing Guidelines (2007) or equivalent) and that they are in line with the level of risk?			
	If NO, please explain why not			
3	If your study involves human tissue other than blood and saliva, have you clearly stated in your application that appropriate guidelines are to be followed (e.g. The Human Tissues Act, or equivalent) and that they are in line with level of risk?			
	If NO, please explain why not			

Travel

Question			Yes	No
1	Does any part of the project require data collection off campus? (e.g. work in the field or community)		X	
	If YES: You must consider the potential hazards from off campus activities (e.g. working alone, time of data collection, unfamiliar or hazardous locations, using equipment, the terrain, violence or aggression from others). Outline the precautions that will be taken to manage these risks, AS A MINIMUM this must detail how researchers would summon assistance in an emergency when working off campus. For complex or high risk projects you may wish to complete and upload a separate risk assessment	The data collection for the in depth interviews will take place mostly in Marrakesh from the 11th to the 14th of January, during a race. The race is a street circuit and it is enclosed. Police force and security will be in attendance. the enclosed space can only be access from people with a ticket, for which it is necessary a reservation on line (with data about the person and his/hers address), and security checks to bags at the gate. I will be travelling with my husband to he race, and will be stay in the hotel where all the teams and organisation are based. this hotel is located at the center of the race track (the race is in a street circuit), with police and security at the hotel and at the circuit. I am in contact with Formula E organisation which will supply passes. The transport from airport to the hotel will be arrange by the hotel itself. Concerning being at the track, garage will be avoided when car are in operation. As Marrakesh is a medium threat for terrorism, crowded places will be avoided and movement will be restricted around the site. the interviews will be taken places at in the teams suite, at the circuit, or at the hotel.		
2	Does any part of the project involve the researcher travelling outside the UK (or to very remote UK locations)?		X	
	If YES: Please give details of where, when and how you will be travelling. For travel to high risk places you may wish to complete and upload a separate risk assessment	Marrakesh, Morocco, 11-15th of January Flying out from Stanstead to Marrakesh on the 11th of January Flying back in from Marrakesh to Stanstead on the 15th of January		
3	Are all travellers aware of contact numbers for emergency assitance when away (e.g. local emergency assistance, ambulance/local hospital/police, insurance helpline [+44 (0) 2071 737797] and CU's 24/7 emergency line [+44 (0) 2476 888555])?		X	
4	Are there any travel warnings in place advising against all, or essential only travel to the destination?			X

	NOTE: Before travel to countries with 'against all travel', or 'essential only' travel warnings, staff must check with Finance to ensure insurance coverage is not affected. Undergraduate projects in high risk destinations will not be approved		
5	Are there increased risks to health and safety related to the destination? e.g. cultural differences, civil unrest, climate, crime, health outbreaks/concerns, and travel arrangements?		X
	If YES, please specify		
6	Do all travelling members of the research team have adequate travel insurance?	X	
7	Please confirm all travelling researchers have been advised to seek medical advice regarding vaccinations, medical conditions etc, from their GP	X	

Appendix 2 Key-informant interview documentation

08th January 2018

Dear XXX,

I am writing to invite you to participate in a PhD project, exploring the dynamic of innovation in the motorsport sector, led by myself with supervisors from the Centre for Business in Society at Coventry University and from School of Management at Cranfield University.

The project is titled 'the dynamic of disruptive innovation: an exploration of Formula E in Motorsport'.

The research seeks to understand the role of actors in facilitating, shaping and enacting innovation in the Motorsport sector. Specifically, considering FIA Formula E as a technological transition within the motorsport sector, this study studies how actors have changed within each season, enabling this technological shifts successfully. Finding will be included in the PhD and are supposed to bring contribution to knowledge for academics and practitioners.

By agreeing to participate in this research project, you will support my documented understanding of the emergence of a radical/discontinuous/disruptive innovation, its dynamics from the 'infancy phase' to the 'growth phase', its potential impact on incumbents and new entrants and the impact on the motorsport sector. To ensure that the information produced is industry-relevant and generates impact, a report will be produced and distributed at the end of the data analysis process alongside more formal research outputs. As a participant, you will be offered a copy of this report.

Given your role in the motorsport sector, I would like to request a formal face-to-face interview with you at your convenience to explore these matters. I anticipate the interview lasting about 30 to 45 minutes.

All information collected will only be used for academic purposes. The data will be anonymised if you wish so, and no quotes will be attributed to any participant.

I hope you will accept my invitation to contribute to the research and if you have any query, please do not hesitate to contact me on XXXX.

I look forward to hearing from you soon.

Kind regards,

Cristiana Pace

Participant Information Sheet

You are being invited to take part in a research project. Before you agree to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. If anything remains unclear or if you would like more information, feel free to ask. Take time to decide whether or not you wish to take part. Thank you for reading this.

Who will conduct the research?

The project is being conducted by Cristiana Pace, PhD Student at the Centre for Business in Society, Faculty of Business and Law, at Coventry University under the supervision of Prof Nick Henry, Dr David Jarvis, all of whom are researchers within the Centre, and Prof Mark Jenkins, from Cranfield University, School of Management.

What is the aim of the research?

The research aims to explore the dynamic and temporal dynamic of innovation in the Motorsport Sector. Specifically, it focuses on Formula E and the role of stakeholders in facilitating, shaping and enact this revolutionary/radical/disruptive innovation during the temporal dimension of innovation (for the PhD this is until end of season 3). The suggested outcome of the research is: 1. drawing from previous business and technology studies, the research builds a Multi-level perspective approach schematic for FIA Formula E, reflecting on locus of innovation and change of stakeholders across and amongst levels during the different FIA FE seasons; 2. this research aims to legitimize the role of motorsport in enabling technological transition (ICE to EV), showing how motorsport can facilitate the acceptance of novel technologies within society; 3. This research aims to identify implications for managing disruption for policymakers and organisations.

Why have I been chosen?

You have been chosen as a result of your involvement with the FIA Formula E. Different sources (such as the media, technical reports, opinion pieces, industry news, and/or conference participation) have identified you as a major contributor in the area. The research aims to interview between 20 and 25 participants.

Do I have to take part?

Participation in the project is entirely voluntary. You are in no way compelled to take part in the research project.

What would I be asked to do if I took part?

You will be asked for an interview about your experience in FIA Formula E, the current state of play and how you believe this arena may evolve. With your consent, the interview will be recorded in audio format and later transcribed. This will constitute data for analysis in the context of the research. The interview will have a duration of around 45 minutes. In any case of a potential follow-up, you will be contacted beforehand and your further agreement to participate sought. The interview will take place when and where is most convenient for you.

Data protection & confidentiality

All the interview transcripts and notes will be anonymised with a key kept in a separate, password-protected file. Only the researchers will have access to this.

All the information will be kept in an encrypted disk. Any quotes extracted directly from interviews – in either the policy report or any academic articles derived from it – will be committed anonymously.

All data collected will be destroyed by the 31st of March 2019.

What are the risks associated with this project?

We anticipate no risks associated with participating in this project for yourself or your organisation.

What are the benefits of taking part?

By agreeing to participate in this research project, you will contribute to producing documented knowledge about the dynamics of disruptive innovation in the motorsport sector. To ensure that the information produced is industry-relevant and generates impact, a report will be produced and distributed at the end of the data analysis process. You will be offered this report.

Withdrawal options

It is up to you to decide whether or not to take part. If you do decide to take part, you will be given this information sheet to keep and a consent form to sign. If you decide to take part, you are free to withdraw at any time before the 11th of January 2018 without offering any reason or explanation.

What will happen with the results of the study?

The objective of the research is to collect information for a PhD. The researcher will publish articles based on the research in academic publications and a report. It is also possible that the research will be presented in academic and policy conferences.

In any potential academic publications or reports, all sources will be kept strictly anonymous if requested.

What if things go wrong? Who to complain to

If you are unhappy with any aspect of this research and wish to make a complaint, please contact:

Professor Nigel Berkeley, Associate Dean of Research

BES, Coventry University

Priory Street

Coventry CV1 5FB

N.Berkeley@coventry.ac.uk

In your letter, please provide as much detail about the research as possible, the name of the main researcher and indicate in detail the nature of your complaint.

Who has reviewed this study?

This study has received approval from the Coventry University Research Ethics Committee.

Contact for further information

Cristiana Pace, Centre for Business in Society, Coventry University, Priory Street, Coventry CV1 5FB email: pacec2@coventry.ac.uk

Informed Consent Form

The research aims to explore the dynamics and temporal dynamics of innovation in the Motorsport Sector. Specifically, it focuses on Formula E and asks if this is a radical, revolutionary, epochal and disruptive innovation (disruptive in Christensen's sense) and the role it has played for transitioning the motorsport sector from ICE to FEV. Hence, the research investigates how various stakeholders, including institutions and incumbent firms influence, facilitate, shape and respond to disruptive innovation over time, identifying implications for managing disruption within a multi-level perspective approach.

You have been asked for an interview about your experience in Formula E.

Please tick

1. I confirm that I have read and understood the participant information sheet for the above study and have had the opportunity to ask questions. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time before the 11th of January 2018 without giving a reason. ☐

3. I understand that all the information I provide will be treated in confidence. ☐

4. I understand that I also have the right to change my mind about participating in the study for a short period after the study has concluded (*22/09/2018*). ☐

5. I agree to be recorded as part of the research project ☐

6. I agree to take part in the research project ☐

Name of participant: ....

Signature of participant: ....

Date: ....

Name of Researcher: Cristiana Pace

Signature of researcher:

Date: 08/01/2018

Topics guide

Introduction

The participant will be greeted at an appropriate and prior agreed location. They will be issued with a participant information sheet to read, along with two participant agreement forms to read, sign and date. One of these forms will be kept by the researcher for their record, and the other will be given to the Participant to keep. Any final question concerning the interview can be answered at this stage. The participant will be asked if they are happy for the researcher to use a sound recorder device and, if so, once they are ready to begin, they will be informed when the sound recorder is about to be turned on.

Topics:

Motorsport sector and innovation

Low-carbon innovation in the motorsport sector

Stakeholders and stakeholder engagements within the low-carbon changes in the motorsport sector

Formula E

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Appendix 3 List of documentary sources

Types of secondary documents	Number of documents used[26]	Detailed list	Date of searches
Newspapers/Media	**30**	www.ft.com www.theguardian.com www.cnn.com www.foxnews.com www.bbc.com www.nytimes.com www.indipendent.co.uk	05/05/2017 06/07/2017 09/09/2017 10/11/2017
Specialised motorsport publications	**210**	www.autosport.com www.italiaracing.net www.racecarengineering.com	
Specialised electric motorsport publications	**60**	www.currente.com	
Specialised business publications	**10**	www.qz.com www.forbes.com www.reconter.fr	
Specialised automotive publications	**34**	www.autocars.com www.topgear.com www.autonews.com www.transporteveolved.com	

[26] A web article has been considered the equivalent of one document

Books	**2**	'The Mechanic', Mark Priestley (2017) 'Motorsport going global', Henry et al. (2007)	
Websites of organisations involved in Formula E **of which:**	**543**		First accessed 01/02/2016 Last accessed 10/11/2018
Teams' website	310	https://www.ds-virginracing.com/ http://www.dragonracing.com/ https://www.jaguar.co.uk/jaguar-racing/index.html http://www.mahindraracing.com/ http://www.msamlin-andrettife.com/ https://www.nio.io/formulae http://www.edamsrenault.com/ http://www.techeetahfe.com/ http://www.venturi.fr/ http://www.audi.com/en/audisport/formula-e.html	Accessed almost every week for continuous updates
Regulators and organisations	200	www.fia.com www.fiainstiute.com www.fiaformulae.com	
Partners	33	https://www.juliusbaer.com/global/en/visionary-thinking/fia-formula-	Accessed almost every week for

		e-championship/fia-formula-e-championship/ https://michelinmotorsport.com/ https://www.visa.co.uk/ https://www.tagheuer.com/en-gb https://www.mumm.com/en https://www.qualcomm.com/ http://arrival.com/ http://www.dhl.com/en/about_us/partnerships/motorsports/formula_E.html https://www.enel.com/en.html http://bmw.com/ https://www.allianz.com/en/ https://www.xaltenergy.com/ https://chargemasterplc.com/	continuous updates
Others	20	http://www.williamsf1.com/advanced-engineering http://www.mclaren.com/appliedtechnologies/ http://www.sparkracingtechnology.com/ https://www.dallara.it/wps/portal	
Grey papers **Of which**	**12**		
Sustainability report	10	DHL Formula E Holdings Mahindra Formula E Team	20/04/2017 07/07/2017

White paper	2	DHL	22/04/2017
Reports by the government, business and industry	**4**	MIA	06/05/2017 12/07/2017
Academies theses and articles	**7**	‘Sustainability and motorsport: an examination of Formula E’, Webster (2016) ‘Formula E: next generation motorsport with next-generation fans’, Standaert and Jarvepaan (2016) ‘How Formula E went from mess to global game changer’, Mitchell, (2017) ‘Major Motorsport event under siege’ Bengtsson and Markovsky (2017)	01/10/2017
Blogs	**8**	www.jwgrandprix.com www.f1professor.com www.joesawardpress.com www.f1elvis.com	15/05/2017
TOTAL documents analysed	**920**		

Appendix 4 Topic guide for scoping phase interviews

Topics guide for scoping phase interviews

Introduction

The participant will be greeted at an appropriate and prior agreed location. They will be issued with a participant information sheet to read, along with two participant agreement forms to read, sign and date. One of these forms will be kept by the researcher for their record, and the other will be given to the Participant to keep. Any final question concerning the interview can be answered at this stage. The participant will be asked if they are happy for the researcher to use a sound recorder device and, if so, once they are ready to begin, they will be informed when the sound recorder is about to be turned on.

Topics:

Motorsport sector and innovation

- Ask when they got involved in Motorsport, previous roles and their current role
- Ask what they think the relationship between motorsport and innovation is
- Ask if they can name one or two major innovation in motorsport (historically)
- Do you consider motorsport relevant for the automotive sector? In which sense (R&D or others)

Low-carbon innovation in the motorsport sector

- Ask when and how in their opinion, the low-carbon theme was introduced in Motorsport (open question)
- Ask which one was the first low carbon change in motorsport on their opinion

Stakeholders and stakeholder engagements within the low-carbon changes in the motorsport sector

- Ask how such changes in regulation are made in Motorsport (define the stakeholders for change in the motorsport sector)

- Ask which actors he thinks they were involved with the low-carbon change in motorsport
- Are they any informal actor to consider?
- Why do you think motorsport went for low-carbon changes?

Formula E

- Awareness of Formula E
- Place that Formula E occupies in the motorsport 'food-chain' (concept to be developed in the questions guide)
- Stakeholders in the development of the Formula E championship
- Informal stakeholders
- Do you think the stakeholders are the same now from when Formula E started? Open question to explain (check on the idea of the migration of stakeholder in different time of the innovation)
- Pivotal moments that have been drawing the history of Formula E (check on moments and time frames within the conceptual model).
- Do you think Formula E is relevant for the Sport?
- Do you think Formula E is relevant for Motorsport
- Do you think Formula E is relevant for the Automotive sector
- Do you think Formula E is disruptive? Why?

Concluding

At the termination of the interview, the sound recorder will be switched off; this being verbalised to the participant who will be made aware that the interview has concluded. They will be thanked for their time and contribution to the study. They will be advised that if they wish to receive a copy of the study upon conclusion, it will be made available in December 2018.

Appendix 5 Topic guide for main phase interviews

Topics guide for main phase interviews

Introduction

The participant will be greeted at an appropriate and prior agreed location. They will be issued with a participant information sheet to read, along with two participant agreement forms to read, sign and date. One of these forms will be kept by the researcher for their record, and the other will be given to the Participant to keep. Any final question concerning the interview can be answered at this stage. The participant will be asked if they are happy for the researcher to use a sound recorder device and, if so, once they are ready to begin, they will be informed when the sound recorder is about to be turned on.

Topics:

Motorsport sector and innovation

- Ask when they got involved in Motorsport, previous roles and their current role
- Ask what they think about the relationship between motorsport and innovation
- Ask if they can name one or two major innovations in motorsport (historically)
- Do they consider motorsport relevant to the automotive sector? In what sense?

Low-carbon innovation in the motorsport sector

- Ask when and how in their opinion, the low-carbon theme was introduced in Motorsport (open question)
- Ask which one was the first low carbon change in motorsport on their opinion

Formula E

- Ask when they started to be involved in Formula E
- Place that Formula E occupies in the motorsport 'food-chain' (concept to

be developed in the questions guide)

- Ask which are the stakeholders which in his/her opinion that has played a role in the development of the Formula E championship
- Ask if he/she can trace these developments changes within the Formula E seasons
- Ask if he/she can see any transformation on the business model side of the championship (if this was covered in the question before as if he can see any change on the technological dimensions and/or the regulatory dimension) –to cover all three dimension and the main changes he/she thinks were done in each season)
- The role of FIA
- Any informal stakeholders
- Do you think the stakeholders are the same now from when Formula E started? Open question to explain (check on the idea of the migration of stakeholder in different time of the innovation)
- Main moments that have been drawing the history of Formula E (check on moments and time frames within the conceptual model).
- Do you think Formula E is relevant for the Sport?
- Do you think Formula E is relevant for Motorsport
- Do you think Formula E is relevant for the Automotive sector
- Do you think Formula E is disruptive? Why?

Stakeholders and stakeholder engagements

- Ask if he/she knows how changes in regulation are made in Motorsport (define the stakeholders for change in the motorsport sector)? Moreover, in Formula E?
- Ask which actors he think are involved with this low-carbon change
- What role the FIA do play in these changes?
- What role the external environment (policy, public opinion) etc.

Concluding

At the termination of the interview, the sound recorder will be switched off; this begins verbalised to the participant who will be made aware that the interview has concluded. They will be thanked for their time and contribution to the study. They will be advised that if they wish to receive a copy of the study upon conclusion, it will be made available in December 2018.

Appendix 6 Sample of N-Vivo coding process

An example of coding is offered below. The interview used was from informant B in table 5B. I transcribed these interviews myself (and all the scoping interviews) and compared the transcriptions with the notes that I have manually taken during the interview.

The interview was freely coded. As explained in section 5.3, as these interviews aimed to understand the industry experts' perceptions on Formula E, to capture the complexity of the researched phenomenon and to identify stakeholders and stakeholders' group to interview in the in-depth phase, the initial coding methods applied were the so-called pattern coding, initially identifying recurrent words, trends and patterns within the interview.

These words were then translated into categories and, when needed subcategories, using axial code methods.

Finally, themes were identified to identify major elements.

An example of this process is given below.

	Transcript	Coding
Line 47	At that time, the main stakeholders were: the organiser (FE Holdings and its shareholders as they put the capital, the risk to get the series up and running); […] the teams were less influential as mostly were privateers; the sponsors of series (interesting stakeholders), the fact that they had FIA sanctioned FE was important. […] Are the fan a stakeholder group? At the early stage, they were trying to create a fan base so probably not the main one was the organiser that was building a successful business model.	At that time=implies that **stakeholders** change with time (at the time), **Season 1** **Early stakeholders: FE Holding, Sponsors of the series** **Teams and FIA were less influential** **Fans: not yet a group at this stage** **Business Model**

Line 87	Now they [stakeholders] are different; it is all about the major company backing teams now so Renault, Mahindra people like that. Major corporations now are involved and their marketing mix, potentially the cities will become more relevant as it becomes a major event the host cities will become much more stakeholders TV companies are a big way to bring money and the fact that it is now bringing home some TV time it makes these guys a stakeholders FANS is a big one	**Now= Season 3** **Major corporation backing teams, Renault, Mahindra** **Marketing** **Host Cities** **TV Companies** **Fans**

Category 1: Early Stakeholders

Code: Formula E Holdings

Category 2: Season 3 Stakeholders

Code: Major Corporations

Code: Host cities

Code: TV companies

Code: Fans

Theme: How stakeholders have changed from season to season

Some emergent categories were also included in the coding, which was then confronted with more qualitative data acquired during other phases.

Appendix 7 FIA Press release dated 28/09/2012

Press release dated 28/09/2012

The Fédération Internationale de l'Automobile (FIA) has reached an agreement to licence the commercial rights of the FIA Formula E Championship to a consortium of international investors, Formula E Holdings Ltd (FEH).

Formula E is a new FIA championship featuring Formula cars powered exclusively by electric energy. It represents a vision for the future of the motor industry over the coming decades.

FEH, the new promoter, has as anchor investor London-based entrepreneur Enrique Bañuelos, and as CEO and shareholder former MEP and racing team owner Alejandro Agag, who has a long experience in the motorsport business. Also associated with the project are Lord Drayson, Managing Partner of Drayson Racing Technologies, and Eric Barbaroux, Chairman of the French electric automotive company "Electric Formula".

Demonstration runs of the Formula E cars will start in 2013, followed by the championship in 2014 with an objective of 10 teams and 20 drivers participating in the competition. The races will be ideally staged in the heart of the world's leading cities, around their main landmarks.

Jean Todt, President of the FIA, said:
"I would like to thank all the parties involved. This new competition at the heart of major cities is certain to attract a new audience. We are pleased with this agreement with Formula E Holdings as they bring a very strong experience in motorsport. This spectacular series will offer both entertainment and a new opportunity to share the FIA values and objectives of clean energy, mobility and sustainability with a wider and younger audience as well."

Alejandro Agag, CEO of FEH said:
"We are very pleased with the agreement reached with FIA. We see this as a great opportunity to create a new and exciting spectacle mixing racing, clean

energy and sustainability, looking to the future. We expect this Championship to become the framework for research and development around the electric car, a key element for the future of our cities."

Professor Burkhard Goeschel, President of the FIA Electric and New Energies Championships Commission, said:

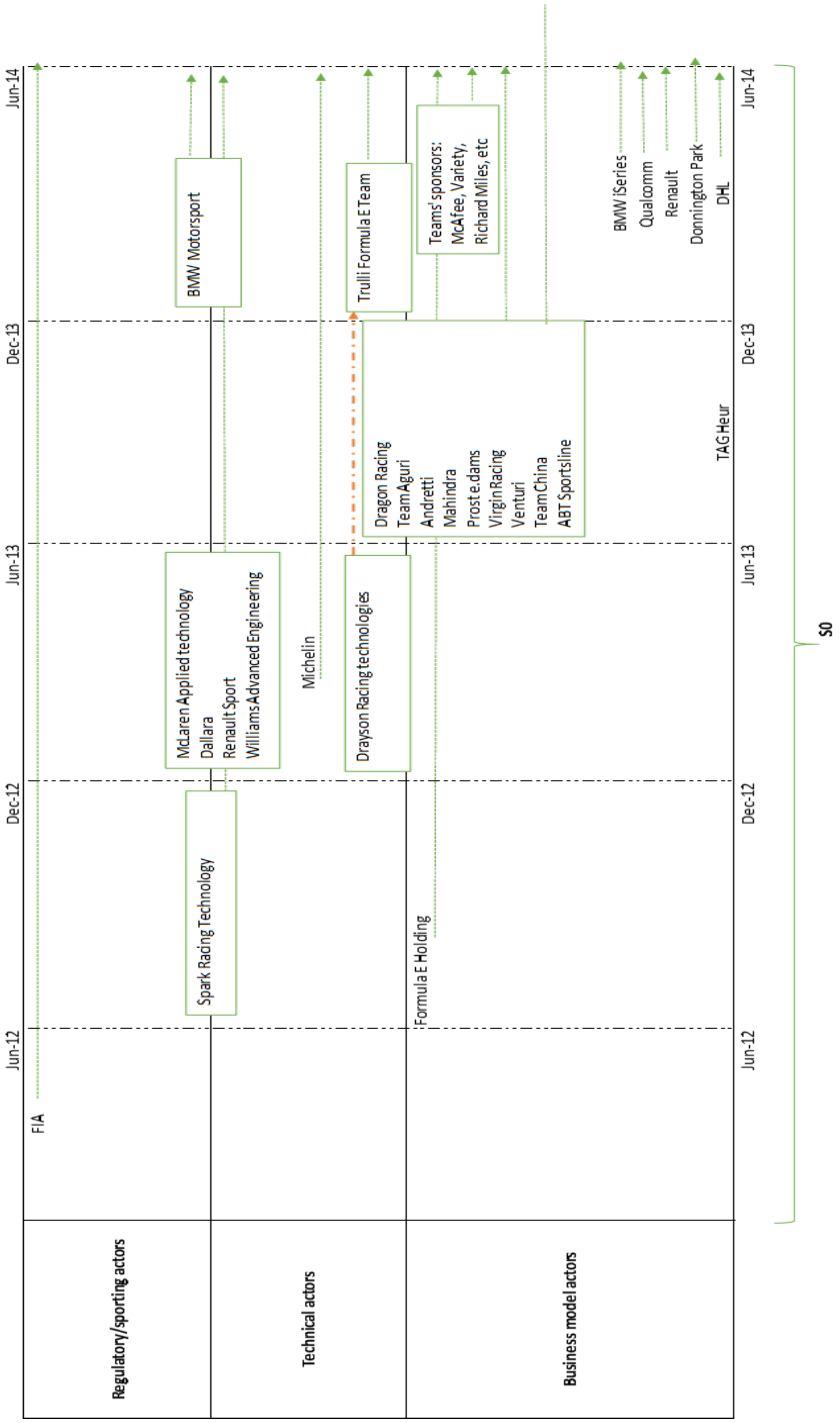
“Formula E will be a milestone for the future of motorsports, driven by the FIA. It follows the global megatrends of our world like sustainability, the growth of the megacities and the digital world of connectivity. I would like to say thanks to all partners, who supported us in creating this new project and also to the partners who will accompany us to a successful launch of Formula E.”

The series will be open to any cars sanctioned as Formula E by the FIA. The consortium will ensure that a Formula E Car, based on the Formulec EF 01 prototype already in operation, is available for those competing teams willing to race with it.

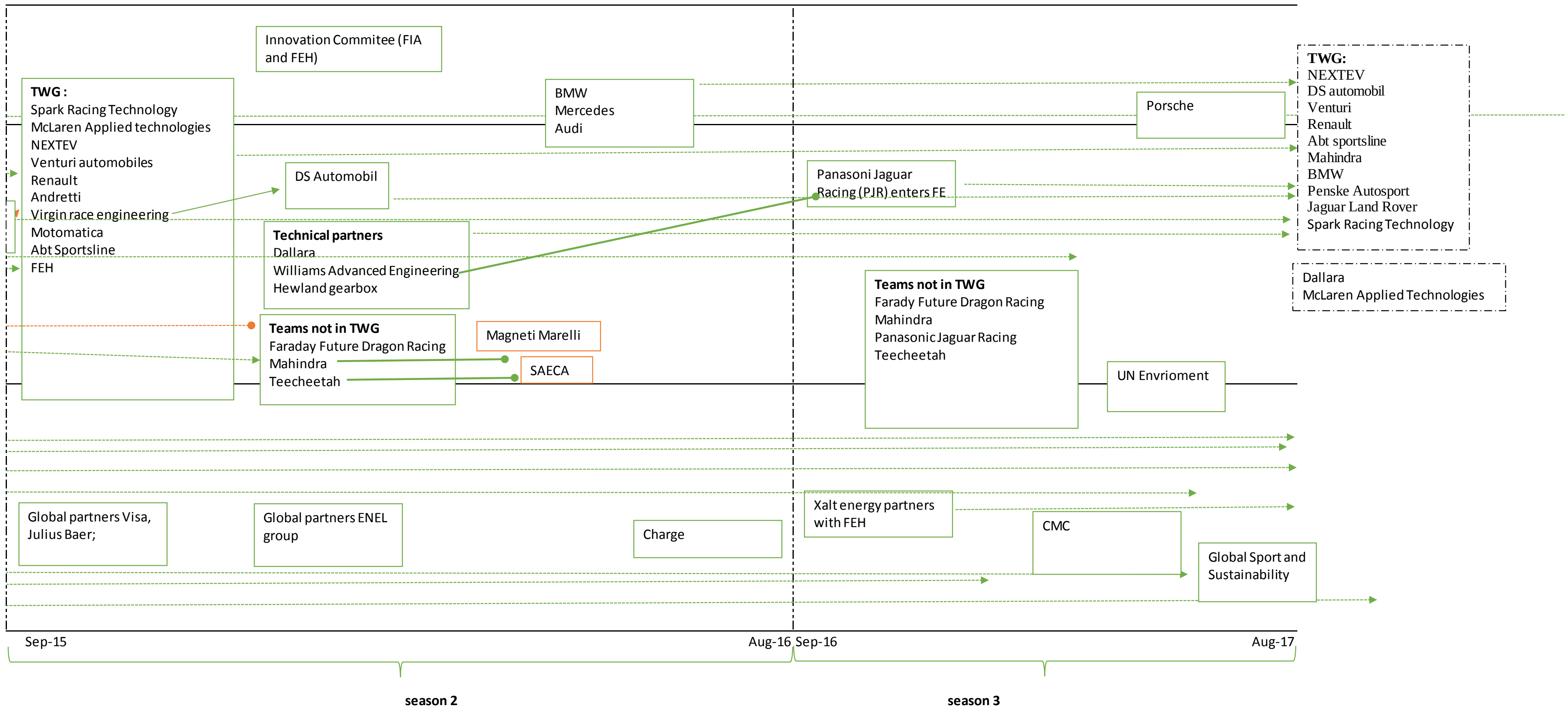
For information, please visit FEH website: www.formulaeholdings.com

Contact for media: Stuart Skinner (PHA MEDIA) - stuart@pha-media.com

Appendix 8 Flow charts



Flow chart for Season zero



Flow chart for season two and season three