



## Master's Thesis Internship – Sustainable Business & Innovation

# The Transition from a Linear to Circular Economy: An Innovation System Analysis of the Composites Industry

**Student Name:** Pieter Leendertse

**Student Number:** 3489671

**Email:** [p.w.leendertse@students.uu.nl](mailto:p.w.leendertse@students.uu.nl)

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**Educational Institution:**

Utrecht University  
Faculty of Geosciences  
Heidelberglaan 8  
3582CS Utrecht

**University Supervisors:**

Dr. Simona Negro  
Denise Reike, MSc

**Principal Institution:**

Rijkswaterstaat, Nederland  
Griffioenlaan 2  
3526GE Utrecht

**Company Supervisor:**

Mattijs Erberveld – advisor Sustainability and Innovation.

## List of abbreviations:

CE = Circular Economy  
IS = Innovation System  
TIS = Technological Innovation System  
MLP = Multi-level perspective  
OEM = Original equipment manufacturer  
EU = European Union

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## Abstract

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In the contemporary ‘take-make-dispose’ economy, significant amounts and types of resources are not recycled or re-used in industrial production processes. This is also the case in the composites industry, which is experiencing a worldwide economic boom due to increased usage of composite materials in wind-energy, maritime and automotive applications. Although much has been written about the benefits of an economic system that circulates materials in closed-loops (i.e. Circular Economy), very little is known about the driving and blocking factors that determine the development process from a linear towards a *circular production model*. The latest insights from innovation studies propose that such sustainable industrial transformations are influenced by how the surrounding system – the Technological Innovation System (TIS) – is structured and functions. In this thesis, a TIS-approach is used to study the Innovation System around the recycling and/or-re-use of composites in the period 2015-2016. Consequently it is one of the first times TIS-research goes beyond the diffusion of technological innovations to study the development process of a sustainable industrial transformation. Through a case study several obstacles for the development of a circular production model are identified: deficient policies at the system level that are poorly aligned with (inter)national CE ambitions; limited market demand for composite recycle due to costs and quality restrictions of various recycling technologies; and the unavailability of financial resources to develop the physical infrastructure that is necessary to carry out activities related to recycling and/or re-use technologies. Overcoming the barriers that hinder further development of a circular production model is not an easy task, but policymakers may address the identified obstacles by the deployment of policy instruments that address the outlined systemic challenges.

## 1.0 Introduction

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During the 20<sup>th</sup> century population growth, globalization, deregulation and the removal of trade barriers have intensified the negative consequences for environmental and societal welfare (Benn et al., 2006; Jenkins, 2005; Lozano & Huisingh, 2011). In the pursuit of economic growth, global extraction of construction materials increased by a factor 34, ores and minerals by a factor 27 and fossil fuels by a factor 12 (UNEP, 2011). According to projections, global material use will again triple over the period 2015-2050. As a result, it is estimated that the total quantity of waste will increase by 45% in 2020 compared to 1995 levels. In today's linear economy, globally, most waste (80%) is dumped at landfill sites, incinerated or ends up in wastewater. This has negative consequences for both human health and the environment, as large shares end up in sub-standard landfills, which results in methane emissions, dust, odor and diseases (McKinsey, 2013).

Several authors (e.g. Ekins, 2002; Greyson, 2007) argued that the global economy can grow sustainably. However, this can only be achieved whenever economic growth and the consumption of finite resources are 'decoupled' (UNEP, 2011). Decoupling means that fewer natural resources are used per unit of economic output, while reducing the environmental impact of any of the used resources in the undertaken economic activities. Cramer (2015) argued that, in order to accomplish sustainable growth, a transition from a linear towards the circular economy (hereafter, CE) is necessary.

Although there is no commonly accepted definition of CE, the notion can be described as the move away from a traditional linear production model, i.e. the 'take-make-dispose' pattern (Zhu et al., 2010). The CE is based on schools of thought such as Cradle-to-Cradle, Industrial Ecology and Biomimicry, which are mainly aimed at eliminating the concept of waste (Kok et al., 2013). This can be achieved by rethinking how linear production models can become 'closed loops' (Yuan et al., 2008). A *circular production model*<sup>1</sup> integrates both forward and reverse supply chains, and focuses on taking back products from customers and recovering added value (Aravendan & Panneerselvam, 2014; Zhu et al., 2010). Hence, in a circular production model, *waste* materials are not disposed of by incineration or landfill, but are re-introduced as input for the same or another production process. In this way less embedded energy and labor are lost, and more materials are preserved.

The projected economic, social and environmental benefits of such a CE are significant. The Ellen McArthur Foundation (2014) calculated that the EU manufacturing sector alone could realize up to 630 billion euro in material cost savings per annum towards 2025. Furthermore, besides direct financial benefits, the CE promotes the development of new knowledge, triggers innovation, creates new business and jobs and enhances resource supply security (Cramer, 2015). While companies have good reason to act on

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<sup>1</sup> Different authors (e.g. Kok et al., 2013; van Renswoude et al., 2015; Xue et al., 2010; Yuan et al., 2008) go into the subject of CE. Based on these papers, a circular production model is defined in this thesis as: "*an economic system that creates value by moving waste materials in closed-loops*". This definition is used in the remainder of this thesis to describe a system where waste materials are re-used or recycled, rather than discarded in incinerators or landfill (Khalili et al., 2015).

these prospects, governments play an equally important role. Governments possess the ability to introduce legislation, strengthen business efforts and stimulate upcoming activities by utilizing its procurement power (Yuan et al., 2008). Several (supra)national governments recognized this ability to exert influence, and articulated the desire to develop closed-loop material and energy flows (European Commission, 2015a; Zhou et al., 2014). The Dutch programme *Waste to Resources* ("Van Afval Naar Grondstof") is an example of the national government's aim to stimulate a circular production model in specific material chains with a considerable environmental burden (Ministerie van Infrastructuur en Milieu, 2013).

One such material is fiber-reinforced plastic (a composite)<sup>2</sup>, which has been increasingly used in wind-energy, automotive and maritime applications (Pimenta & Pinho, 2011). The popularity in these applications has to do with the properties of composites: high strength to weight ratio, corrosion resistive, no maintenance and a long lifespan (McConnell, 2010). According to Witten (2012) the estimated amount of end-of-life composites in Europe reaches 0.43-megaton p.a. in 2012, 10%-20% of which is present in the Netherlands. To give an indication, 0.43-megaton p.a. is comparable to the amount of large household appliances (e.g. dishwashers, fridges and ovens) that are annually collected for recycling purposes (WEEE, 2008). With approximately 350 active actors in composites industry in the Netherlands alone (VKCN, 2015), the conventional linear production model functions well. There is, however, currently no operational closed-loop for these composite materials, despite the availability of various recycling and/or re-use technologies. Due to a boom of the composites industry, which grows at a rate of 15-20% per year worldwide (Pimenta & Pinho, 2011), it has nevertheless become increasingly urgent from an economic and environmental perspective to look for alternatives to the current make-take-dispose system (Job, 2014; Marsh, 2009; Wood, 2010).

Although a circular production model offers theoretical economic and environmental opportunities for the composites industry, there is currently a large gap between aspirations and practice. This indicates that there are certain *factors* hindering the composites industry from transitioning towards a circular production model. At present there are, however, no established theories that elaborate on what driving and blocking factors behind such a transition are, how they can be accelerated or overcome, and who should take a leading role in this process. Due to this knowledge gap it also remains unclear how the government, generally considered to have an important role in steering transitions (Rotmans et al., 2001), can accelerate drivers and help overcome barriers.

Sustainable industrial transformations and socio-technological transitions have been studied through various approaches, e.g. Transition Management (Rotmans et al., 2001), Multi-level perspective (Geels & Schot, 2007) and Technological Innovation Systems (Hekkert et al., 2007; Bergek & Lindmark, 2008). *Transition Management* studies focus on explaining general transformation processes in society over the time-scale of generations. However, this theory is rather prescriptive and faces drawbacks in actual

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<sup>2</sup> Out of the main reinforcement materials – glass and carbon fibers – glass fiber-reinforced plastics are the most prolific, with a market share of 95% within the composites industry (Witten, 2012). The focus of this thesis therefore lies on this segment of the composites industry. For the ease of reading, glass fiber-reinforced plastics are referred to as 'composites' in the remainder of this thesis.

policy contexts (Kern & Smith, 2008), whereas *Technological Innovation Systems* (hereafter, TIS) and *Multi-level Perspective* (hereafter, MLP) are closely related concepts that offer well-established frameworks that aid in better understanding innovation and transition processes. According to the MLP transitions occur due to the interplay between dynamics at different levels, i.e. niche, regime and landscape-level (Geels & Schot, 2007). What the MLP misses, however, are factors that explain a successful system transition and rationales for policymaking (Negro, 2007). The TIS-approach covers this policy legitimacy gap, by analyzing a system's *structure*, *functions* (key processes) and *failures* (weaknesses) that determine the diffusion of new products, services and processes (Hekkert & Negro, 2009). The TIS-perspective has nevertheless failed to go beyond the diffusion of a specific technology to address the challenge of transforming broader industrial production and consumption models (Markard et al., 2015).

However, recent insights from innovations studies indicate that such sustainable industrial transformations, like the transition from a linear to a circular production model, are to a large extent influenced by how the surrounding system – the innovation system – is structured and functions (Markard et al., 2012). Weber and Rohracher (2012) therefore complemented the traditional TIS-approach by incorporating transition thinking into the framework of system functions, failures and policy instruments. Due to this integration, the TIS-approach arguably offers a building block to explain the development processes of sustainable industrial transformations, and suggests strategic innovation policies to direct industrial transformations towards particular goals (Markard & Truffer, 2008; Weber & Rohracher, 2012). Since the transformational challenge from a linear to a circular production model in the composites industry is to a large extent reliant on several recycling and/or re-use technologies, a TIS-approach serves as a suitable method to analyze this particular development challenge in terms of structures and key processes that support or hamper it. A more elaborate description of the current attempts and technological possibilities to recycle and/or re-use composites follows in section 3.1.

To determine the *factors* – system structure, functions and failures – that drive or block the development from a linear to a circular production model in the composites industry, it is necessary to study how the Innovation System around the recycling and/or re-use of composites is built up and how it functions. Insight into these factors can also clarify *how* the system has to change in order to bring about an environment for firms to accommodate a goal-oriented sustainability transition. Thereby this thesis aims to provide a handhold for policymakers to indicate where policy interventions in the system are likely to matter most; so that the institutional environment of the composites industry is more suited for firms to deal with the challenges that occur during a transition from a linear to a circular production model.

The following research question of this thesis is:

***What factors trigger or hamper the transition to a circular production model in the composites industry, and how can policymakers accelerate drivers and overcome barriers?***



To provide an answer to the research question through the use of an Innovation Systems approach, knowledge on a system's structure, functions and failures is required. Additionally it is necessary to understand what instruments are available for policymakers to overcome obstacles that hinder the development of a system. Consequently the resulting sub-questions are formulated:

- (1) What are the main structural components of the Innovation System around the recycling and/or re-use of composites?*
- (2) What factors drive or block the development of this innovation system?*
- (3) How can policymakers stimulate driving forces and assist in overcoming barriers to the development of this innovation system?*

To explore the sub-questions, a specific case study within the composites industry is analyzed. This case allows an assessment of the Innovation System around the recycling and/or re-use of composites by examining the system's structure, functions and failures. Based on this analysis, recommendations are formulated for policymakers to address transition obstacles and develop policies accordingly. To aid this process, a conceptual framework is constructed that depicts how the system elements - structure, functions and failures - conceptually relate to the development of an Innovation System. Outcomes of the framework can make it more evident for policymakers of governments to address development obstacles in a systematic and coherent way (Wieczorek et al., 2013). It furthermore helps policymakers to distinguish key processes and structures within a system where policy interventions are expected to matter most (Jacobsson & Bergek, 2011). Herein lies the societal relevance of this thesis, since this handhold can contribute to overcoming the challenges facing a sustainable industrial transformation with profound social, environmental and economic benefits.

Lessons learned from this research are also relevant for business and industry, because it allows companies to examine the environment (innovation system) in which activities related to recycling and/or re-use technologies develop. For firms this can ultimately provide novel insights in the search of new business opportunities or strategies.

Besides being societally relevant this thesis also has scientific relevance, as it is one of the first times a TIS-approach is applied in the context of a CE. Consequently the academic relevance is twofold. Firstly, new insights in the TIS research field can be generated by examining system functions and failures in relation to the challenge of transforming broader production and consumption models, rather than the diffusion of (technological) innovations within a system. In this respect this thesis is a first attempt to address a common critique of the TIS-approach: the inability to deal with the study of sustainability transitions – a new field of research that concentrates on industrial transformation processes towards more sustainable modes of production and consumption (Markard et al., 2015). Secondly, present knowledge from the TIS-approach can enhance the understanding of currently under-researched driving and blocking factors that determine the development of a circular production model within an industry. An enhanced understanding of these factors can also lead to policy considerations in transition management regarding the CE, which have not been prominent in respective literature yet (Weber & Rohrer, 2012).

The thesis is conducted at Rijkswaterstaat - the executive body of the Dutch Ministry of Infrastructure and Environment – that has the long-term ambition to achieve a CE in the Netherlands (Rijkswaterstaat, 2015a). For Rijkswaterstaat (see appendix A) this study is relevant, because within Rijkswaterstaat composites are perceived as a promising material for building and maintenance activities in the future. Rijkswaterstaat recognizes, however, that recycling or re-use of composites still poses a challenge (Rijkswaterstaat, 2015b). Since this thesis aims to identify obstacles that hinder the development of a system in which composites are recycled and/or re-used, the findings can provide a handhold for advice regarding action, national policy and regulation in an industry with mounting environmental concerns. The scope of this thesis is limited to the Dutch composites industry because Rijkswaterstaat is mainly operational in the Netherlands.

## 2.0 Literature review

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As described in the introduction, it is currently unknown which *factors* trigger or hamper the development of a circular production model in the composites industry. Consequently there is no legitimate rationale for policymakers to intervene in this process. To examine this topic, this thesis departs from a TIS-perspective. Namely, recent insights from innovation studies suggest that a TIS-approach can be used beyond the diffusion of specific technological innovations, to study the transformation of broader production and consumption structures (Weber & Rohrer, 2012).

This literature review is meant to lay the theoretical basis that is needed to gather a better understanding of the posed issues. In doing so, first the main theoretical TIS components are described, i.e. structure and functions (sections 2.1-2.2). Hereafter, systemic failures are examined that can prevent the development of an innovation system (section 2.3). Section 2.4 elaborates on the policy instruments that can be used by policymakers to strengthen driving forces or address systemic barriers. Ultimately these sections come together in a conceptual framework that visualizes how the different elements conceptually relate to the development of an innovation system.

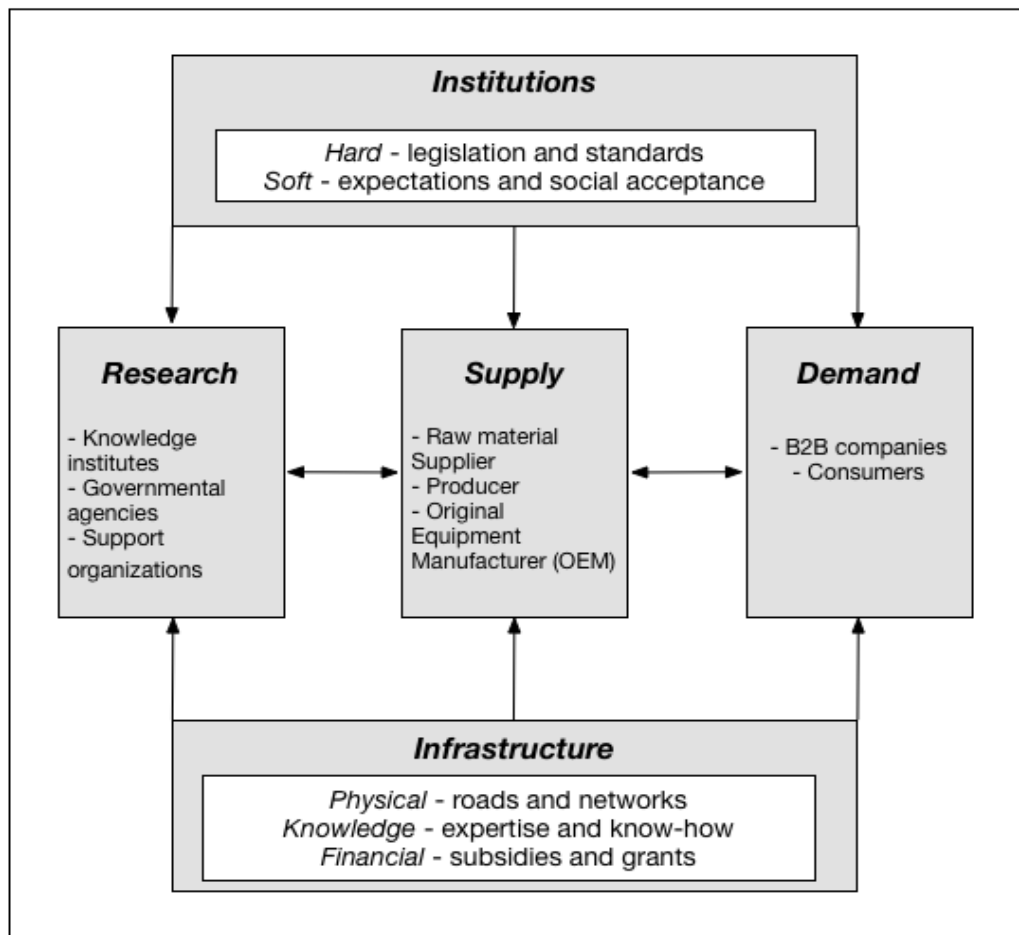
Since this thesis is one of the first attempts to apply a TIS-approach in relation to an industrial transformation, the traditional TIS concepts are not tailored to this new context. Consequently, in case it is necessary, the author proposes how the outlined theoretical concepts in the remainder of this literature review should be interpreted in the context of this research.

### 2.1 Technological Innovation Systems

A TIS consists of the relationships between *structural* components, i.e. actors, interactions, infrastructure and institutions (Wieczorek et al., 2013). The key processes that contribute to the goal of innovation systems are called *functions* (Hekkert et al., 2007). In other words, the structure presents the components that are active in an innovation system; the functions give insight into what the components are doing to develop this system (Luo et al., 2012). Mechanisms that block the functions are called system weaknesses, which can lead to system *failures* that prevent a system from developing (Klein Woolthuis et al., 2005). Analyzing these three elements – structure, functions and failures – is relevant for the purpose of this thesis, as it gives insight into what happens in an innovation system, what goes wrong and why.

#### 2.1.1 Innovation System Structure

This section, which focuses on the TIS structure, addresses the first sub-question of this thesis – identifying the main components of the Innovation System around the recycling an/or re-use of composites. According to Wieczorek & Hekkert (2012) the structural components of a TIS consist of the following dimensions: actors, institutions, infrastructure and interactions. Insight into the structure is relevant because the development and direction of an innovation system is influenced by the configuration of these components (Suurs & Hekkert, 2009). A schematic depiction of the relation between the different components is presented in figure 1.



**Figure 1** – Structural components of an Innovation System (Kuhlmann & Arnold, 2001).

### **Actors**

The presence and capabilities of actors, like governments, industry, knowledge institutes and support organizations, contribute to the development and direction of the system (Wieczorek & Hekkert, 2012).

### **Institutions**

Institutions regulate relations between actors, and can be divided into hard and soft categories (Edquist, 2001). The former refers to rules, laws and regulations, whereas the latter category indicates expectations and social acceptance of these regulations. The presence and ability of hard and soft institutions is significant, since both can constrain the TIS from functioning well (Wieczorek et al., 2013).

### **Infrastructure**

Although the position of infrastructure is not conclusive in TIS-literature, generally three elements are defined: physical, knowledge and financial (Smith, 2000). Physical infrastructure consists of objects such as roads, networks and bridges. Such infrastructure is maintained by knowledge and financial arrangements, all of which are important for the functioning of a system (Wieczorek & Hekkert, 2012).

### **Interactions**

Interactions are the relations between actors (shown as arrows in figure 1). These interactions are vital for knowledge exchange, learning and shared vision building of a

system. The focus here is on relationships, which can occur on the network and individual level (Wieczorek & Hekkert, 2012).

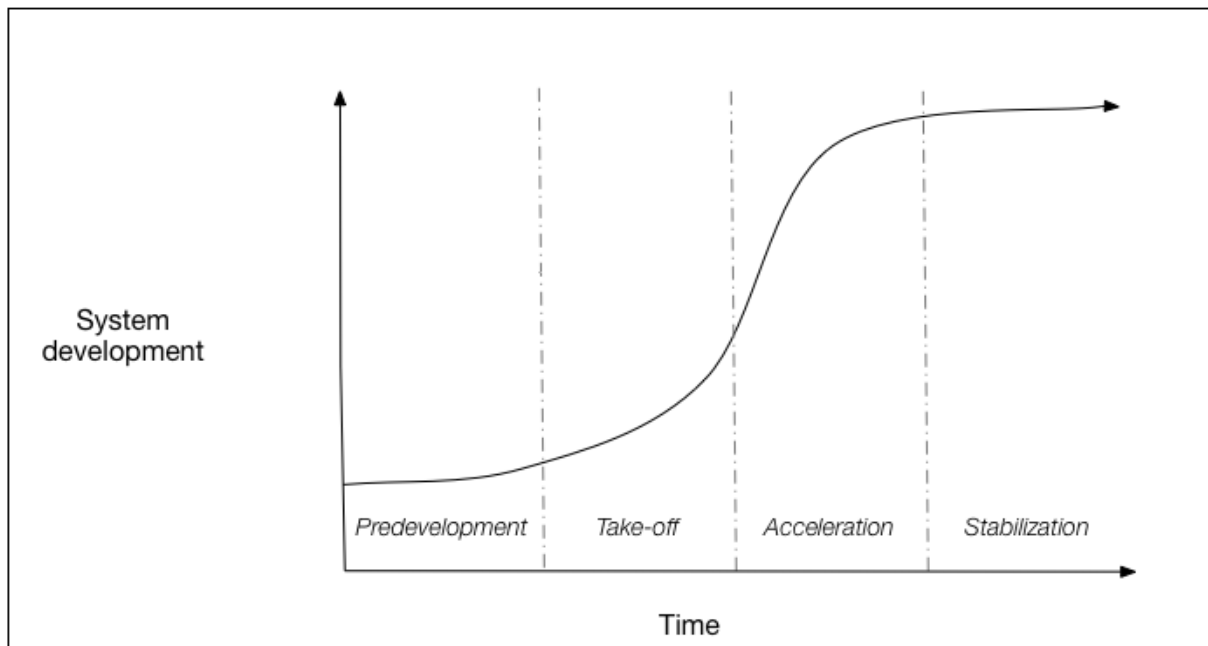
## 2.2. Innovation System Functions

Besides gathering an overview of a system's structure, it is also relevant to assess how a system performs by analyzing the system functions – i.e. key processes for successful system development and performance (Luo et al., 2012). In TIS-literature, system functions are used as intermediate variables between a system's structure and failures; through functions the structural components contribute to the development of the system (Jacobsson & Bergek, 2011). The functions approach offers a systematic method of examining 'inducement and blocking mechanisms' that contribute to the development of new products, services and processes (Hekkert et al., 2007). This section on system functions, together with failures (section 2.3), therefore addresses the second sub-question of this thesis – factors that drive or block the development of the Innovation System around the recycling and/or re-use of composites.

Before going into specifics, it is important to stress that the phase of development determines the functional patterns of a TIS (Negro, 2007). By comprehending these interaction patterns between functions, clues can be obtained to understand how innovation systems develop (Hekkert & Negro, 2009). Consequently it becomes more obvious where intervention is needed to accelerate this development.

TIS-literature often recognizes four development phases (figure 2) that are derived from transition management studies (Rotmans et al., 2001). In the *predevelopment* phase organizations experiment with a new innovation concept, although there is no visible change. The *take-off* phase is characterized by a system that starts to move: pilot projects are started and other guiding approaches that lead to structural change are developed. Actual changes in the economy, regulations and society become visible in the *acceleration* phase in the form of more and more projects (Rotmans et al., 2001). Ultimately, in the *stabilization* phase, the new concept is completely implemented as the new standard (van der Brugge et al., 2005).

In the context of a transition from a linear to a circular production model, the author proposes that the development phases should be interpreted as follows: in the predevelopment phase organizations experiment with activities related to recycling and/or re-use technologies, but landfilling and incineration are still the conventional means of handling waste materials. In contrast, in the stabilization phase material recycling and/or re-use activities are the new standard. So it is assumed that a system develops from a make-take-dispose (linear) model towards a system in which waste materials are recycled and/or re-used, i.e. a fully entrenched circular production model.



**Figure 2** – *System development phases* (Rotmans et al., 2001).

Since an operational circular production model is not yet fully entrenched in the Innovation System around the recycling and/or re-use of composites, the focus of this thesis is expected to lie at the beginning of the S-curve, i.e. phase 1 and 2. Although Luo et al. (2012) described the most relevant system functions for these phases with respect to the diffusion of new technological innovations; such a distinction is not yet established for system development in relation to the transformation of industrial production and consumption models. Therefore all system functions, as outlined by Hekkert et al. (2007), are presented below in table 1. Where possible, these definitions are followed by a description of how governments can exert influence on the system functions. These explanations are based on various TIS-literature sources, such as Bergek et al. (2008), Hekkert and Negro (2009), Jacobsson and Bergek (2011) and Luo et al. (2012).

Although the functions (table 1) were originally meant to describe the diffusion of a particular technology or product, recent debates in the field of innovation studies (e.g. Markard et al., 2015) suggest that system functions also offer explanations when studying transformations of broader systems of production and consumption, such as development challenges in systems of recycling. It is therefore proposed that the individual system functions provide a basis for driving and blocking factors for the development of a circular production model.

The functions are, however, not independent and can influence each other, either in a positive or negative manner. This, in turn, can lead to a reinforcement of system functions that eventually lead to cycles that strengthen or weaken the development momentum (Negro, 2007). For instance, a certain amount of guidance (F4) towards a circular production model is needed to stimulate entrepreneurial activities (F1), which is required to form a market (F5) for recycled or re-used composites.



Table 1: Overview of system functions.

Function	Description
<b>F1: Entrepreneurial activities</b>	Entrepreneurs are of vital importance for the existence of an innovation system. The role of entrepreneurs is to test new technologies, applications, learning processes, services and markets (Hekkert & Negro, 2009). To drive the development of a circular production model, governments can for instance initiate pilot projects to let firms experiment with the concept.
<b>F2: Knowledge development</b>	Knowledge development and mechanisms of learning are prerequisites of every innovation system (Hekkert & Negro, 2009; Luo et al., 2012). To stimulate the development of a circular production model governments can, for example, fund R&D programmes to allow for knowledge development.
<b>F3: Knowledge diffusion through networks</b>	Information exchange through networks is essential for innovation and for the build-up of innovation systems (Luo et al., 2012). To drive a transition towards circular production model governments can, for example, exchange information through conferences, workshops, form alliances with companies and stimulate coalitions within markets.
<b>F4: Guidance of the search</b>	Guidance or direction is necessary to provide incentives and/or pressures for actors to enter the system or to further invest into it (Jacobsson & Bergek, 2011). To trigger the development of a circular production model, firms can be guided by governments in the form of visions, growth expectations, regulations and the articulation of a specific demand.
<b>F5: Market formation</b>	The formation of a market for new products or services is vital for the development of an innovation system (Hekkert & Negro, 2009). The uptake of a circular production model requires a market for re-used and recycled products and services. Governments can influence the market formation process by, for instance, creating protected niche markets, tax regimes, quotas or environmental standards (Hekkert & Negro, 2009).
<b>F6: Resource mobilization</b>	Both financial and knowledge resources are required as basic input for the activities within an innovation system (Hekkert & Negro, 2009). To stimulate the development of a circular production model, governments can provide grants or subsidies to mobilize the necessary resources.
<b>F7: Creation of legitimacy</b>	Actors with vested interests in the current regime often oppose the development of an innovation system (Negro, 2007). In order to drive a system away from a linear production model, governments can create legitimacy by: lobbying, putting the issue on the political agenda, and create favorable tax regimes (Bergek et al., 2008).

Source: adapted from Bergek et al. (2008); Hekkert & Negro (2009); Jacobsson & Bergek, 2011; Luo et al. (2012); Negro (2007).

According to Luo et al. (2012) it is customary that the first few functions (e.g. F1-F3) are most critical in the early stages of the system development i.e. *predevelopment* phase. In this stage, it is expected that poor performance of other system functions, such as guidance of the search (F4) and resource mobilization (F6) negatively influence further system development. Then, after a phase of entrepreneurial experimentation (i.e. *take-off* stage), it is ordinary that later functions (F4-F7) become critical in *accelerating* the system transition. In the last stage of system development – i.e. *stabilization* – market formation (F5) remains important, with resource mobilization (F6) and guidance of the search (F4) as supportive functions.

It should be noted that not every function necessarily forms a barrier whenever it is not positively fulfilled. However, in case too many critical supportive functions are negatively fulfilled in a particular stage, further system development can be hampered (Negro, 2007). Then, in order to trigger the development process, governmental intervention is needed to realize measures to overcome specific barriers. Which governmental instruments are required can only be understood by analyzing the underlying reasons that lead to the reinforcement cycles of system functions (ibid.). These underlying reasons, or system failures, are discussed in the next section (2.3).

### 2.3 Innovation System Failures

System functions and failures are not mutually exclusive. Rather, an inter-relation exists between the system functions and failures; failures are theoretical categories that link specific functional barriers to broader systemic problems. In other words: when system functions are badly fulfilled and block further development of the system, this indicates that a systemic failure is at the root of this problem (Luo et al., 2012; Negro et al., 2012). Identifying system failures therefore provides a guide to where governmental intervention is required and likely to matter most (Jacobsson & Bergeck, 2011).

Markard and Truffer (2012) argued that, due to the context of transforming industrial production models – the transition from a linear to a circular production model in this case – additional types of failures come in to play compared to traditional technological innovation. Weber & Rohrer (2012) therefore derived four transformational failures from the MLP to complement existing structural failures, as outlined by Klein Woolthuis et al. (2005). Together these structural and transformational system failures<sup>3</sup> provide a basis for possible policy interventions that may stimulate further system development. An overview of the transformational failures is presented in table 2 below (see appendix B for the structural failures). Transformational failures are emphasized in this section because they are most suitable for dealing with transition challenges with regard to systems of production of consumption (Weber & Rohrer, 2012), such as the development of a system where waste materials are recycled and/or re-used.

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<sup>3</sup> Four market failures that are also discussed by Weber and Rohrer (2012) are combined and renamed as ‘market failure’, according to the definition of Bergeck and Lindmark (2008). This failure is added to the overview of structural failures in table 8 (appendix B). This is done because traditional market failures are mainly related to the (mis)use of public goods; a mechanism that is of lesser importance for the topic of this thesis.



Table 2: *Overview of transformational system failures.*

Type of failure	Failure mechanism	Description
<b>Transformational system failures</b>	Directionality failure	The absence of system development is caused by a lack of direction and setting of collective priorities for societal problems or challenges.
	Demand articulation failure	The lack of system development originates from production and consumption issues. Demand articulation failures are caused by a mismatch between producers and users of products or services, which point to insufficiently developed market demand.
	Policy coordination failure	The absence of system development is caused by poorly aligned policies and activities at (inter)national, regional and sectoral levels. Due to the focus on coordination of specific actions, the policy coordination failure goes beyond the directionality failure.
	Reflexivity failure	The lack of system development originates from an inflexible and maladaptive system. The reflexivity failure represents the inability to monitor, anticipate and involve actors in processes of self-governance.

Source: adapted from Weber & Rohrer (2012).

TIS theory indicates that, similar to system functions, systemic weaknesses are not independent (Markard & Truffer, 2012). Impaired parts of the TIS can cause problems in other parts of the system; for example, market failures can be strengthened by a problematic physical infrastructure. Whenever a failure is present, governmental intervention is needed to foster the intended system development by diminishing a failure's obstructing effect (Weber & Rohrer, 2012). In such case, the identification and categorization of systemic failures helps to provide a justification for policy intervention (Negro et al., 2012). The next section, 2.4, elaborates on a portfolio of instruments that can be used by policymakers to address structural and transformational system failures.

## 2.4 Policy Instruments

By understanding the underlying system functions and failures that hamper system development, suitable policy instruments can be advised to governments that serve as tools to overcome development obstacles. Governments possess the ability to introduce legislation, strengthen business efforts and can stimulate upcoming activities by utilizing its procurement power (Yuan et al., 2008). The role of the government here is plural: 1) steer system innovation; and 2) facilitate and evaluate processes that mobilize actors (Rotmans et al., 2001). Policy instruments aid in fulfilling these governmental roles, by coordinating and managing actor processes at multiple levels (Geels & Schot, 2007). Its aim is to provide public decision-makers and private actors insight into how changes at the micro-level can lead to developments at the system-level (ibid.). Examining these systemic instruments addresses the third sub-question of this thesis – how

policymakers can stimulate driving forces and assist in overcoming barriers to the development of the Innovation System around the recycling and/or re-use of composites. To do so, Weber & Rohracher (2012) proposed a portfolio of instruments to address the previously discussed failures (section 2.3) that obstruct further development of an innovation system, which are elaborated below. It is, however, not certain that these tools will resolve a particular failure, as no one can know this in advance.

### **Directionality instruments**

To overcome directionality failures, first the desired transition has to be translated. Hereafter guiding orientations have to be formulated, so that the different actors can interpret the transition goals (Weber & Rohracher, 2012). Policymakers can achieve this by, for instance, establishing a shared vision with the intention to achieve collective orientation. Soft instruments, like orchestrating coordination and providing information, can be used when implementing policies in line with the shared vision. Hard instruments, such as standards and regulations, can also prove to be useful when guiding the direction of industrial transformations (ibid). For instance by demarcating what activities are permitted and which are illegal (McManus, 2009).

### **Demand articulation instruments**

To address demand articulation failures, public decision-makers can introduce policy instruments that support joint learning processes, which involve both producers and users (Weber & Rohracher, 2012). Examples are living labs that include innovative experimentation in real world settings (Almirall & Wareham, 2011); 'incubation rooms' for niche-innovations (Kemp et al., 1998); and user-led innovation that involves a high level of end-users in the transition process (Ornetzeder & Rohracher, 2006). Such instruments can support further development of an innovation system, by stimulating learning processes and raising awareness of new possibilities among consumers and producers.

Governments are furthermore major investors that can use their procurement power to stimulate novel solutions from the demand side (Weber & Rohracher, 2012). In other words, the government can act as a 'launching customer' to eliminate a demand articulation failure.

### **Policy coordination instruments**

Policy failures that obstruct the development of a system can occur in both horizontal and vertical directions. The former refers to coordination failures between different policy areas, e.g. energy, health and transport. The latter occurs whenever coordination between different levels of government fails, such as regional, national and EU levels. When such incoherencies arise, instruments should focus on coordinating policies in different domains; since addressing policy coordination failures is more effective through coordinated policy action than by individual actors (Weber & Rohracher, 2012).

### **Reflexivity instruments**

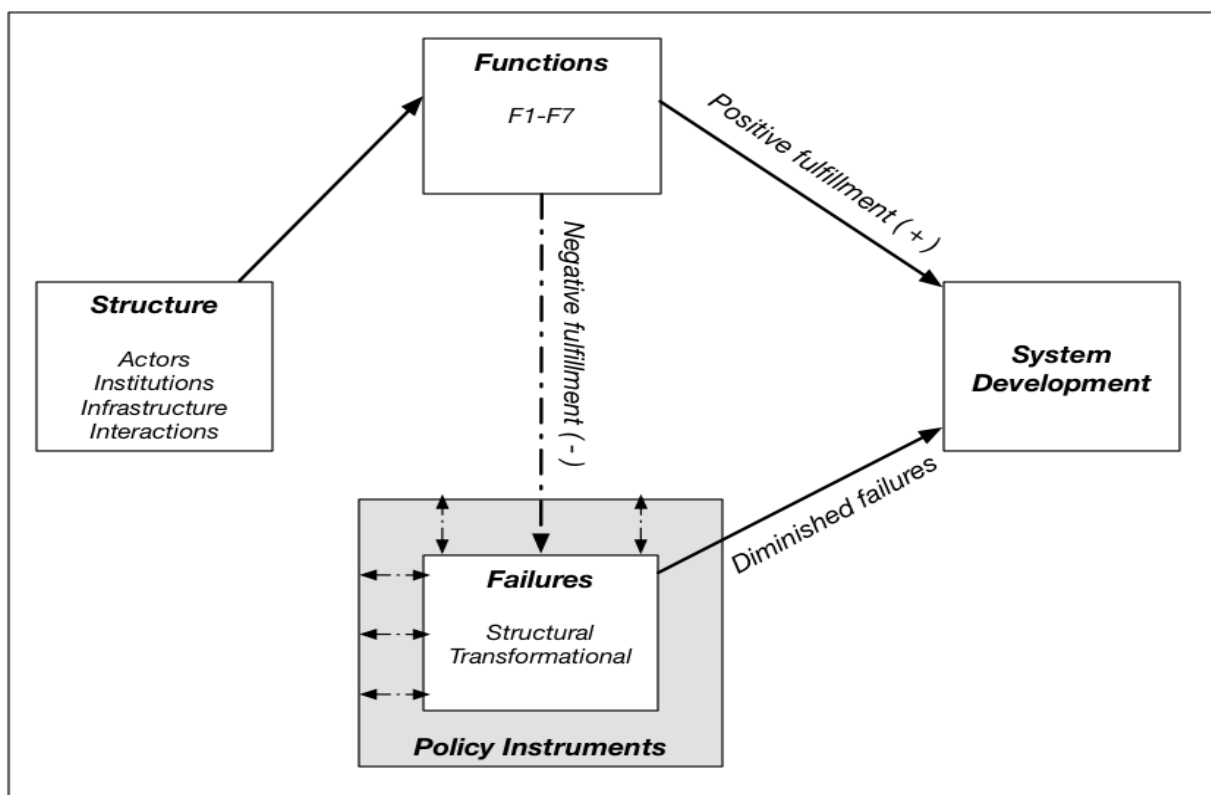
Reflexivity failures originate from the inability to change presumptions and current practices. As a result, institutions, markets and society are conceived as given, and unable to change. To stimulate the development of an innovation system, reflexivity instruments require to be able to draw on the system's ability to interact, experiment

and monitor activities (van Mierlo et al., 2010). Continuous monitoring therefore needs to be established as a pre-condition for an adaptive policy approach (Weber & Rohrer, 2012). For instance, by providing a platform for network meetings with key stakeholder groups, feedback discussions and monitoring activities can be stimulated.

## 2.5 Conceptual framework

In this section the preceding concepts are combined into a conceptual framework (figure 3). The purpose of the framework is to schematically represent how the different system elements – structure, functions and failures – influence the development of an innovation system from a *predevelopment* to a *stabilization* phase. The primary application of this conceptual framework is the identification of system failures, articulated in functional terms. This is relevant for the purpose of this thesis, because identifying system failures enables us to understand what blocks system development towards the stabilization phase, i.e. the phase where a circular production model is fully entrenched in the Innovation System around the recycling and/or re-use of composites.

Figure 3 shows that the development of an innovation system is determined by the functions, which originate from the system's operating parts, i.e. structure. To accomplish further development of a system, a positive and a negative fulfillment 'route' can be distinguished. It is assumed that whenever (enough) functions positively (+) reinforce each other, the system develops further<sup>4</sup>. In short, whenever enough positively fulfilled functions reinforce each other with the objective of realizing a circular production model, no governmental intervention is needed to accomplish a transition from a linear towards a circular production model.



**Figure 3** – Schematic representation of the development of an Innovation System.

<sup>4</sup> How many functions (or cycles) are 'enough' is not specified in TIS-literature. According to Negro (2007) a well-developing system is characterized by one or more positive cycles.

Negatively fulfilled (-) functions demonstrate that a systemic failure is active, which in turn blocks further system development. Hence, a relationship exists between the system functions and failures; failures are the underlying reasons for negatively fulfilled functions. The premise is that whenever (too many) functions negatively reinforce each other, this indicates that a system failure is present. In such a case governmental intervention is needed to drive the system development forward.

Empirical research should therefore focus on identifying the blocking dynamics, as they provide legitimate rationale for policymakers to utilize policy instruments. Figure 3 shows how the different system failures are 'boxed in' by policy instruments. This is meant to illustrate that these instruments can serve as tools for policymakers to diminish system failures that hamper further system development. If policy instruments are applied, and prove to be successful, failures are diminished and a transition from a linear to a circular production model can occur. For this reason the system structure and failure boxes are not directly connected in the conceptual framework (figure 3), because in a situation where no failures are present (because enough functions are positively fulfilled) system development occurs without the need for policy intervention in the system's structure.

The framework is solely meant to show the relationship between the different concepts, not to measure the extent of an Innovation System's development, i.e. percentage of circularity. In the next chapter it is specified how the conceptual framework is applied to study the factors – structure, functions and failures - that trigger or hamper the development of a circular production model in the Innovation System around the recycling and/or re-use of composites. Based on the identification of these factors, suitable policy instruments can be recommended to policymakers and Rijkswaterstaat.

## 3.0 Methods

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In order to provide an answer to the main question, the following sections are addressed in respective order: case study (3.1) research design (3.2), data collection methods (3.3), data analysis (3.4), research validity (3.5) and limitations (3.6).

### 3.1 Case study

This thesis focuses on the transition process from linear towards circular modes of production within the composites industry, by analyzing the Innovation System around the recycling and/or re-use of composites. It was, however, not possible to analyze this entire system within the timeframe of this research. Therefore a case study within the composites industry was selected (section 3.1.2). The purpose of the case study was to test the previously formulated conceptual propositions. To understand the rationale behind the case selection, first an extensive industry background is presented that examines the applicability of composite materials, sustainability aspects and demonstrated recycling technologies and re-use options (section 3.1.1).

#### 3.1.1 Industry Background

In many of today's modern industries, fiber-reinforced plastics play an important role in engineering, production, usage and education (Nijssen, 2015). These plastics, often referred to as composites, consist of at least two combined materials that work together to achieve enhanced results. Due to the specific properties of composites - high strength to weight ratio, corrosion resistive, rigid and a long lifespan - the material is increasingly used for specific purposes in aviation, automotive, maritime and wind-energy applications (Yang et al., 2012). Many of those applications have to deal with extreme weather conditions, and are therefore more compelling than materials such as aluminum and steel. Additionally, composite structures often have a lower Eco-footprint compared to alternatives. Lower emission can be allocated to lower weight in transportation, easier installation, longer lifespan and reduced maintenance (Dutch Polymers Institute, 2015).

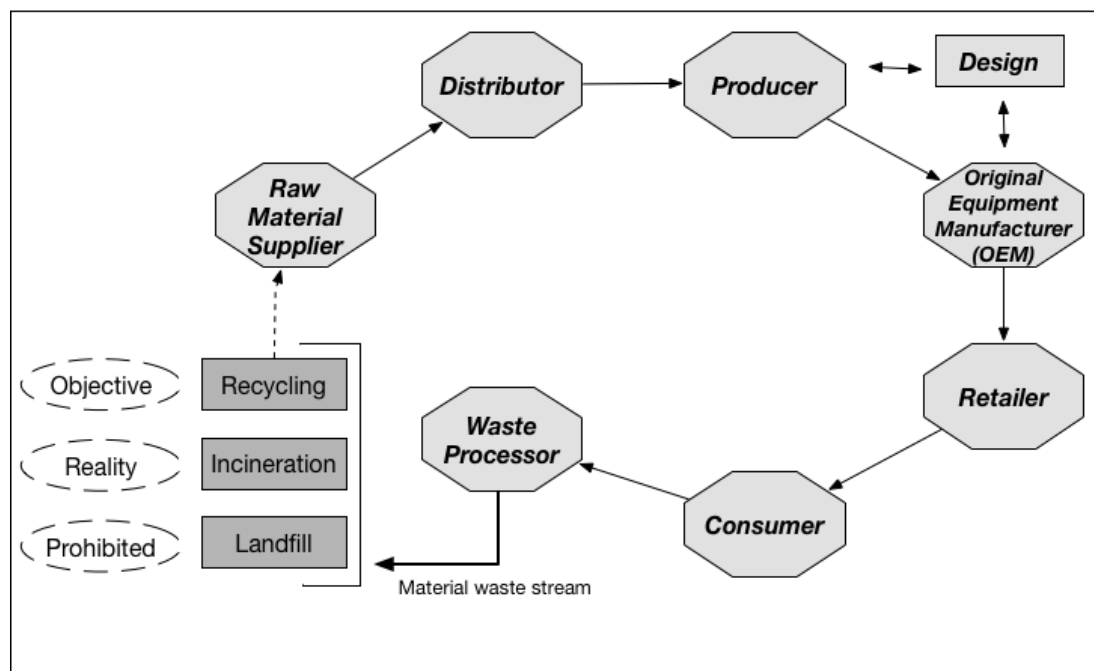
Several multinational corporations are increasingly using composite materials in various applications. 50% of the new Boeing 787 Dreamliner and Airbus A380 is made of carbon fiber-reinforced plastic, and the new BMW 'I' (electric) series consists of a carbon fiber frame (Ashby & Johnson, 2013). In the wind-energy industry, a market that is rapidly growing globally, mainly glass fiber-reinforced plastics are used to manufacture the rotor blades of wind turbines (in 't Groen, 2010). Glass is also the reinforcement material in composites that are used to construct the hulls of recreational and sports boats (Krishnamoorthi & Shinzhao, 2012). The use of composites in these upcoming applications implies that both glass and carbon fiber-reinforced plastics will be even more relevant in the near future. The focus of this thesis lies on the glass fiber segment of the composites industry, because glass fiber-reinforced plastics are the most prolific with a market share of 95% (Witten, 2012). The remainder of this section therefore concentrates on glass fiber-reinforced plastics, which are from now on referred to as 'composites' for the ease of the reader.

Despite the various advantages of composites, currently the usage of this material comes at a price. The fibers are ultimately derived from oil and the production process is rather energy intensive (Crook, 2014). Most importantly, however, is that the environmental

burden of the material is intensified in the end-of-life phase. While it is already difficult to recycle 'regular' plastics, end-of-life treatment of composites is even more complex. Composites are most often thermosetting materials. This means that, in contrast to thermoplastic materials such as plastic bottles and bins, thermoset composites cannot be remolded by heating (Pickering, 2006). Consequently, for a long time (thermosetting) composites has been perceived as non-recyclable, since the material is 'intractable by design' (McConnel, 2010). This is why most composites currently end up being incinerated or landfilled at the end of their lifespan (Cherrington et al., 2012; Miller et al., 2014; Dutch Polymers Institute, 2014; 2015).

These waste management options are, however, discouraged from an environmental perspective. Landfilling results in the loss of raw materials and the embodied energy content (Reynolds & Pharaoh, 2009). According to Halliwell (2006) energy recovery is also not lucrative from an environmental viewpoint. A typical composite product consists of 40% glass, 30% inorganic filler and 30% resin. The glass and the filler do not burn, so approximately 70% of the composite is left as a residue within an incineration plant. Because there are hardly posterior applications for this residue, this waste stream creates a problem on its own (in 't Groen, 2010). Various authors (e.g. Cherrington et al., 2012; Miller et al., 2014; Pickering 2006) have therefore suggested that, in order continue the use of composites in various applications; it is vital that the life cycle of composites moves from energy recovery and landfilling to material recycling and/or re-use, i.e. a circular production model.

To illustrate what such a life cycle would look like, figure 4 depicts a typical supply chain within the Dutch composites industry. The production of a product starts with the raw material supplier, which delivers the synthetic fibers. Then, via a distributor, the raw materials are processed into virgin composite. The production of a product starts with the raw material supplier, which delivers the synthetic fibers. Then, via a distributor, the raw materials are processed into virgin composite.



**Figure 4** – Circular production model for a composite product (Dutch Polymer Institute, 2014).



With or without help of a designer, the composite material is used by an original equipment manufacturer (hereafter, OEM) to produce an end product. Consumers subsequently buy the product from a retailer, after which it is used until the end-of-life phase. Currently, after the end-of-life phase, composite waste is incinerated because landfilling of composite materials is prohibited in the Netherlands (Dutch Polymer Institute, 2014). The objective is, however, to collect the composite material for recycling and/or re-use purposes, which allows the re-introduction of end-of-life materials at the start of the supply chain. Because this link is not operational in the contemporary linear production model, a striped arrow is used in figure 4. The different technologies that can provide this link between the end-of-life output of one process with input for another are elaborated below.

### **Demonstrated Recycling Technologies**

At present, there are several recycling technologies that can be used to regain value from composite waste materials: thermal, chemical and mechanical recycling processes (Meira Castro et al., 2014). These options are nevertheless still largely absent from the Dutch marketplace (in 't Groen, 2010). Several companies outside the Netherlands are, however, taking waste from the composite industry and turning it into marketable products (Job, 2014). That is, a recyclate of value for posterior applications, so that end-of-life composite waste can be re-used for other products, materials or substances. This does, however, not necessarily mean that these recycling processes - including operational and transportation costs - are commercially viable. Examples of contemporary technologies are presented in table 3.

Composite recycling by mechanical grinding is the most common and straightforward. It involves the breaking down of a composite by shredding, crushing or milling. This option does, however, damage and shorten the individual fibers, which has the disadvantage of reducing the material value for re-use purposes (table 3). This means the recyclate is of inferior quality, and cannot replace virgin material for the same application, i.e. down cycling (Reynolds & Pharaoh, 2009). Another disadvantage of this process is that the grinding machines require energy, and the recyclate can only be used to replace low grade and inexpensive commodities, i.e. filler materials such as sand and pebbles (in 't Groen, 2010).

Table 3: *Composite recycling technologies.*

<i>Process</i>	<i>Advantages</i>	<i>Disadvantages</i>
<b>Mechanical</b>		
<b>Grinding</b>	<ul style="list-style-type: none"> <li>• Recovery of both fibers and resin</li> <li>• No hazardous materials are used or produced</li> <li>• Relatively inexpensive</li> </ul>	<ul style="list-style-type: none"> <li>• Degradation of mechanical properties (short fibers) which result in lower value recyclate</li> <li>• Limited possibilities for re-use and remanufacturing (down grading)</li> </ul>
<b>Thermal</b>		
<b>Pyrolysis</b>	<ul style="list-style-type: none"> <li>• High preservation of mechanical properties (long fibers)</li> <li>• No use of chemical additives</li> <li>• High contamination tolerance</li> </ul>	<ul style="list-style-type: none"> <li>• Production of environmentally hazardous gasses (although less harmful than incineration)</li> <li>• High (incineration) costs</li> <li>• Thermal stress on recovered fibers, reducing the original strength (0-50%)</li> </ul>
<b>Co-processing (cement route)</b>	<ul style="list-style-type: none"> <li>• 30% energy recovery from resins and 70% as raw material input for cement</li> <li>• Endorsed by the European Composites Industry Association (EuCIA)</li> </ul>	<ul style="list-style-type: none"> <li>• Replaces sand, which is an inexpensive filler product in cement</li> <li>• Possibly influences hardening of cement</li> </ul>
<b>Chemical</b>		
<b>Chemical solvents</b>	<ul style="list-style-type: none"> <li>• High retention of fiber length and mechanical properties (long fibers)</li> <li>• Prospective of material recovery from resin</li> </ul>	<ul style="list-style-type: none"> <li>• Low contamination tolerance</li> <li>• Use of environmental hazardous chemicals</li> <li>• Discolorations</li> <li>• Reduced adhesion in later applications</li> </ul>

Source: adapted from Job (2014); Pimenta and Pinho (2011); Reynolds and Pharaoh (2009).

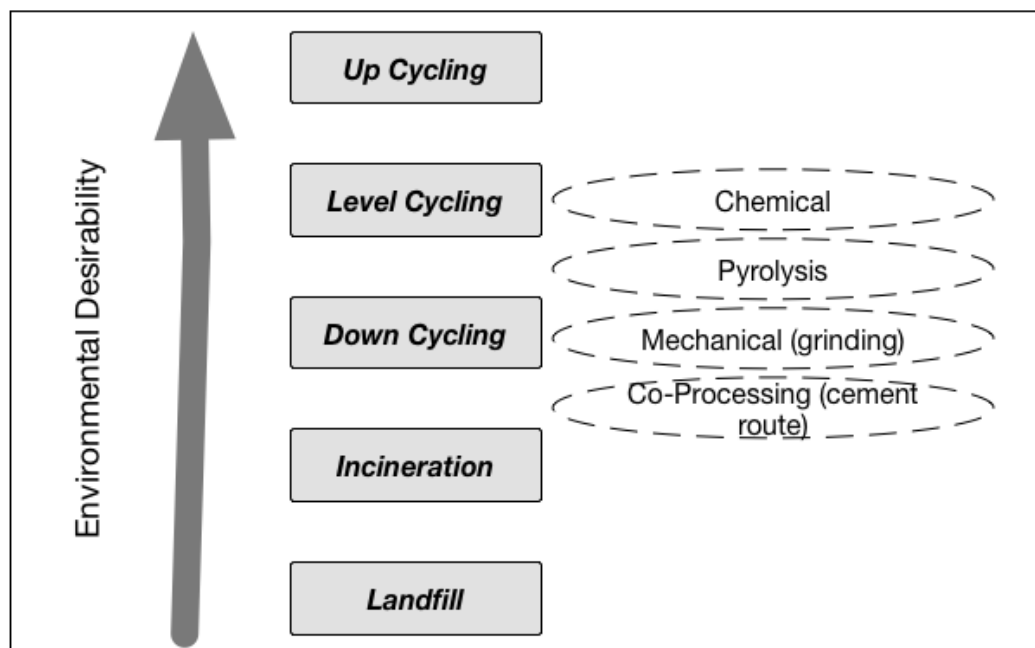
The most common thermal process, pyrolysis, involves heating composites in the (near) absence of oxygen. This technology offers several advantages: energy recovery from the resins and, in contrast to mechanical recycling, a relatively high preservation of the fiber strength (Pimenta & Pinho, 2011). On the other hand, typical composite materials require to be exposed to pyrolysis at 600°C; and are therefore subjected to high operating costs (Evans et al., 2000). In addition, because the composite is exposed to high temperatures, the mechanical strength of the recyclate can reduce up to 50% (in 't Groen, 2010).

Since pyrolysis can be energy intensive and thus costly, another technology is operational in Germany. With the co-processing method, which is endorsed by the European Composites Industry Association (EuCIA), two-thirds of the end-of-life composite is transferred into a raw material for cement production. The remaining one-third resin-based leftover is used for energy recovery. Because cement kilns normally use a high amount of coal, using composites offsets CO<sub>2</sub> emissions in cement production (in 't Groen, 2010; Krebbekx & Lintmeijer, 2015).



Lastly, the chemical recycling technology involves using chemical products that dissolve the polyester resin under room temperature. As a result of not being exposed to high temperatures, this method allows for high fiber strength retention (Morin et al., 2012). A drawback of this recycling process is the use of environmentally harmful and hazardous solvents, which on its own forms a waste challenge (Pimenta & Pinho, 2011).

To compare the different methods, Krebbekx and Lintmeijer (2015) provided an overview of the desirability of the various recycling technologies for composite waste from an environmental point of view (figure 5). A distinction is made between the least desirable options, i.e. landfilling and incineration, and various forms of material recycling: down-cycling, level-cycling and up-cycling.



**Figure 5** – *Environmental desirability of end-of-life solutions for composites* (Krebbekx & Lintmeijer (2015)).

As seen in figure 5, mechanical recycling and co-processing are forms of down-cycling; a process of converting end-of-life composite into recyclate for applications that require lesser quality and functionality. Examples of applications for this low-grade recyclate are: pavement blocks (Itoh & Kanenko, 2002) and raw material filler for cement (DSM, 2013; Halliwell, 2006). Pyrolysis results in a relatively higher-grade recyclate, and, depending on the remaining mechanical strength after being subjected to high temperatures, the recycled glass fibers can be used as reinforcement for plastic materials (in 't Groen, 2010). Chemical recycling provides the only opportunity of level-cycling, which means recovered composite materials can be used for the original purpose (Krebbekx & Lintmeijer, 2015).

### Material Re-use Examples

In case of an end-of-life situation, ideally, it is aimed to re-use the product for a next-life function (Krebbekx & Lintmeijer, 2015). In practice, there are only sporadic material re-use examples of composites. Applications are found in the use of end-of-life windmill blades as playground equipment and re-using boat hulls as sheds (see figure 6).



**Figure 6** - Examples of re-used composite windmill blades and boat hulls (European Commission, 2011; Krebbekx & Lintmeijer, 2015).

### 3.1.2 Case selection and system delineation

After the examination of the industry background, which demonstrated how various (composite) recycling technologies and material re-use options could provide a link between the output of one industrial process with input for another, this section turns to the selected case study. First a general sketch of the problem surrounding the case study is provided, followed by the urgency of a transition from a linear to a circular production model. Hereafter follows a description of how the system around the case study was delineated.

The case study of this thesis focuses on composite waste from recreational boats in the Netherlands. Recreational boats serve as a compelling case study, because in approximately 60-85% of the cases the hull of these boats is made out of composite (Cieniewicz & Parbleu, 2015; WaterrecreatieAdvies, 2014). In the Netherlands around 500.000 recreational boats are either afloat in harbors, canals and small ditches or stockpiled in storage boxes; containing 286.000 tons of composite materials (Waterrecreatie Advies, 2014). After a boom in the number of recreational boats in the '70s and '80s, this fleet and their owners are ageing. Because these recreational boats lack resale value, owners lack the interest or capacity to go boating or have financial difficulties, some of these boats end up abandoned in harbors or water networks (Nieuwenhuis, 2014). This is possible because it is not mandatory for boats to be registered in the Netherlands, which makes it difficult to trace an owner (Rijksoverheid, 2015a). Currently around 6.000 composite boats are in need of disposal and are awaiting an effective and attractive recycling or re-use regime<sup>5</sup>. It is expected that this number will increase to 12.500 in the next 5 years, 25.000 between 2020-2025, and 35.000 boats in the period 2025-2030 (Waterrecreatie Advies, 2014).

For Rijkswaterstaat, as the executive body responsible for implementing policies and regulations with respect the main waterway network and their waste, these recreational boats represent an urgent environmental problem (Rijkswaterstaat, 2015d). When left in the water, the composite hull of a boat can disintegrate into microbeads, which has devastating effects on marine organisms and can also eventually end up in the human

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<sup>5</sup> Technically, these recreational boats are often not at the end-of-life phase. Due to the long lifespan of composites, these recreational boats rather reach an *end-of-use* phase. Because composite boats currently have a negative economical value, which means that end-of-life treatment is more costly than the total value of the boat, owners want to dispose of the boats (WaterrecreatieAdvies, 2014).

food chain (Al Abbar, 2015). In addition, abandonment of these recreational boats can lead to environmental risks related to battery, fuel and oil leakages (Cieniewicz & Parbleu, 2015). According to Nieuwenhuis (2014) sustainable dismantling and recycling of these boats is the only option to avoid serious environmental damage. However, due to the durability of composite boats, until recently there has been no need for a system that enables organized material re-use or recycling (Cieniewicz & Parbleu, 2015).

On 16<sup>th</sup> November 2015, at the Future of Yachting Recycling Conference in Amsterdam, the president of the Marine Industry Association argued that the boating industry is due for a wake up call on this issue; and stated: “*The linear take, make, dispose model is over, we need to move to a circular economy*” (Demaria, 2015:3). This statement emphasizes the urgency of a transition from a linear to a circular production model for composite boats. Despite this and similar calls for action (e.g. Marsh, 2013), recycling and/or re-use of composite boats remains problematic in most countries. There are however countries, such as France, Sweden and Norway, that already have a dismantling and disposal scheme in place (Dragland, 2011). In the last two countries, leading waste processors are now cooperating with small commercial boat recycling companies to build a system for boat and yacht recycling (Sweboat, 2015). Because such a system is not present in the Netherlands, but its feasibility has been demonstrated in other countries, the case study of this thesis concentrates on the Innovation System around the recycling and/or re-use of composite boats.

Summarizing, the case study revolves around recreational boats made from the most prolific fiber in the composites industry: glass fiber-reinforced plastic. For these boats a linear make-take-dispose model is currently operational, which means that there is no option to recycle and/or re-use the composites components of a boat. Because of the recognized urgency to move from a linear to a circular production model, the development in the Innovation System around the recycling and/or re-use of composite boats serves as a compelling case study for the purpose of this research.

This system, which will be referred to as the ‘recreational boating system’ in the remainder of this thesis, includes all the relevant components - actors, institutions, infrastructure and networks - that are involved in the production, use, collection, recycling and/or re-use of composite boats within the Netherlands. The analysis was performed in the period 2015-2016. How this system was analyzed is further elaborated in the sections below.

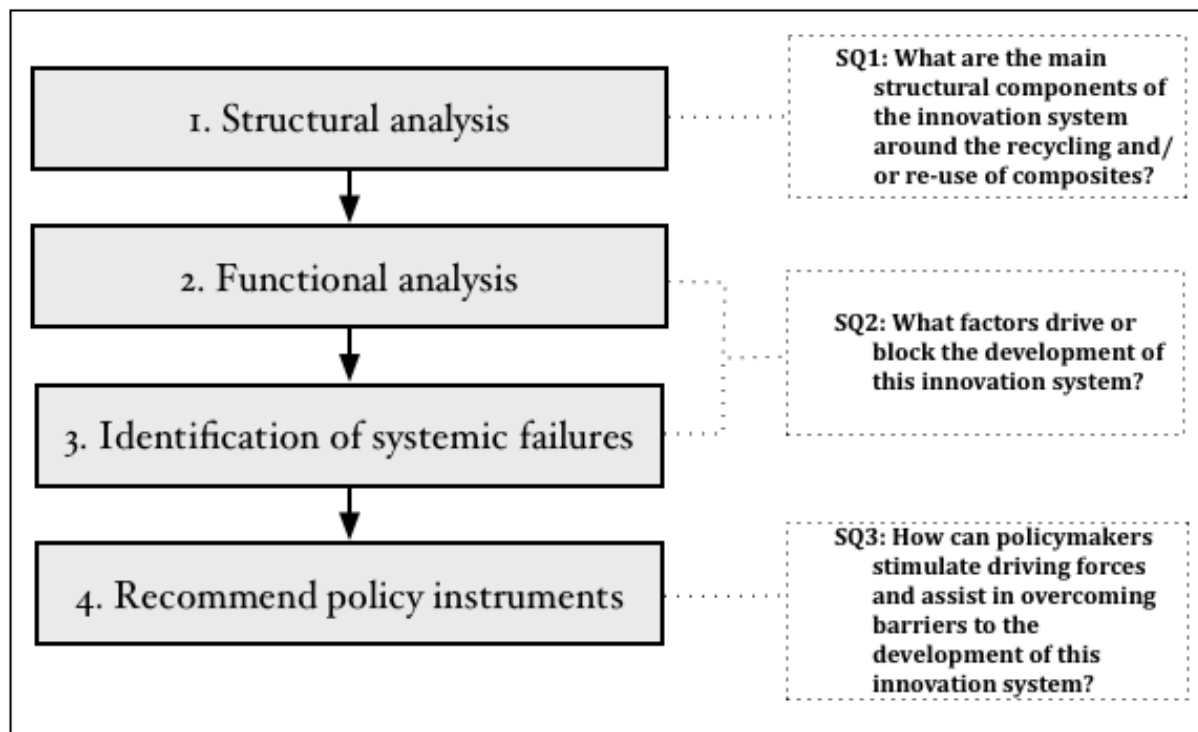
### 3.2 Research Design

A case study approach allows identifying problems and subsequently provides recommendations for further investigation (Gable, 1994). By selecting the recreational boating system as a case within the Innovation System around the recycling and/or re-use of composites, problems regarding the development from a linear to a circular production model were analyzed. The steps that were followed are outlined below.

First, in order to make a ‘snapshot’ of the contemporary recreational boating system in the period 2015-2016, the structural components that are involved in the innovation system were mapped. With this *structural analysis* (step 1) an overview of all the relevant actors, institutions, infrastructure and networks of the analyzed innovation system was obtained. Once the structure of the system was understood, it was subsequently assessed how these structural components function; and whether this is

sufficient to further develop a circular production model. These key processes, defined as system functions, were examined in the *functional analysis* (step 2) to complement insights from the structural analysis. During this step it was evaluated which system functions, as described in section 2.2, are positively or negatively fulfilled. In this way it was determined how each individual function performs, thereby allowing for the identification of drivers and barriers that influence system development. The underlying reasons for the functional barriers, the system failures, were hereafter defined (step 3). Together, the outcomes of steps 2-3 served as the justification for recommendations to policymakers in order to stimulate driving forces and assist in overcoming barriers to the development of the innovation system (step 4).

Figure 7 presents a schematic depiction of the step-by-step process that was adopted to provide an answer to the main research question, by addressing the three sub-questions.



**Figure 7** - Visualization of step-by-step research method (Bergek & Lindmark, 2008; Hekkert et al., 2007; Jacobsson & Bergek, 2011; Luo et al., 2012; Wieczorek & Hekkert, 2012; Wieczorek et al., 2013).

### 3.3 Data Collection

For this thesis, two different methods of data collection were used. Desktop research, 3.3.1, was used to map the relevant structural components (step 1). Semi-structured interviews, 3.3.2, were conducted in order to collect data for the functional analysis and for the identification of system failures (steps 2-3). Semi-structured interviews were most suitable for the data collection purposes of the second and third step, because interviews permit addressing pre-determined issues, while also allowing for clarification and follow-up questions (Leedy & Ormrod, 2005). In doing so, relevant data on the factors – system structure, functions and failures - that drive or block the development of the system was collected, while also allowing the interviewees to provide recommendations.

### 3.3.1. Desktop Research

For the purpose of gathering an overview of the recreational boating system's structure – i.e. actors, institutions, infrastructure and interactions - data was collected through desktop research. To map the relevant actors, the company index of the association for plastics and composites ("VKCN") and the company index of the yachting industry in the Netherlands were consulted (JachtbouwActueel, 2015; VKCN, 2015). Every company in the VKCN (2015) index that is referenced to as in the boatbuilding and yachting industry was included. Additionally, every company in the JachtbouwActueel (2015) index that is connected to composites was incorporated in the actor list (see appendix E). Through these databases it was possible to distinguish between the different actors in a boatbuilding supply chain: raw material suppliers, composite producers and Original Equipment Manufacturers (OEMs), engineers and designers, dismantlers, waste processors and knowledge institutes and consultants. Although this database is relatively complete, whenever a new and relevant actor was identified during the research process, this company name was added to the list in appendix E.

To complement this actor database with institutions, infrastructure and interactions, data was also gathered from grey literature such as: professional magazines, industry reports, press articles and working papers. The use of grey literature was necessary to find a reasonable amount of literature and data, because academic publications alone (accessed via Google Scholar and Scopus) provided insufficient information.

### 3.3.2 Semi-structured Interviews

In-depth, semi-structured interviews were conducted to complement the desktop research by gathering information for the functional analysis. This was done by a set of interview questions that stem from the seven system functions that were derived from TIS-literature (section 2.2). An overview of the interviewees and posed questions is provided in appendix D.1 and D.2 respectively.

By interviewing 12 relevant actors with diverse roles in the recreational boating system, it was aimed to generate the most comprehensive overview. At least one interview was conducted per relevant actor category, as outlined by Wieczorek & Hekkert (2012) in section 2.1.1. Eventually this resulted in interviews with the following actors: governmental bodies (1), support organizations (2), industrial actors (8) and knowledge institutes (1). Most interviews were conducted with industrial actors, because it was aimed to interview a set of actors with a very diverse position in the supply chain of composite products (see figure 4). In doing so, it was intended to conduct interviews with respondents that differ in experience and knowledge in the research topic. Ultimately the following industrial actors were interviewed: raw material suppliers (2), OEM/producers (2), waste processors (2) and (prospective) recyclers (2). This means that of all industrial actors that add value to a composite product, thus excluding distributors, consumers and retailers, at least two interviews were conducted per role in the boat-building supply chain (figure 4). Due to this diversity it was, however, not always possible to use a standardized set of interview questions.

The interviews, which ranged from one to two hours, were conducted in a face-to-face setting. Whenever the situation occurred that interviewees were unable to meet in person, the interview was conducted via Skype. During the interview minutes were made and, when approved, digitally recorded. The interview questions were set-up to



gather data on: the activities per function in relation to recycling and/or re-use of composite boats. How these ultimately functions were assessed is discussed in the next section.

At the end of every interview, the interviewee was requested to assess the performance of each function; and evaluate whether this function forms a barrier for the development of a circular production model. This was done by means of a survey form with a 5-tier scale - ranging from very weak (1) to weak (2), moderate (3), strong (4) and very strong (5). The used evaluation form is presented in appendix D.2. The interviewees were additionally invited to provide recommendations on what should be done in order to facilitate further system development, what the role of the government is in this process and what Rijkswaterstaat can do in particular.

### 3.4 Data Analysis

Gathered data through desktop research and semi-structured interviews served as input for the structural analysis (step 1), the functional analysis (step 2) and the identification of system failures (step 3).

#### **Structural analysis**

In the structural analysis all relevant actors, institutions, infrastructure and networks for the development of a circular production model in the recreational boating system were described. The structure gives insight into who is active in the system, by presenting an extensive overview of: the industrial actors within a boatbuilding supply chain; knowledge and educational institutes; support organizations; (inter)national laws and regulations; the social acceptance of recycling and/or re-use activities; an indication of the number of recreational boats; the physical boat-disposal infrastructure; and grants and subsidies for the knowledge infrastructure. The structural analysis was merely meant to provide an overview of the recreational boating system, without the intention of assigning measurement values to the performance of this innovation system.

#### **Functional analysis**

During the functional analysis it was examined *how* the recreational boating system is performing with respect to the development of a circular production model. The functioning of this innovation system was assessed by asking the interviewed stakeholders specific questions to evaluate whether: the activities related to recycling and/or re-use of composite boats are sufficiently developed per function, or whether these functions form an obstacle for the development of a circular production model (see interview questions in appendix D.2). In case an interviewed stakeholder suggested that a particular function is insufficiently developed to move recycling and/or re-use activities in the system forward, it was subsequently asked what specific barrier(s) block this function from performing well. A similar approach was adopted for identifying drivers. In this way it was possible to distinguish what specific drivers and barriers are present that stimulate or block the development of a circular production model in the recreational boating system.

In order to be able to compare the functional performance of the seven key processes, the interviewed stakeholders assigned a score to each function. Thereby every function was rated, which eventually resulted in a final performance score - the average of the

individual scores from the 12 interviews – for each function. Consequently every function was considered: very weak (0-1), weak (1-2), moderate (2-3), strong (3-4) or very strong (4-5). Although the performance scores were not meant to definitively label which functions are positively or negatively fulfilled, a comparison of the performance scores does indicate which functions need to be strengthened to ensure further development of the system. This means that no specific boundary was defined, for instance a score of 3,5 or higher, to demarcate whether a function is positively or negatively fulfilled. Rather, the fulfillment was assessed in terms of comparative performance; the functions with the lowest performance scores were perceived as most problematic. In this way it was possible to distinguish deficient functions and subsequently determine where policy intervention is likely to matter most.

This ranking process also helped establishing at what development phase the recreational boating system is; namely, according to Luo et al. (2012) functions 1-3 are expected to be positively fulfilled (score relatively high) in early stages of the system development, whereas functions 4-7 are expected to be negatively fulfilled (score relatively low). Functions that are negatively fulfilled, for example those functions with a final score of very weak or weak, are a sign that system failures are present which block further development of a circular production model.

### Identification of system failures

The outcome of the functional analysis was that a number of specific barriers were identified which prevent a deficient function from performing well, and therefore hamper the development of a circular production model. To know the underlying reasons for these obstacles, broader systemic problems that cause the functional barriers were defined. To do so, all interviews were transcribed to allow this thesis' author to code the semi-structured interviews. In appendix C (table 9) a list of indicators is presented that shows how, by means of using specific indicators and keywords, functional barriers were linked to broader systemic failures. NVivo10 served as a tool to code and categorize the system failures from the transcribed interviews. NVivo10 therefore allowed the interview data to be organized efficiently, help recognize relationships and assist in analyzing the results.

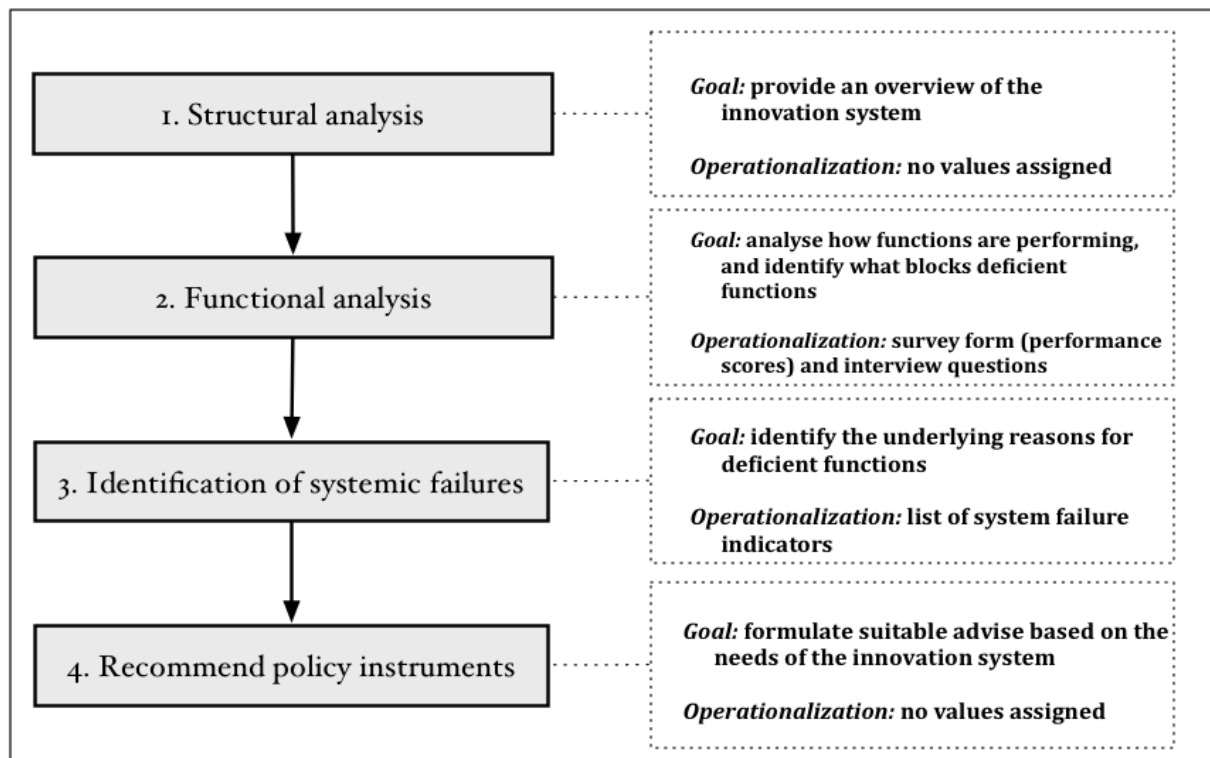
An example of the coding procedure follows hereafter. For instance, whenever an interviewee mentioned: *"Without a shared vision to back the boating industry, the government does not stimulate the search for solutions"*, according to the list of indicators in table 9 this was labeled as a 'directionality failure'. The underscored parts of the statement were linked to the following keywords: no shared vision and lack of direction to identify this specific system failure. For all other functional barriers a similar approach was adopted. It must be noted that the used keywords just serve as suggestions; recognition of synonyms for keywords or implicit references to an indicator were open to the subjective interpretation of this thesis' author.

### Recommendations to policymakers

Based on the aforementioned analyses, suitable policy instruments on how to simultaneously overcome the identified negatively fulfilled functions and system failures were recommended to policymakers. This was a rather straightforward process, in which broader systemic weaknesses were linked to the associated policy instruments (as outlined in section 2.4).

In short, to assess the development of the Innovation System around the recycling and/or re-use of composite boats, four steps were taken. In the first two steps the system structure and functions were mapped. After establishing the phase of development and identifying functional barriers that lead to negatively fulfilled functions, in step 3 the underlying reasons for these deficient functions were identified. Together these main barriers provided handholds for recommendations to policymakers.

Figure 8 provides an overview of the operationalization scheme that summarizes the goal of each taken step. It is subsequently described how these goals were measured and/or identified.



**Figure 8 – Operationalization scheme.**

All in all, a combination of figures 7 and 8 show the link between the main research question – divided in three sub questions – and the operationalization of how the functions and system failures that drive or block the development of the recreational boating system were measured and/or identified. Thus, by addressing all the sub-questions, the selected method of analysis was therefore suitable for answering the main research question.

### 3.5 Research method Validity & Reliability

This section addresses the internal validity, external validity and reliability of this thesis' methods. The internal validity, which refers to the confidence in the robustness in the findings (Bryman, 2012), can be influenced by data collection quality, choice of interviewees and interview structure (Saunders et al., 2007). To address the former concern, present research combined methodological and data triangulation – the use of multiple methods and sources to collect data in a study (Decrop, 1999). This included a combination of desktop research with semi-structured interviews to gather data on the



development problem, to subsequently analyze this data from different angles to strengthen the research findings. The use of multiple data collection and methodological methods to examine one issue assisted in verifying the empirical findings and enhanced the internal validity of the data (Denscombe, 1998).

To address the interviewee selection issue, a set of actors with diverse roles in the system was interviewed. In doing so, it was intended to offer a comprehensive sample that is representative of the entire Innovation System around the recycling and/or re-use of composites. Lastly, with regard to the interview structure, all the posed interview questions were directly linked with this thesis' main and sub-questions. Moreover, to ensure that all aspects of the topic were covered, key decisions about the interview set-up (and throughout the entire project) were discussed with both University and company supervisors.

External validity refers to the degree to which the findings of this thesis can be generalized outside the research setting (Guala, 2003). In order to address this issue, a case study was chosen that is typical of the targeted system. As explained in section 3.1.2 it was aimed, by selecting the recreational boating system, to pick a case study that faces a challenge that is representative of the entire Innovation System around the recycling and/or re-use of composites. In this way it was thus intended to enhance the generalizability of the findings.

The reliability of the methods means to what extent the findings can be replicated whenever another case study is undertaken using the same research methods (Ritchie & Lewis, 2003:44). To support other researchers in understanding the methods that were used during this thesis, it was intended to be fully transparent with respect to the research design, explicit guidelines and sequence of steps (see figures 7 and 8) that were followed throughout this project. Showing how these procedures led to the conclusions of this thesis increase the probability that other researchers can replicate present study to verify the findings.

### 3.6 Method Limitations

Despite the best efforts to ensure a comprehensive set of collected data, Patton (2002) argued that consulted documents might have limitations regarding the accuracy and completeness of the data. Indeed, data that was gathered during the desktop research part was limited to information that is freely accessible online. This also meant that, due to the rather specific scope of this thesis' case study, the variety of up-to-date sources and the number of available documents was limited.

Next to data gathering and accuracy limitations of desktop research, the use of complementary interviews may also influence this thesis' validity. Limitations that can occur due to the nature of semi-structured interviews are: participant bias, participant error, observer bias and observer error (Saunders et al., 2007).

A participant bias can occur when interviewees do not feel confident to give honest answers. To address this matter, whenever desired, interviewees were ensured anonymity and that data is treated confidentially. Participant errors, which may for example occur when limited time is available for the interviews, were addressed by communicating the expected duration of the interview beforehand.

An observer bias refers to the researcher's interpretation of the interviews. To minimize this bias, findings were discussed with both University and company supervisors. The observer error, which can occur when a study is performed by multiple researchers, was non-existent due to the fact that this thesis was carried out individually. It is, however, possible that translation (the interviews were conducted in Dutch) affected the original meaning of the interviewee and thereby the interpretation during analytical stages of this thesis.

As described in the preceding section, a number of measures were undertaken to increase the reliability of this thesis. A perfect replication of the semi-structured interviews in particular is, however, very difficult to accomplish. For example, assigning a performance score to a specific function (see appendix D.2) at the end of each interview is prone to some kind of subjective interpretation. So, whenever different stakeholders are interviewed in other studies that run the same research design, the outcomes may possibly differ.

## 4.0 Findings

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In this chapter the main findings of this thesis are presented. In order to provide an answer to the first sub-question, the findings of the structural analysis are presented in section 4.1. Next, the main findings with regard to the second sub-question are shown in the functional analysis (section 4.2) and the identification of system failures (section 4.3). Then, based on the identified needs of the recreational boating system, in section 4.4 suitable policy instruments are recommended to policymakers in order to address the last sub-question.

### 4.1 Structural analysis

A TIS contains four types of structural components: actors (section 4.1.1), institutions (section 4.1.2), infrastructure (section 4.1.3) and interactions (section 4.1.4). This chapter outlines these structural components for the Innovation System around the recycling and/or re-use of recreational composite boats in the Netherlands.

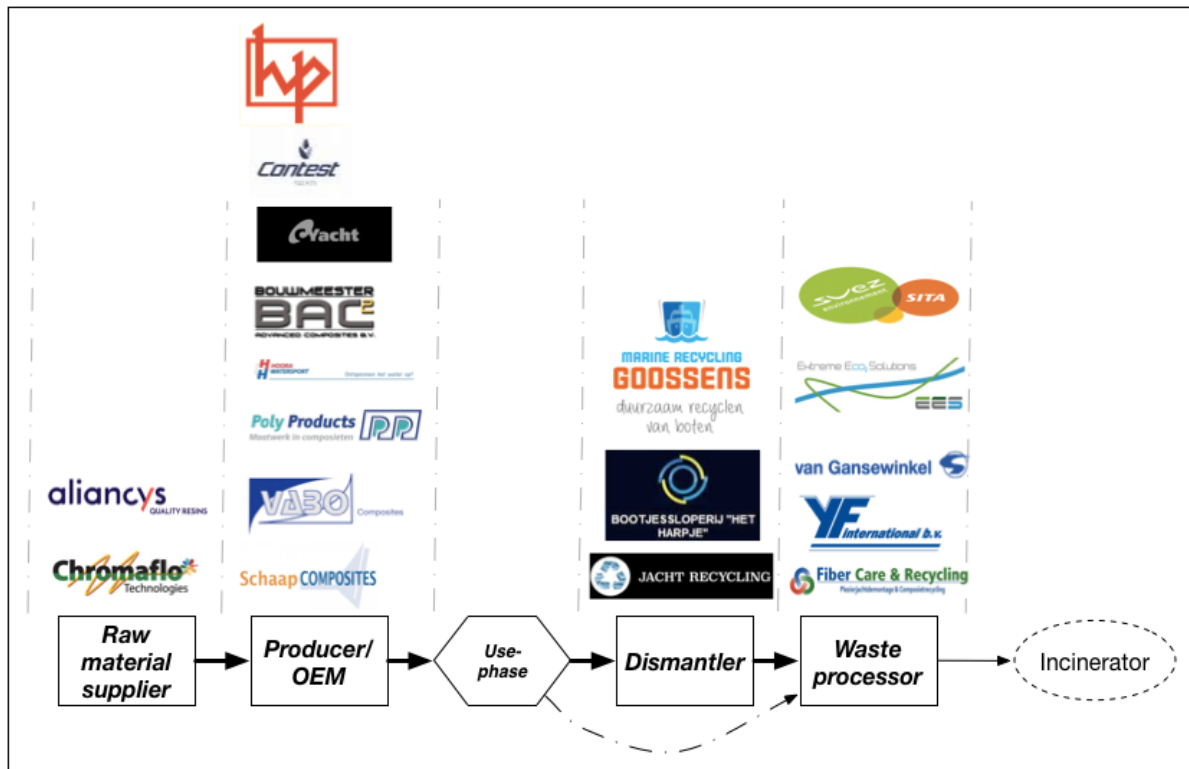
#### 4.1.1 Actors

According to the HISWA (2014), the aquatics industry association, the Dutch recreational boating market currently employs 20.300 people in over 4.200 companies. These employees and companies are, however, not all working with composite boats. In this section it is therefore analyzed which actors are involved in the recreational boating system in the Netherlands.

#### Industrial Actors

Due to the various applications of composites in different markets, like maritime, aerospace and wind-energy, a very dispersed composites industry emerged (VKCN, 2006). Within these markets consumers have different performance requirements and cost restrictions. For example, the performance and cost specifications for aerospace applications are dissimilar to requirements for recreational boats. Consequently there are many small and medium sized enterprises (hereafter, SME) active in each specific niche market of the composites industry. This is also the case for the recreational boating system.

To illustrate the contribution of key industrial actors, figure 9 depicts the contemporary linear supply chain of a recreational boat. In total there are 295 registered industrial actors involved in the contemporary linear production model (see appendix E for an overview). The arrows indicate the direction of the composite material throughout the supply chain. Compared to the depicted circular production model in figure 4, the actors that are responsible for transport, distribution or retail are left out because these actors do not add value to the end product. In addition, since many composite producers are also boat builders (i.e. OEMs), these industrial actors are merged in figure 9.



**Figure 9** – Composite boatbuilding supply chain (Dutch Polymer Institute, 2014).

The supply chain of a composite boat starts with the raw material supplier, originating from the chemical industry. This industry is characterized by a small number of multinational corporations, which operate with economies of scale and on a global level (VKCN, 2006). One example is Alicancys (the new name for 'DSM composites' since January 2016), a company with 450 employees worldwide (DSM, 2016).

On the other hand, the company profile of the producers/OEMs is entirely different. In the Netherlands there are currently 270 industrial actors<sup>6</sup> involved in the production and construction of composite boats (Ministerie van Sociale Zaken en Werkgelegenheid, 2013). The companies are often family owned and, by the definition of the EU, these actors mostly fall in the category of small and micro companies, i.e. <50 and <10 employees respectively (European Commission 2015b; VKCN, 2006). Out of the 270 shipbuilders, 77% have less than 10 employees and 23% between 10 and 99 employees (Ministerie van Sociale Zaken en Werkgelegenheid, 2013). The fact that these OEMs have relatively little employees can be allocated to the fact that recreational boats are mostly tailor-made and appear in all shapes and sizes (WaterrecreatieAdvies, 2014). Van der Woude (personal communication, 2015) reasons that, unlike in the car industry, recreational boats are not made in series of mass production, which generates a market with a diverse set of producers.

After the use phase of recreational boats, two disposal routes are available for boat owners. It is possible to hand-in the boat directly at the waste processor, or to make use

<sup>6</sup> In the absence of precise statistics, it is assumed that the total amount of recreational shipbuilders (OEMs) that work with composites is in proportion to percentage of glass fiber reinforced plastic boats - i.e. 72,5% (average of 60-85%) of 373 (Ministerie van Sociale Zaken en Werkgelegenheid, 2013; WaterrecreatieAdvies, 2014).

of a 'boat dismantler and recycler'. In case of the latter option, a specialized firm strips the valuable materials of the boat first. Hereafter the invaluable components, like the composite hull, are eventually also transported to the waste processor. As depicted in figure 9, there are currently three micro collection and dismantling firms (<10 employees) that hand-in composite waste from recreational boats at a waste processor (see appendix E.1).

These waste processors currently have no sustainable removal or recycling methods for composites. As a result, the material is incinerated together with other residual waste (Waternet, 2014). Waste processors are, like the raw material suppliers, generally large and internationally operating firms. Examples of such incumbents – i.e. large companies with a stable position in the market - are: van Gansewinkel, SITA (GDF-Suez) and Icovia (see appendix E.1). Only recently two prospective composite waste recyclers have been added to this list. FiberCare & Recycling is aimed at the recycling of recreational boats and ExtremeEcoSolutions focuses on composite waste streams in general. According to van der Woude (personal communication, 2015) these firms are, however, still in the experimentation phase and have no operational factory yet.

In summary, the contemporary linear supply chain is relatively complete with a variety of experienced industrial actors and start-ups. Alongside the incumbents, a large number of relatively small producers/OEMs are present that manufacture the composite boats. The interplay between start-ups and incumbents is relevant for the development process of the innovation system. Hockerts & Wüstenhagen (2010) argued that in the early stages of an industry's sustainable transformation, small start-ups are more likely to pursue sustainable entrepreneurial activities than incumbents. The incumbents then tend to follow; although these large companies are often less ambitious, the extent of their influence is often broader due to an established market presence (ibid.).

### **Knowledge and Educational Institutes**

To resolve the issue of composite waste, new knowledge has to be developed. The purpose of this section is to distinguish the main knowledge and educational institutes that study solutions for composite waste from recreational boats. The knowledge development that is relevant for recreational boats is, however, not restricted to educational programs in the boatbuilding market. For instance, it can be useful to cross-over know-how and expertise that is developed for wind-energy applications; to prevent that each market within the composites industry 're-invents the wheel' (Dutch Polymer Institute, 2014). Table 4 presents a list of the different knowledge institutes and educational organizations that offer courses devoted to composite development in the Netherlands.

Table 4: *Overview of knowledge and educational institutes devoted to composite development.*

#	Company	Location
2	TU Delft	Delft
2.	Universiteit Twente	Enschede
3	Instituut voor Composietontwikkeling (ICO)	Emmeloord
4.	Noordelijke Hogeschool Leeuwarden, Kenniscentrum Jachtbouw	Leeuwarden
5.	Windesheim Flevoland	Almere

Source: adapted from VKCN (2015).

At the academic level, two organizations offer courses: TU Delft and the Universiteit Twente. None of the courses do, however, specifically focus on recreational boats. This was to be expected, since higher education generally offers a more holistic perspective on such issues (Maclean & Wilson, 2009). Both universities offer bachelor, master and PhD tracks with respect to composite properties, functionality and sustainability in a variety of market segments such as: maritime, wind-energy and automotive. This ensures that knowledge is distributed over similar fields with different applications (Dutch Polymer Institute, 2014).

Vocational education at HBO- and MBO- levels is, on the other hand, more explicit. The Noordelijke Hogeschool Leeuwarden, shown in table 4, specifically focuses on technical innovations and process optimizations within the field of boatbuilding (NHL, 2016). This also includes a specific course on the use and re-use of composites. At another Dutch Hogeschool (Windesheim), lecturer van der Busschen (personal communication, 2015) confirmed that recycling issues of recreational boats have also been treated in the curriculum. This shows that the topic of recycling and/or re-using composite waste from recreational boats is not unfamiliar at both knowledge and educational institutes. Whether sufficient knowledge is available to develop the system is more closely examined in the functional analysis (F2, knowledge development) in section 4.2.

### Support Organizations

Support organizations are all actors that are not covered in the categories discussed above, but are in some capacity relevant for the structure of the recreational boating system. This is a rather broad category, so only a few relevant public and private actors that were encountered during the progress of this thesis are mentioned below.

There is a number of specific support organizations devoted to recreational boats, each dealing with separate issues (see appendix E). WaterrecreatieAdvies, a consultant in the field of recreational watersports, estimated how many boats are currently afloat in the Netherlands. Based on the average age of these boats, the report projects how many composite boats require to be dismantled and recycled in the next 15 years (WaterrecreatieAdvies, 2014). Another consultant is BiinC, a private company that supports in identifying new business opportunities for composites. This ranges from the development of new products to advice on end-of-life solutions for composite waste (BiinC, 2015).

In the public sphere, Rijkswaterstaat and local municipalities fulfill an important role in the system structure. Rijkswaterstaat is responsible for the management and maintenance of the Dutch waterways and water systems, i.e. the location of most boats. Municipalities are responsible for the areas that border the waterways, such as the shore and wharfs.

In sum, there are various knowledge and educational institutes at multiple academic levels that devote attention to the recycling and/or re-use of composite boats. Also in the realm of private organizations, several specified consultants are involved with the issues that surround waste management of composite boats. In the public sphere governmental bodies, such as Rijkswaterstaat and local municipalities, are also relevant actors within the contemporary system. Although this list of support organizations is far from complete, it gives a general sense of other players besides the already discussed industrial actors.

#### **4.1.2 Institutions**

##### **4.1.2.1 Hard institutions**

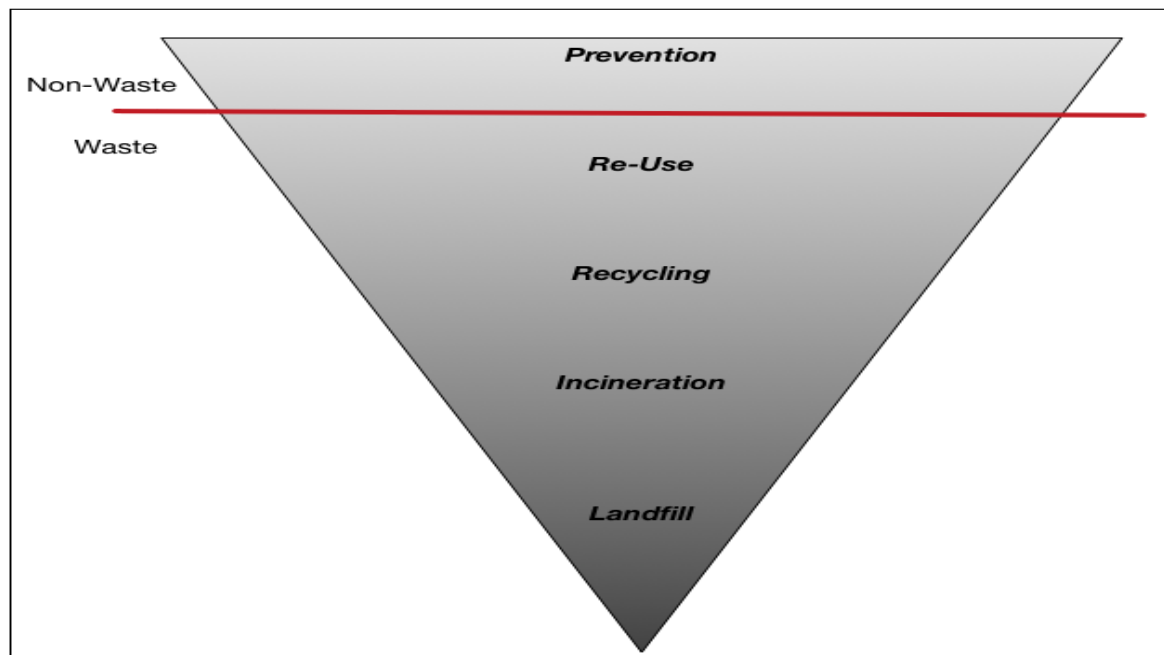
To ensure that composite waste from recreational boats is managed, regulatory instruments are important tools to control environmental issues. These laws and regulations influence the behavior of citizens and businesses, and demarcate what activities are permitted and which are illegal (McManus, 2009). Below follow (inter)national legislative instruments that are relevant for composite waste from recreational boats in the Netherlands.

##### **European Union Directives**

According to Cherrington et al. (2012), the European Union (hereafter, EU) has driven 95% of the environmental legislation in individual member states in the last 10 years. In case of recreational end-of-life boats there is, however, no regulatory framework across Europe.

Although the EU directs no specific legislation at composite materials from boats in particular (Witten, 2012), there are several directives that could potentially impact the management of recreational boats in the Netherlands. Examples of such directives are the Waste Framework Directive (2008/98/EC) and the 'Circular Economy Package' (Halliwell, 2006). The former provides an overarching legislative framework for collection, transport, recovery and disposal of waste (European Commission, 2015c). This is presented in the shape of a waste hierarchy, as depicted below in figure 10.





**Figure 10** – *Waste Hierarchy* (European Commission, 2015c).

The cornerstone of this directive is the focus on the hierarchy of material prevention (reducing), re-using, recycling, energy recovery and landfill as a last option (European Commission, 2015c). In addition to this directive, on 2-12-2015, the EU adopted a 'Circular Economy Package', which established a concrete plan of action, including measures focused on: everything from production to consumption, waste management and the creation of a market for secondary raw materials (European Commission, 2015a). Consequently the following new long-term targets for waste management, landfill and material re-use were established (European Commission, 2015c):

- A common EU recycling target of 65% for municipal waste, and 75% for packaging waste by 2030;
- The promotion of economic incentives to reduce landfill to a maximum of 10% of all waste by 2030;
- The promotion of concrete measures that stimulate re-use and industrial symbiosis – to turn one industry's waste products into raw materials for another industry.

As these targets present general objectives, no product specific aims related to composite waste from recreational boats are revealed. While the first two long-term targets propose specific recycling rates and economic incentives to reduce landfill, these objectives are unlikely to influence the disposal and processing of composite waste from recreational boats. At present, recycling rates are 88% and only 2 to 3% of its waste goes to landfill in the Netherlands (Rijkswaterstaat, 2015e). So, the entire Dutch waste management system is already far ahead of the proposed targets, which does not put additional pressure on the recreational boating system to develop a circular production model.

The national implementation of the Circular Economy Package – *Waste to Resources* ("Van Afval Naar Grondstof") – focuses mostly on the third EU target; the use of end-of-life materials to serve as raw material input at the start of the supply chain (Ministerie



van Infrastructuur en Milieu, 2013). Similar to EU legislation, in this national programme there are no references to the use of composite waste from recreational boats or composites in general. These Dutch policies do, however, show a level of government commitment and reliability of policy towards the development of a CE in specific sectors and for explicit products.

### Dutch Legislation

As previously mentioned, at the national level there are no specific policy procedures to stimulate recycling and/or re-use of composites. There are, however, two laws that aim to regulate the amount of recreational boats that end up abandoned in the natural environment. Namely, the *Wrakkenwet* and *Registration Fast Motorboats* (“Registratie Snelle Motorboten”).

In the *Wrakkenwet*, originated in 1885, a shipwreck is defined as (freely translated): ‘*A ship or vessel, stranded or sunk in open water, ran aground or stuck in water management structures*’ (Al Abbar et al., 2015). In case the shipwreck represents a problem for the administrator – i.e. the person or organization responsible for the maintenance, monitoring and security of a specific waterway - the *Wrakkenwet* states that an administrator is eligible to remove the vessel, and transfer the removal costs to the boat’s owner (Nab, 2007). In the contemporary situation surrounding recreational boats, this legislation poses several deficiencies. Firstly, the law is only applicable whenever a boat complies with the previously mentioned definition; which excludes boats that are not stranded, sunk or stuck. In addition, it can be unclear who the administrator is: a recreational boat can for example be located partly on the shore or connected via an anchor to a wharf. Since the waterway and the shore/wharf have different administrators, this creates ambiguity about who is responsible for the removal of a boat. (Nab, 2007). And lastly, the *Wrakkenwet* does not define that the owner of a recreational boat should get rid of the vessel in a responsible way. There is for instance no specific prohibition on dumping or sinking boats.

The lack of responsibility for boat-owners stems from the *Registration Fast Motorboats*. Under this regulation, registration is only obligatory for yachts and boats that have the following characteristics: shorter than 20 meters in length and faster than 20km/h. Owners of a boat that fits this description are required to register and, similar to cars, are forced by law to display a license plate (Rijksoverheid, 2015a). As a result, the owner is by definition unknown for boats that do not fit into ‘fast motorboat’ category. An exception exists for vessels that are stationed inside harbors, because boat owners are charged a port fee. This means that the harbor authorities can identify the boat-owner. Outside harbors, the inadequate registration of vessels creates a situation where it becomes difficult for authorities to trace the owner. Consequently it becomes problematic to demand that a boat is removed and transported to a dismantling site (Eklund et al., 2013; WaterrecreatieAdvies, 2014).

According to Al Abbar et al. (2015) both laws combined constitute the following problems with respect to recreational boats:

- Unclear what administrator is responsible for (abandoned) boats;
- Abandoning or sinking a boat is not an illegal activity;
- In case it is impossible to identify a responsible owner of an abandoned boat, municipalities and public authorities are forced to deal with these boats;

- No procedure or protocol for administrators or owners in dealing with recreational boats.

In conclusion, there is currently no (inter)national regulatory framework that intends to specifically stimulate the development of a circular production model for composite waste from recreational boats. There are, on the other hand, specific Dutch laws - *Wrakkenwet* and *Registration Fast Motorboats* – aiming to prevent abandonment of recreational boats. In contrast to the national *Waste to Resources* programme, these laws and regulations do specifically target the system of recreational boats.

#### 4.1.2.2. Soft Institutions

##### Expectations and social acceptance

Although the *Waste to Resources* programme does not specifically mention recreational boats, it provides a generic vision for the growing expectations of a circular economy in the Netherlands. Based on these prospects, multiple industry magazines (e.g. *JachtbouwNederland*, 2014; *Jachtmedia*, 2015) highlighted the recycling issues surrounding composite waste from recreational boats. According to *JachtbouwNederland* (2014) regulation and recycling targets are to be expected in the near future. In this scenario, several policy developments are conceivable. For example: the government instates a disposal fee based on the amount of composites (per ton), payment of a disposal fee at the moment of purchase, or a yearly disposal fee per boat.

To study the social acceptance of such legislation among recreational boat owners, the EU funded a project called 'BoatDIGEST' in 2013 (International Institute of Marine Surveying, 2015). By means of a survey, the research focused on identifying awareness among boat owners about end-of-life responsibilities and options (BoatDIGEST, 2015a). Although the Netherlands was not one of the 5 researched countries, it gives a general idea about the social acceptance of expected regulations among recreational boat owners. According to the results of the BoatDIGEST (2015b) study:

- 75% of the recreational crafts have a composite hull;
- 23% of the recreational boat owners assume it is free to dismantle and recycle the boat, and 17% expect money from the scrap value;
- 68% is unwilling to pay dismantling and recycling of their boat;
- 37% of the boat owners are unaware of the problems surrounding composite disposal.

The fact that 37% of the boat owners are unaware of the end-of-life treatment problems surrounding composites clarifies why, combined, nearly 40% of the boat owners expect that dismantling and recycling will not cost money or will even yield a scrap return. However, unlike the significant scrap value of wood and metal boats, composite vessels cannot rely on embodied scrap value to reduce the removal and disposal costs (Marsh, 2013; *WaterrecreatieAdvies*, 2014). As a result, there is currently no incentive structure for boat owners to dispose of their vessel adequately.

#### 4.1.3 Infrastructure

In this section the following components of the existing physical, financial and knowledge infrastructure are presented and analyzed: number of recreational boats and

the disposal infrastructure (section 4.1.3.1); and the availability of financial resources, such as presence of grants and subsidies (section 4.1.3.2).

#### 4.1.3.1 Physical infrastructure

In the case study description (section 3.1.2) it has already been stated that around 500.000 boats are currently afloat or stationed ashore in the Netherlands. The total number and material composition of these boats is well documented by the market research consultant WaterrecreatieAdvies (2014). Since this is the only available source that describes the number of boats in the recreational boating system, the examination that follows below is mainly derived from this rapport.

##### Number of recreational boats

Of the 500.000 boats – including surfboards and canoes – 154.000 boats are located in harbors, 43.500 are situated in ditches and canals, and 210.000 are stored on the shore. These boats are still used with some regularity (WaterrecreatieAdvies, 2014). The type of boat is, however, very different per storage location. Boats that are located within harbors are often sailing or motorboats. The boats that are situated in ditches or canals are generally smaller in size (a difference of 3 meter on average) and have no cabin. In contrast to the 400.000 boats that are still being used, there are currently approximately 100.000 boats subsiding in sheds, garage boxes and hangars. Most are surfboards and small sailing, motor and rowing boats (ibid.).

The hulls of the mentioned boats generally consist of three different materials: wood, steel or composite. In total, the 500.000 boats weigh around 900.000 tons. Although the majority of the boats are made out of composite (60-85%), due to the lightweight properties of the material, composite materials in boats ‘only’ weigh 286.286 tons (BoatDIGEST, 2015b; WaterrecreatieAdvies, 2014). This comes down to 1.75-ton composites per boat on average. How the total weight is distributed per storage location, can be observed in table 5.

Table 5: *Total amount of composites in the Dutch fleet.*

<i>Location</i>	<i>Glass fiber-reinforced polyester weight [ton]</i>
Afloat	219.890
On the shore, in service	62.150
On the shore, out of service	4.246
Total	286.286

Source: adapted from WaterrecreatieAdvies (2014).

While yachts and recreational boats made of composite materials generally have a long lifespan - between 30-50 years on average - these boats also reach an end-of-life phase eventually (Eklund et al., 2013). WaterrecreatieAdvies (2014) sketched a scenario for the number of composite boats that is in need of disposal in the Netherlands over the next decades. In the first five years, the period 2015-2020, it is expected that around 12.500 boats require dismantling and recycling; increasing to around 25.000 between 2020-2025; and up to 35.000 between 2025-2030. In this estimation not all boats are composed of composites, therefore table 5 illustrates the total weight of composite materials that requires recycling and/or re-use until 2030.

Table 6: *Composite waste from end-of-life boats in the period 2015-2030.*

<i>Period [year]</i>	<i>Glass fiber-reinforced polyester weight [ton]</i>
2015-2020	7.157
2020-2025	13.956
2020-2030	19.888
Total	41.001

Source: adapted from WaterrecreatieAdvies (2014).

Based on this scenario, it becomes apparent that approximately 72.500 boats will require a recycling infrastructure in the next 15 years; which amounts to 41-kiloton composites in the Netherlands alone (table 6). It must be noted that this amount is fairly uncertain, since the projection does not take into account import and export of recreational boats. The scenario furthermore does not offer specifics with regard to the location of the boats. Such information is particularly relevant for the contemporary boat disposal infrastructure (next section), and ultimately for the development of a circular production model. It has been argued that without more knowledge of the composite waste stream, it is difficult to justify a business case for different recycling and re-use methods (Krebbekx & Lintmeijer, 2015).

### Disposal Infrastructure

There is currently no organized disposal infrastructure for recreational boats (WaterrecreatieAdvies, 2014). When a vessel reaches an end-of-life status, the owner has three options: personally dispose of the boat, request the service of a waste processor or make use of a so-called 'yacht dismantler and recycler'. In case of the first option, the owner delivers the composite hull at the municipal recycling station ("milieustraat"). According to Rijkswaterstaat (personal communication, 2015f) there is, however, no specific container for composites. The composite boat-hull should therefore be delivered at the collection category 'hard plastics'. Because this is a particularly unpractical route for most boat owners, given the size of an average boat, it is also possible to place a disposal request at a waste processor. Since the average length of a boat is 8,3 meters (WaterrecreatieAdvies, 2014), the hull often requires chopping in advance of retrieval. After a boat is sawed into pieces, and fits into the waste container, the waste processor transports the chopped boat-hull to an incineration plant. Van Eersel (personal communication, 2015) stated that the three major waste collectors with a national coverage exercise the collection: van Gansewinkel, SITA and Shanks. In addition, it is also possible to place a disposal request at a smaller and more regional company, such as van der Heide or Post. Since the composite hull is currently of no economic value to the waste processors, a certain amount per ton is charged for transportation and incineration costs<sup>7</sup>. This is where the location of the recreational boat becomes relevant, since transportation costs are dependent on the volume of a boat and distance from the storage location to the incineration plant.

The last possibility is to start a procedure with a so-called yacht dismantling and recycling station. At present, there are only three of such stations in the Netherlands: 'T Harpje, Stichting Jacht Recycling and Marine Recycling Goossens (see appendix E.1). According to Hans van Smoorenburg (personal communication, 2015) these different

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<sup>7</sup> According to in 't Groen (2010) the incineration plant charges €80-90/ton, excluding transportation costs.

collection and dismantling stations often work according to a similar stepwise process. First, the economic value of a recreational boat is evaluated, and checked for environmental pollutants and asbestos. Hereafter a custom made dismantling and recycling plan is produced for each vessel. These are necessary, because boats and yachts come in various shapes, forms and are composed of dissimilar materials. Then, when the boat's owner approves of the process, the vessel is transported to a designated dismantling site. The means of transport depends on the state of the boat, i.e. via the road whenever the vessel is unable to sail. At the dismantling site components of economic value are stripped, such as wood and metals. The parts that are currently of no value, such as the composite hull, are hereafter transferred to the waste processor. The waste processor, like in the second option, subsequently transports the boat-hull to an incineration plant. Similar to a service request directly at the waste processor, the boat owner is charged €80-90/ton for the costs of the incineration plant (in 't Groen, 2010).

In conclusion, there is no systematic and organized disposal infrastructure for recreational boats (WaterrecreatieAdvies, 2014). Owners themselves are responsible for adequate disposal and are confronted with three possibilities, all of which are likely to result in net costs for the boat-owner. The ultimate disposal costs are dependent on the location, disposal option, mass and material composition of the end-of-boat. How many composite boat-hulls eventually wind up at the incineration plant through the contemporary linear production model, and how many are abandoned, is impossible to say. Namely, according to Cornelissen (personal communication, 2016) composite materials from recreational boats are mixed with domestic waste from households. Accurate details are therefore missing, since the waste stream is not properly monitored.

#### 4.1.3.2 Financial & Knowledge infrastructure

The industry background (section 3.1.1) shows various recycling technologies – mechanical, thermal and chemical – for composite waste from recreational boats, which have been extensively researched in academic literature. Below, the reviewed knowledge infrastructure therefore focuses on knowledge development with respect to composite waste from recreational boats that goes beyond the technological understanding.

In the Dutch House of Representatives ("Tweede Kamer"), issues related to the abandonment of recreational boats were addressed for the first time in July 2013 (Ministerie van Infrastructuur en Milieu, 2015). The raised awareness resulted in a subsidy for the previously mentioned study - carried out by WaterrecreatieAdvies, 'T Harpje and the Nederlandse Jacht Industry (NJI) - to estimate the number of recreational boats in the Netherlands (see section 4.13.1). Based on this study, which demonstrated that end-of-life boats currently have no adequate disposal infrastructure, the Ministry of Infrastructure and the Environment decided to fund research into the recycling possibilities for composites. This was justified in the context of the *Waste to Resources* programme, since studying the recycling and/or re-use opportunities for composite waste is relevant for more than just recreational boats (Ministerie van Infrastructuur en Milieu, 2015). The Dutch ministry consequently commissioned multiple studies (e.g. Krebbekx & Lintmeijer, 2015; Dutch Polymer Institute, 2014) with the aim to concretize the national operational goals with respect to a Circular Economy. The Dutch Polymer Institute (2014) study examined and highlighted the issues of high-grade recycle in posterior applications for composites. Besides know-how of applications for recycled or



re-used composites, another knowledge implication became apparent during this study: measuring the composite waste streams. Subsidized research by Berenschot Consultants – performed by Krebbekx and Lintmeijer (2015) - therefore proposed a monitoring system for all identified composite waste streams; which includes recreational boats. The aim of this research is to set up a monitoring system for the composite waste stream, which helps in estimating the quantity of the flow. As of this moment, research funds for the topic of composite waste from recreational boats did not go beyond these exploratory research and monitoring proposals.

Alongside the knowledge infrastructure, the availability of capital and funds are important to build a reliable and continuous disposal system. It is, however, difficult to examine what financial resources are available to develop a currently non-existent circular system. Several qualitative interviews suggest that the availability of capital for setting up the required disposal and processing infrastructure can be problematic. This subject is examined more elaborately in the functional analysis (F6, resource mobilization) in section 4.2.

#### 4.1.4 Interactions

The exchange of information and knowledge can occur at various levels: within actor groups (for instance between scientists only), among actor groups (e.g. university-industry partnerships) or across the entire recreational boating system. In academic circles, the specific issue of composite waste from recreational boats is not extensively discussed; only two scientific publications (Marsh, 2013; Bardet, 2010) on this subject were identified, both studies from the United Kingdom. As discussed in the previous section, the topic of composite waste from recreational boats is most discussed and distributed in non-academic circles; for example, by support organizations such as WaterrecreatieAdvies and Berenschot. Most scientific publications that are relevant for composite recycling are focused on technological improvements in other segments of the composites industry, such as wind-energy, automotive and aerospace markets (e.g. in 't Groen, 2010; Halliwell, 2006; Krishnamoorthi & Shizhao, 2012). This is, however, not necessarily problematic if the developed knowledge is exchanged between actors and across different industries.

Such cross-market interactions show in collaborative partnerships between knowledge institutes and industry. Recently, in 2014, the Dutch Polymer Institute (DPI) and the Materials Innovation Institute (M2i) – two technological institutes in the Netherlands - started a joint research programme that focuses on glass fiber polyester development (i.e. composite). The objective of this platform is to create an innovative knowledge network around composites in selected market segments, including yachts and boats in the maritime sector (Dutch Polymer Institute, 2014). In this network industrial and academic actors are partnered to focus on both the technological and scientific aspects of composites, including sustainability and recycling aspects. Although this network is not specifically aimed at recreational boats, it shows that knowledge is exchanged across various industries that work with composite materials.

In addition to these cross-market networks, recently a more issue specific interaction took place during the first *'International Yacht Recycling Conference'* in Amsterdam (Jachtmedia, 2015). Throughout this symposium various industrial experts, ranging from incumbents to start-ups, discussed the problem of composite waste from



recreational boats. During the conference a steering group was formed to generate proposals in the run up to possible incoming legislation, and reach out to a widespread base of industrial actors to utilize all available expertise on the subject of composite recycling (Jachtmedia, 2015). This conference was not launched out of thin air. Prior to the event, information on this issue was distributed through a variety of articles in industry reports and working papers (e.g. HISWA Magazine, 2015; JachtbouwNederland, 2014; WaterrecreatieAdvies, 2014). So, re-use or recycling issues surrounding recreational boats were already widely known and discussed among industrial actors.

## 4.2 Functional Analysis

The structural overview (section 4.1) outlined the structure of the Innovation System around the recycling and/or re-use of composite boats in Netherlands. This section, the functional analysis, aims to complement the structural overview by assessing how this system is functioning in the period 2015-2016. An evaluation of the functions provides insight into the performance of the innovation system, and allows for the identification of barriers that hamper the development of a circular production model. To do so, each function is evaluated separately according to the same analytical pattern: first the findings of the structural analysis are outlined in short, followed by a qualitative evaluation of the performance per function according to the interviewed stakeholders. This functional analysis concludes with a section, 4.2.1, where the functional performance and pattern is interpreted.

### Function 1 - Entrepreneurial Activities

The structural analysis shows (section 4.1.1) that a small number of incumbent firms are dominant in the beginning (i.e. raw material suppliers) and end (i.e. waste processors) of the supply chain. Alongside these incumbents, a large number of relatively small producers/OEMs is present. The interplay between these small and large firms is relevant for the development of the innovation system, since small firms tend to initiate entrepreneurial activities and incumbents are more inclined to follow (Hockerts & Wüstenhagen, 2010). To assess whether the entrepreneurial activities function is positively fulfilled, the interviewees evaluated whether there are sufficient entrepreneurial activities to develop a circular production model for composite waste from recreational boats.

According to multiple interviewed stakeholders, currently there are two start-ups that are experimenting with the waste processing of end-of-life boats; for instance, Drogd argued: *“ExtremeEcosolutions and FiberCare & Recycling have developed a chemical method to recycle composites at a high grade”*. Both companies use a method with heavy chemical solvents, which can be re-used 4-5 times, to dissolve the resins at room temperature. Van der Woude, founder of FiberCare & Recycling, stated: *“Our new method, which has been tested in the laboratory, suggests we can get the long fibers back with 80-95% of their original strength”*. Both companies are, however, not fully operational yet. Both entrepreneurial start-ups are still experimenting in the laboratory, but need a recycling facility to test if the new method works on composite boats in practice.

In contrast, abroad there are several operational entrepreneurs that already turn composite waste into marketable products. Although this thesis focuses only on the

recreational boating system in the Netherlands, several interviewed stakeholders suggested that composite waste from Dutch recreational boats is transportable across the national border. In Hamburg, Germany, a company called 'Zajons' started the cement route in 2010 (see section 3.1.1.). Wegman is of the opinion that the cement route is the best option: *"Although it does not offer the highest grade of recycling, this method offsets huge amounts of CO2 from the cement industry and requires little initial investment"*. In France, a company called Mixt Composites Recyclables (MCR) processes sheets from end-of-life composites. Wegman stated: *"These sheets can for instance be used to manufacture the rear cover of a car"*. In addition, Schrama mentioned a Belgian waste processor, Reprocover, which *"uses composite waste to construct crossovers for railroads, garbage bins, manhole covers and mailboxes"*.

In conclusion, as taken by of the interviewed stakeholders, there are sufficient entrepreneurial activities to develop a circular production model for composite waste from recreational boats. In the Netherlands there are two prospective recyclers, and outside the national borders several entrepreneurial companies are already turning composite waste into useful posterior applications. With an average score of 3,5 on a 5-tier scale, the different stakeholders evaluate the entrepreneurial activities function as *strong*.

### **Function 2 – Knowledge Development**

The structural analysis (sections 4.1.1) shows that a number of different knowledge institutes, industrial actors and support organizations are involved with composite waste from recreational boats. Knowledge development on this topic can be divided into two relevant sub-categories: research into the technological recycling methods for composite materials (section 3.1.1); and studies that go beyond the technological understanding, for instance concentrating on waste stream, transportation and posterior applications of recyclate (section 4.1.3.2). To evaluate if the knowledge development function is positively fulfilled, the interviewees assessed whether the knowledge development in both sub-categories is sufficiently developed to stimulate the development of a circular production model.

In general the interviewed stakeholders agree that the technological knowledge is adequate, but emphasize that the recycling technologies are not necessarily economically viable. For instance, Drogts stated: *"The technological knowledge is there. However, recycling always faces the following problem: collection and processing costs money, what misses right now is a smart application to make a profit on the sales part"*. Van Eersel, who indicated that *"There are multiple technologies available, getting the boat from a boat-storage location to a potential recycling facility is more problematic"*, confirms this statement. Because the technological knowledge is available, several interviewed stakeholders indicated that research should shift to making the technologies economically viable; for example, by focusing on the identification of the composite waste stream and finding a high grade function for recyclate in posterior applications. Various actors are already making this happen; for example, according to Schaap: *"The NJI and HISWA have researched the number of end-of-life boats, and Berenschot proposed a monitoring system for the composite waste streams"*. In addition, Ten Busschen, a lecturer at the Windesheim Hogeschool, mentioned that he was recently recruited to *"Add something to the curriculum on the reoccurring question of composites recycling, by searching for a product with a high grade function in a posterior application"*.

The knowledge development function therefore seems to correspond with the system's needs.

In the opinion of the interviewed stakeholders, the level of developed knowledge is sufficient to drive the development of a circular production model for recreational boats made from composites. With an average score of 3,5 on a 5-tier scale, the different interviewed stakeholders evaluate the knowledge development function as *strong*.

### **Function 3 – Knowledge diffusion through networks**

In the structural analysis, the overview of interactions (section 4.1.4) shows that knowledge dissemination of composite recycling and/or re-use technologies is widespread in academic circles. This technological knowledge is distributed through innovation platforms, in which knowledge institutes and industrial actors form collaborative partnerships. Such networks are not new, according to Wegman: *“Already in 2004 we came together with important knowledge institutes, resin and fiber producers, cement producers and waste processors to discuss the cement route”*. As a result, working groups on composite recycling followed. For instance, Drogts stated: *“In Germany and the Netherlands I set up working groups for composites with regard to sustainability and the various recycling methods”*. These networks do, however, mainly focus on recycling technologies for composite waste in general. To evaluate if the knowledge diffusion function is positively fulfilled in the recreational boating system, the interviewed stakeholders assessed whether sufficient knowledge is exchanged to develop a circular production model for composite boats.

Academic publications on the specific topic of end-of-life boats are scarce, as section 4.1.3.2 shows. So far knowledge exchange mainly occurs in non-academic circles, by support organizations such as WaterrecreatieAdvies and Berenschot (section 4.1.3.2). In general this knowledge is well diffused, since almost all interviewed stakeholders were aware of these non-academic reports; for example, Steensma stated: *“WaterrecreatieAdvies wrote and distributed a report about the estimated amount of end-of-life boats”*. Alongside knowledge diffusion through publishing, many interviewees indicated they were also present at the ‘*International Yacht Recycling Conference*’ in Amsterdam. During this platform, different (inter)national industrial actors and knowledge institutes exchanged information about the contemporary condition of end-of-life boat recycling. For instance, Schrama mentioned: *“At the event there were speeches and discussions about: recycling status abroad, incoming legislation, composite recycling and possible finance schemes”*. As becomes evident from this statement, the network was not only intended to gather the relevant stakeholders, but also to diffuse the knowledge that corresponds with the needs of the recreational boating system.

Based on these considerations, the interviewed stakeholders conclude that sufficient knowledge is diffused through networks to develop a circular production model for composite waste from recreational boats. With an average score of 3,4 on a 5-tier scale, the different interviewed stakeholders evaluate the knowledge diffusion through networks function as *strong*. It must be noted that, although knowledge diffusion scores high overall, both interviewees at the end of the supply chain (i.e. waste processor and prospective recycler) assessed this function as *very weak*. To clarify this evaluation, van Eersel stated: *“When we were busy with setting up a circular system for PET bottles, my whole schedule was full with meetings on this subject. To really progress, more attention is*

*needed and more networks have to be organized*". This could indicate that, despite various networks that facilitated the exchange of information, prospective recyclers may require more networking activities or a different kind of knowledge to be exchanged.

#### **Function 4 – Guidance of the search**

The overview of relevant institutions (section 4.1.2) demonstrates that a distinction must be made between a vision and expectations (soft institutions) and actual laws and regulations (hard institutions) that are currently in effect. With regard to the former, the *Waste to Resources* programme provides a generic direction; for example, by offering long-term targets and goals with respect to waste management, material re-use and production and consumption patterns. This policy outlook does, however, lack a consistent and coordinated vision with respect to recreational boats or composite materials in general (section 4.1.2.2). Regarding laws and regulations, two relevant hard institutions are in place – the *Wrakkenwet* and *Registration Fast Motorboats* (section 4.1.2.1).

As taken by the interviewed stakeholders, the *Waste to Resources* programme does not offer a stable framework for activities related to recycling and/or re-use technologies in the recreational boating system. According to Wegman, such guidance seems desirable because: *"The boatbuilding industry is unprofessionally organized in comparison to for instance the car industry, the government has to adopt a guiding role in dialogue with industrial actors"*. Ten Busschen complements this statement, by adding that: *"When a shared vision and legislation back the boating industry, the government stimulates the search for solutions"*. These statements indicate that the recreational boating system currently lacks a shared vision or legislation that stimulates the development of a circular production model.

Alongside lacking soft institutions, laws and regulations within the innovation system are also not configured to drive the development of a circular production model. Van Smoorenburg, for instance, refers to a deficiency in the *Registration Fast Motorboats* law, which mandates registration for boats that sail faster than 20km/h. He mentioned: *"The fact that there is no mandatory registration forms a barrier for boat recycling"*. Since registration is not obligatory, owners do not feel accountable for adequate disposal, and as a result more and more boats are abandoned. This is clarified by Van Smoorenburg: *"Owners can disappear when the costs keep increasing...but due to liability and ownership rights in the Netherlands, the administrator of the boat's location is not eligible to remove the vessel without consent of the owner"*. So, the fact that boats cannot be linked to a responsible owner in case of abandonment hinders a disposal trajectory for these vessels. This shortcoming in the *Registration Fast Motorboats* law therefore acts as a barrier to the development of a circular production model.

Another hampering factor can be linked to deficiencies in the *Wrakkenwet*. Because only when boats comply with this law – i.e. the boat is stranded, sunk or stuck – is a site administrator eligible to remove and dispose of a boat. Van Eersel mentioned that it is sometimes ambiguous who the administrator is: *"It is often unclear who is responsible for the removal of a boat and accountable for the costs"*. This is followed by uncertainty about who is responsible for adequate disposal; for example, van Smoorenburg mentioned: *"I have witnessed multiple situations where the municipality claimed that Rijkswaterstaat was responsible for the removal of a boat, and vice versa"*. From a

guidance perspective, such regulatory uncertainties do not constitute stable drivers for the development of a circular production model in this innovation system.

In conclusion, in the view of the interviewed stakeholders, the mentioned hard- and soft institutions provide uncertain guidance for the development of a circular production model in the recreational boating system. Although most interviewees are aware of the generic vision to develop a CE in the Netherlands, national laws and regulations provide no direction for the innovation system. Existing regulations – i.e. the *Wrakkenwet* and *Registration Fast Motorboats* – only aim to regulate the amount of boats that end up abandoned in the natural environment. Even if these laws were to function well, which is not the case according to the interviewed stakeholders, these laws do not provide a stable framework to drive activities related to recycling and/or re-use technologies. Consequently, with an average score of 2,2 on a 5-tier scale, the interviewed stakeholders evaluate the guidance of the search function as *moderate*.

It is notable that, although guidance of the search is assessed as *moderate*, multiple interviewed stakeholders expect incoming regulations for composite waste from recreational boats in the near future. For instance, van der Woude stated: *“I spoke with someone from the Ministry of Economic Affairs, who told me of legislation that demands higher recycling rates for boats is inevitable”*. Depending on the nature of these potential regulations, it is possible that legislation will translate into an enhanced performance of the guidance of the search function.

### Function 5 – Market Formation

In this section it is assessed whether there is market demand for the outcome of a circular production model: recycled or re-used composites from recreational boats. To evaluate whether this function is positively fulfilled, the interviewed stakeholders assessed if there is sufficient demand for recycled or re-used composites to form such a market. Since the formation of such a market is different for recycling or re-use purposes, below both categories are discussed separately.

Composite materials from boats can be re-used in two ways: re-sell the boat on a second-hand market or find an alternative next-life function. Re-selling is an option, because in most cases a recreational boat reaches an end-of-use phase for owners rather than an end-of-life phase of the composite materials. Currently there is, however, barely a second-hand market for boats; according to van Smoorenburg: *“Composite boats have a negative economic value. There is no market for old boats, although they are not end-of-life per se”*. Several interviewees also mentioned the second option, i.e. searching for an alternative next-life function. For instance, Drogts stated: *“I always say composites reach an end-of-use phase, so materials can often be used afterwards. Examples I have encountered are swimming pools made from composite boat hulls, or playgrounds from decommissioned windmill blades”*. Although these examples sound attractive, such next-life routes occur only sporadically; according to Drogts: *“There is only one playground I know of, located in Rotterdam”*. So, the mentioned next-life applications do not appear to be able to serve as a structural market outlet for the 72.500 end-of-life boats.

On the other hand, market demand for recycled composite waste from recreational boats builds on the recycle's ability to compete with virgin materials. Whether this competition is feasible depends, in turn, on a variety of market incentives. This is



clarified by van Eersel: *"It is always tricky to re-introduce recycled products into the market. Waste processors are always subjected to recycling costs and the quality of the recyclate"*. Thus, based on the preceding determinants – recycling costs and quality of recyclate – the market formation function is evaluated below. Since these determinants differ per recycling method, the interviewed stakeholders weighed in on the recycling technologies as discussed in section 3.1.1.

The most straightforward route, mechanical grinding, is relatively low-cost but produces a recyclate with short fibers. In the view of most interviewed stakeholders, this recycling method is currently economically unfeasible; for instance, Hauwert mentioned: *"Short virgin fibers can be bought for 80 eurocents per kilo from China. If you have to include transportation and energy costs of composite recycling by shredding, it is at the moment just not economically workable"*. And he added: *"Even if you were to produce cost competitive composite recyclate, the quality can be uncertain"*. So although the mechanical grinding is relatively inexpensive, due to the low costs of virgin composites there seem to be insufficient (economic) incentives for the market to choose inferior recyclate over virgin products. This problem seems also accurate for pyrolysis. Although pyrolysis provides higher quality recyclate, the initial investment and operational costs of a recycling facility form a barrier. Wegman clarifies this: *"The costs of setting-up a pyrolysis factory can be problematic"*. Thus, both mechanical grinding and pyrolysis are likely to produce a recyclate that is unable to compete with virgin materials on the basis of price and product quality. Consequently both aspects form a barrier for market demand.

Demand for the composite waste from recreational boats can also come from other industries, such as the cement industry. According to Wegman *"the cement industry would be quite happy with composite waste from boats, but logistics and transportation costs are a problem"*. This statement indicates that there is demand for composite waste from end-of-life boats in the cement industry, but transportation costs form an obstacle to make the cement route economically viable.

Beside the preceding economic considerations, van der Woude, founder of a prospective chemical recycler, adds a regulatory barrier; he stated: *"Legislation will mandate a certain recycling rate in the near future. Then the market demand will grow"*. Currently there is, however, no concrete plan of action from the Dutch government to mandate recycling rates for composite waste. The absence of regulations therefore also forms a blocking mechanism for the market formation function.

In conclusion, as taken by the interviewed stakeholders, the market for recycled or re-used composites from recreational boats is insufficiently formed to stimulate the development of a circular production model. For re-use purposes, demand for boats on the second hand market is missing, and alternative next-life applications are only encountered sporadically. For recycling purposes, competition with cheap and qualitatively superior virgin materials and missing regulations form barriers that hinder the market formation function. As a result the interviewed stakeholders evaluated the market formation function as *weak*, with an average score of 2,0 on a 5-tier scale.

On the other hand, the interviewed stakeholders also see potential market formation incentives for recycled composite waste from recreational boats. According to ten Busschen: *"Companies that make a product from end-of-life composites can use that as a*



*promotion*". Schrama concurs, and adds: *"I can see how producers could advertise with more sustainable products"*. So, market demand for recycled or re-used composites from recreational boats can also be driven by advertisement and promotion benefits that stem from selling sustainable products.

### **Function 6 – Resource Mobilization**

The structural analysis (section 4.1.3.1) shows it is projected that approximately 72.500 boats - containing 41-kiloton of composite waste – reach the end-of-life stadium in the period 2015-2030. To ensure that this waste stream is dealt with, the availability of financial capital and funds is important for both: the construction of recycling facilities and an adequate boat-disposal system (i.e. physical infrastructure); and data collection on the extent of the composite waste stream (i.e. knowledge infrastructure). To evaluate if the resource mobilization function is positively fulfilled, the interviewed stakeholders assessed whether there is a willingness to invest financial resources into the physical and knowledge infrastructure that is necessary for the development of a circular production model for composite boats. Thus, contrary to the market formation function (F5) that focused on *demand* for recycled composites, this function evaluates if resources are available to ensure that activities on the *supply-side* – disposal of composite waste from recreational boats - are sufficiently developed. This is mainly relevant for the actors at the end of the supply chain, such as waste processors and prospective recyclers.

As demonstrated in the structural analysis (section 4.1.1) there are various educational and knowledge institutes in the Netherlands that attempt to address composite recycling issues by a number of programmes and courses. Ten Busschen, lecturer at Windesheim Hogeschool, concurs: *"We are searching for high grade applications for composite waste. This includes everything from boats to windmill blades"*. In addition, section 4.1.3.2 shows that research (e.g. WaterrecreatieAdvies, 2014; Krebbekx & Lintmeijer, 2015) from support organizations also focuses on posterior applications for composite waste and the adequacy of the physical disposal infrastructure. To be able to conduct these studies, both parties were financially assisted by grants from the Dutch ministry of Economic Affairs and the Ministry of Infrastructure and the Environment. According to van Smoorenburg support from public funding for such research is worthwhile, because it allows a shift from knowledge development to actual recycling practices: *"If a company or institution finds a way to make recycled composites a valuable commodity, it would be possible to invest money into recycling as a commercial business"*. This statement shows that, so far, financial resources have been mainly available for research and knowledge development, not for the development of a physical infrastructure. Ten Busschen confirms that there is a shortcoming in the availability of financial resources to invest in a recycling infrastructure, by stating: *"There is currently hardly any initiative to invest in the necessary equipment and physical infrastructure that is needed to close material loops"*.

The interviews moreover suggest that, in order for recyclers or waste-processors to start investing into the necessary physical infrastructure, the (financial) benefits of the business case to recycle recreational boats have to outweigh current incineration practices. Drogdt clarifies this: *"Waste processors are economically driven companies. If no extra revenue can be earned in comparison to incineration, they will not get into composite recycling"*. To make composite recycling commercially viable, the private business case

is dependent on: a continuous waste stream from recreational boats (input volume) and a profitable price for the produced recyclate (output). With regard to the former, Steensma argued: *"No one is going to invest in a recycling facility for a product with an unknown supply"*. The cause of this uncertain supply can be attributed to the fact that end-of-life boats are dispersed over broad areas in small numbers. Due to absent measuring and monitoring activities it is currently unknown *when* these boats become available for recycling purposes and *where* they are located. This data absence makes it difficult to justify private investments into the necessary physical infrastructure.

The interviews furthermore indicate that the inadequate boat disposal infrastructure enhances the uncertain waste stream. Even if all recreational boats would be monitored, the interviewed stakeholders agree that the contemporary physical infrastructure is insufficiently developed to ensure an ample supply; for example, van Smoorenburg stated: *"T Harpje, the collector with the highest capacity, is able to collect and process 1 vessel per day. This is not enough if you see how many boats will reach an end-of-life status in the coming decades"*. Wegman concurs, he stated: *"A better organization behind the collection and transportation of boats is required, likely from all over Europe"*.

In addition to waste stream insecurities, the interviewees also agree that the willingness to invest financial resources into the system is limited due to a non-profitable price for the produced recyclate (output). For instance, Schrama mentioned: *"It is difficult to persuade a business to invest in a product that might only be worth 50 eurocents per kilo"*. In sum, an inconclusive business case, due to supply uncertainties and non-profitable prices for recyclate, makes investors unwilling to mobilize financial resources for the development of a circular production model for composite boats.

Alongside the preceding economic considerations, van Eersel mentioned that legal ambiguity also forms a barrier for the private business case. He stated: *"In case a boat is abandoned, it is now often unclear who is legally responsible for the disposal"*. Since it is unclear *who* is responsible for the disposal of a boat, a recycler does not know what actor or organization will bear the financial burden. This knowledge is essential for the private business case of a recycler, because according to van Eersel: *"As an investor, you have to know who your potential customers are"*. Thus, this regulatory uncertainty, too, forms a barrier for the resource mobilization function.

In conclusion, as taken by the interviewed stakeholders, public financial resources in the form of grants and subsidies from Dutch ministries are available to advance the knowledge infrastructure that is necessary to go beyond incineration of composite waste from recreational boats. The necessary physical recycling infrastructure itself is, however, missing and private funds aimed at the development of this infrastructure are difficult to mobilize. Resource mobilization barriers are related to an inconclusive business case for recyclers, due to: an uncertain waste stream from recreational boats; a low-priced recyclate; and regulatory uncertainty about the actor or organization that is (financially) responsible for the adequate disposal of recreational boats. With an average score of 2,2 on a 5-tier scale, the interviewed stakeholders evaluated the resource mobilization function as *moderate*.

### Function 7 – Creation of Legitimacy

To assess whether the creation of legitimacy function is positively fulfilled, the interviewed stakeholders evaluated the level of resistance from vested interests against the development of a circular production model for composite waste from recreational boats.

In general, the interviewed stakeholders agree that vested interests are not a hindering factor; for example, Bouwmeester stated: *“If it is possible to recycle, why would there be resistance against recycling?”* Van Eersel concurs: *“I do not see how anyone can be against the disposal and recycling of old boats”*. The interviews furthermore show that seven interviewees hardly recognized a level of resistance, and four stakeholders did not assign a score to this function<sup>8</sup>. This indicates that the interviewed stakeholders do not perceive the creation of legitimacy function as relevant.

Although the majority of the interviewed stakeholders suggested that there are little vested interests against the development of a circular production model for composite waste from recreational boats, several interviewees noted that the expansion of the composites industry as a whole does face resistance. For example, according to Wegman *“there is a steel, concrete and aluminum lobby that does not want composite materials to flourish”*. This resistance is, however, directed at the composites industry as a whole, not at the transition from a linear to a circular production model within the recreational boating system.

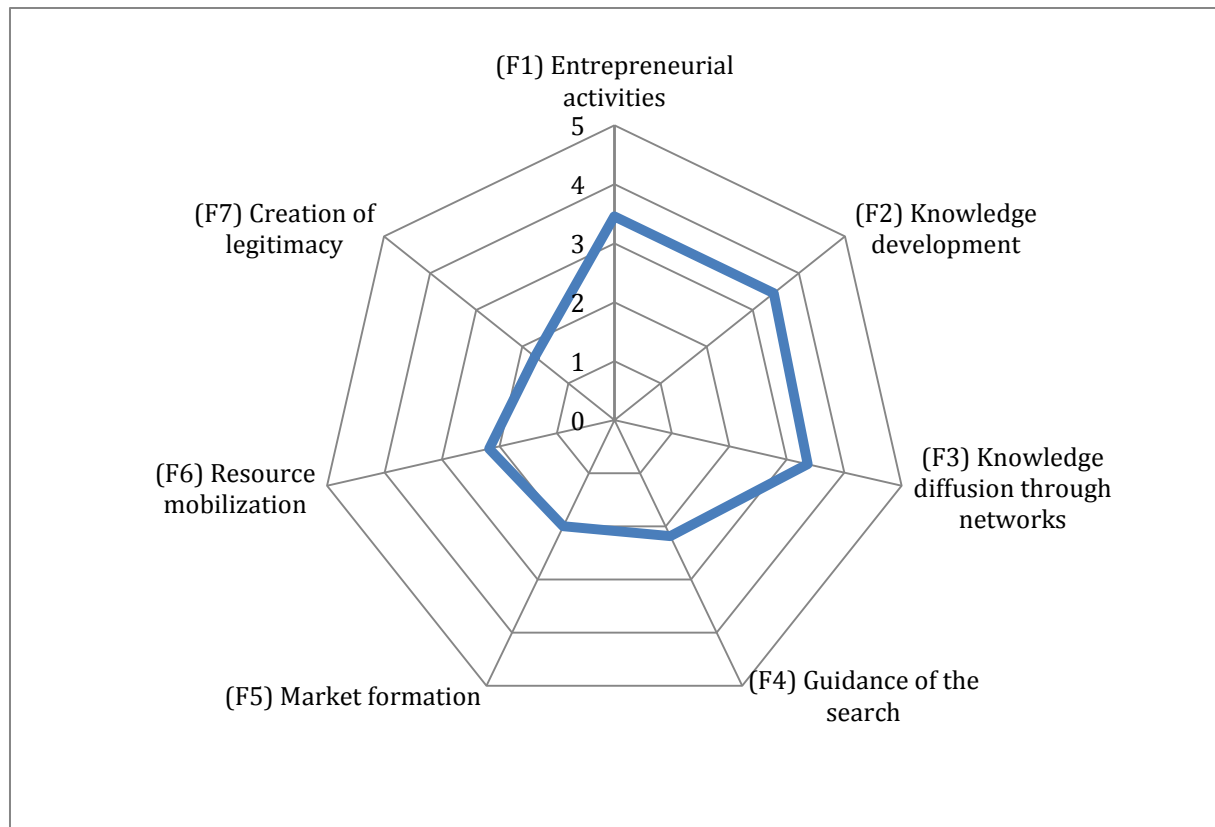
Overall, as taken by the interviewed stakeholders, there is hardly any level of resistance from vested interests against the development of a circular production model for composite waste from recreational boats. Four interviewees even reasoned that this function is not relevant at all, and did not assign a score. With an average score of 1,7 on a 5-tier scale, the interviewed stakeholders evaluated the creation of legitimacy function as *weak*. This suggests as if there is no legitimacy for system development, but rather the opposite is accurate. Due to the phrasing of the interviews questions (see appendix D.2), which focus on the level of resistance by vested interests, the interviewed stakeholders evaluated this function as relatively weak. This means, however, that the interviewees perceive low levels of resistance against the development of a circular production model for composite waste from recreational boats.

#### 4.2.1 Interpretation of system functions

Figure 11 provides an overview of the evaluations per function according to the interviewed stakeholders. The scores in the figure represent the performance of each function: very weak (0-1) to weak (1-2), moderate (2-3), strong (3-4) and very strong (4-5).

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<sup>8</sup> This option is listed in the evaluation form whenever a function is deemed irrelevant by the interviewee (see appendix D.2).



**Figure 11** – *Functional Pattern.*

Within the recreational boating system there are high expectations of a CE, and in general it is recognized that recycling and/or re-use activities are necessary to avoid environmental damage (section 3.1.2). In practice this is shown by the fact that different recycling technologies are developed and several organizations are experimenting with these concepts, but so far no pilot projects or other guiding approaches that lead to structural changes have been advanced (Rotmans et al., 2001). The latter indicates that the system is indeed in a *predevelopment stage*; the empirical findings confirm this by showing that entrepreneurial activities (F1), knowledge development (F2) and knowledge diffusion (F3) functions score relatively well compared to functions 4-7 (figure 11).

In the *predevelopment* phase, it is anticipated that a poor performance of guidance of the search (F4) is negatively influencing further system development (Luo et al., 2012). The empirical findings, which show that this function is evaluated as *moderate*, back this expectation. As considered by the interviewed stakeholders, barriers for the performance of this function are: deficiencies in the *Wrakkenwet* and *Registration Fast Motorboats* regulations, and a lacking vision to provide direction for the innovation system. One possible explanation for the absence of vessel registration laws is provided by Van der Woude, he speculates that the Dutch Yachting Association (“NJI”) is reluctant to implement a registration register because: “*there is a lot of black money going around in the yachting industry. A registration register would limit the amount of purchases from the criminal circuit*”.

However, this speculation fails to offer a comprehensive explanation for the missing vision to stimulate the development of a circular production model in the innovation

system. The analysis (section 4.1.2) shows that in the changing waste management policy regime of the Netherlands, there is an increasing emphasis on the development of a CE since the introduction of the *Waste to Resources* programme in 2013 (Ministerie van Infrastructuur & Milieu, 2013). Despite this trigger from the Dutch government, *how* the concept should be implemented remains vague and focuses only on a select range of materials in policy documents - such as phosphate and (common) plastics (Ministerie van Infrastructuur & Milieu, 2013). In practice this means that it is not specified how the programme should be operationalized, nor does it offer any binding targets. For this reason guidance of the search (F4) provided by the national government to drive recycling and/or re-use activities is virtually absent. This implies that, in order for the recreational boating system to develop further, the national government could provide a long-term vision with complementary laws and regulations to address the observed institutional issues (Weber & Rohrer, 2012). Specifically, the latter involves the removal of bottlenecks in the *Wrakkenwet* and *Registration Fast Motorboats* laws.

The market formation (F5) and related resource mobilization (F6) functions are evaluated as *weak and moderate* respectively; an indication that the system has indeed not reached the *acceleration* phase (Luo et al., 2012). The interviewed stakeholders perceived different kinds of problems concerning the market formation function. For re-use purposes, there is insufficient demand for boats on the second hand market, and alternative next-life applications are only encountered sporadically. For recycling purposes, competition with cheap and superior virgin materials and missing regulations that mandate a certain recycling rate form barriers that hinder market demand.

The former demonstrates that if the available recycling technologies are not able to simultaneously bring the costs down and enhance the recycle quality, the incapability of these recycled materials to compete with virgin materials will persist. It can therefore be argued that, if the recycling technologies do not improve and virgin materials continue to be relatively cheap, it is likely that market demand for recycled composites remains problematic and keeps hindering market formation (F5). It seems, therefore, realistic to assume that the recycling technologies need a protective environment to enable further development. Here, a governmental body could intervene by shaping the right conditions for the technologies to prosper. For example, by forming a niche market for composite recycle with favorable tax regimes and environmental standards. This would allow actors to improve and experiment with the technologies, as suggested for renewable energy technologies by Hekkert and Negro (2009).

In addition to limited market demand for recycled or re-used composite waste from recreational boats, insufficient financial resources can be mobilized to develop the necessary physical infrastructure. Resource mobilization (F6) barriers are related to an inconclusive business case for recyclers due to: competition with incineration practices; an uncertain waste stream from recreational boats; and regulatory uncertainty about the actor or organization that is (financially) responsible for the adequate disposal of recreational boats.

The inconclusiveness of the business case means that, as long as the different recycling technologies remain more expensive than current incineration practices, there is no incentive to invest in a recycling infrastructure. This implies that the previously mentioned barriers need to be addressed, but also that the associated costs of recycling have to come down in order to compete with waste incineration. The pyrolysis technology, for example, has to decrease the investment and operational (i.e. energy



usage) costs of a facility to make composite recycling economically viable. The chemical method must prove to be economically feasible beyond the laboratory scale, and provide evidence of a high quality recyclate. Such developments are necessary, even when hindering factors such as the uncertain waste stream and regulatory ambiguities are addressed. Otherwise recycling continues to be non-competitive with incineration, which resumes the situation where mobilizing financial resources for the physical recycling infrastructure is challenging (F6). Here, the government could for example intervene by providing subsidy schemes to make return on investment more interesting for projects that are too expensive without said subsidy (Hekkert & Negro, 2009).

From the preceding argumentation it seems reasonable to assume that further development towards *take-off*, *acceleration* and *stabilization* phases not only depends on tackling the identified obstacles in functions 4-6 (section 4.2), but that addressing economic viability of the recycling technologies is also a prerequisite. That is, the technologies keep improving by decreasing costs and increasing the quality of the recyclate. Otherwise the different recycling technologies either remain uncompetitive with incineration practices on the supply-side (F6), or with virgin composite materials on the demand-side of the market (F5).

The last function, creation of legitimacy (F7) scores the lowest. In the preceding section (4.2, function 7) it is, however, already explained that the creation of legitimacy is not a negatively fulfilled function, but rather that vested interests do not prevent this function from performing well. The creation of legitimacy function therefore is not interpreted as a barrier to the development of a circular production model.

The fact that functions 1-3 and 7 are positively fulfilled, in contrast to deficient functions 4-6, is a relevant insight for businesses' that are operational within the recreational boating system. The functional analysis helps individual firms recognize what parts of the system can be a target for action, and what parts of the innovation system are very difficult to change. For example, to stimulate guidance of the search (F4) it is likely that multiple organizations will need to lobby in a collective effort (with governmental agencies and other industrial actors) to direct the recreational boating system towards the development of a circular production model. The mobilization of financial resources (F6) for physical infrastructure (e.g. recycling facilities), on the other hand, is a key process within innovation system that is more easily addressed by individual business strategies.

In sum, the functional analysis (section 4.2) shows that identified functional barriers are quite specific for composite waste from recreational boats, whereas the recognized driving forces are more general in nature. The few recognized drivers are mainly related to promotion and advertisement benefits that stem from selling sustainable products, and the acknowledgement that the production of more sustainable products and services is necessary from an environmental perspective.

Identified barriers, such as: deficiencies in the regulatory framework and lacking government guidance (F4), limited market demand for recyclate due to competition with cheaper and superior virgin materials (F5) and an inconclusive business case to recycle because incineration is more economical (F6) are more explicit for the analyzed system. Since these functional barriers are rather system specific, addressing these processes can only be enhanced by governmental intervention into structural components that build the recreational boating system. In the next section, 4.3, the



underlying reasons for the mentioned barriers, the system failures, are therefore defined. These failures serve as the basis for instruments that can assist policymakers in overcoming barriers to the development of this innovation system.

Before going into the system failures, it must be noted that several relevant aspects of a CE came up during the interviews that could not be compartmentalized in the 7-function TIS-framework. Due to the focus on activities related to recycling and/or re-use technologies, other concepts that are generally associated with a CE could not be classified under one of the seven key processes – e.g. new business models (e.g. Kok et al., 2013; van Renswoude et al., 2015). For example, Smoorenburg mentioned: “*What you increasingly see is that private owners start renting out their boats via websites, like snappcar for boats*”. This statement shows there are businesses that have seized the opportunity of decreasing demand for boat-ownership by facilitating sharing services via online websites. So, unlike in the contemporary situation where boats are mainly purchased by consumers; in this new business model boats are leased, rented or shared whenever possible. According to Kok et al. (2013) this is consistent with the idea that in a CE the concept of a consumer is replaced with that of a user.

The preceding statement shows that another inherent CE concept, besides activities related to recycling and/or re-use technologies, was also observed during the interviews. However, new business models are in essence not *technologies* – the basis of a TIS – but *services*, for which a functional approach is not tailored. So, although the development of new business models is related to the concept of a CE, this could not be linked to one of the key functions in the utilized framework. It is, however, debatable whether boat-sharing services would provide a definitive solution to the challenges that the recreational boating system faces. Several interviewees mentioned, for example, that providing an online sharing platform (website) might prove to be a solution for some composite boats, but that many are in such a state of decay that recycling is the only option.

### 4.3 Identification of System Failures

Based on a joint structural-functional analysis (sections 4.1 and 4.2), in this section the pre-identified systemic weaknesses are outlined. As explained in the literature review (see section 2.3 and appendix B), system failures are underlying reasons for the functional barriers that prevent further system development. These weaknesses are subsequently used as input to justify recommendations for policymakers (section 4.4) to address the failures in a systematic manner.

#### Structural failures

The findings show that two hard institutions, the *Wrakkenwet* and *Registration Fast Motorboats*, are characteristics of the system structure that hinder innovation towards a circular production model for recreational boats. These ambiguous regulations indicate that a *hard institutional failure* is present in the recreational boating system. In addition, the functional analysis (F6) shows that the contemporary system structure lacks the physical infrastructure to adequately dispose the projected number of recreational boats. The absence of clear disposal routes for recreational boats, combined with the nonexistence of composite recycling facilities, shows that a *physical infrastructure failure* exists. The findings (F5) furthermore show that transportation, investment and

operational costs of potential recycling technologies are likely to produce a relatively expensive and inferior recyclate. Due to competition with cheap and superior virgin materials, market demand for recycled composites is consequently lacking; and for waste processors there is no private business case to abandon less expensive waste treatment through incineration. The fact that activities related to recycling and/or re-use technologies are unable to compete with these incumbent substitutes, both on the supply and demand side of the market, results in systemic under-investment in the physical infrastructure (F6). This inability to compete with incineration and virgin material substitutes, due to higher prices and poorer performance, implies that a *market failure* is also present to block further system development.

### **Transformational failures**

The malfunctioning structural parts of the system invoke transformational challenges. Although competition with incumbent substitutes results in under-investment in the physical infrastructure of the system, the market failure argument does not cover issues between the demand and supply side of the market. In other words, if the market does not show demand for recycled or re-used composites from end-of-life boats (F5), waste processors or recyclers are not inclined to mobilize resources in order to supply the recyclate (F6). This mismatch between producers (supply) and users (demand) of composite waste from recreational boats therefore indicates that a *demand articulation failure* is present.

The functional (F4) examination furthermore shows that, despite triggers dedicated to the development of a CE in the Netherlands (i.e. *Waste to Resources*), there are currently no institutions to back further development of a circular production model in the recreational boating system. This indicates the presence of two transformational failures. Firstly, the system lacks guidance and direction from the government, implying that a *directionality failure* exists within the innovation system. Secondly, the generic vision of a CE at the national and EU level is poorly aligned with policies and regulations at the system level. This means that different levels and areas of policy are not coordinated, which indicates that a *policy coordination failure* is present.

In addition to directionality and policy coordination failures, the recreational boating system is unable to identify and reflect on outcomes with respect to the development of a circular production model. The findings (F6) show that composite waste streams, including recreational boats, are not measured or monitored in any way. It is therefore impossible to identify and reflect on transition outcomes, or to alter the process based on this information. This lack of analytical and forward-looking abilities indicates that a *reflexivity failure* exists within the innovation system.

Looking at the findings obtained through the above, it can be said that the recreational boating system does not follow a promising path towards the next development phase. Currently the associated costs of different recycling technologies are higher than for the incumbent substitute (i.e. incineration) and the potential recyclate is unable to compete with virgin materials. Based on the analysis of system functions and failures it can therefore be concluded that, in order to develop further, there is a strong need for three functions (F4-F6) to be strengthened by policy through: coordinated and consistent guidelines and a clear regulative framework, which is aligned with the generic vision to develop a CE in the Netherlands and EU (F4); the stimulation of demand articulation for

re-used or recycled composites from recreational boats, so that waste processors and recyclers are inclined to mobilize financial resources (F5); and the development of a physical disposal and recycling infrastructure, in which the composite waste stream is monitored to allow for reflexive measures (F6).

If the recreational boating system is unable to reach the next development phase, it means that the non-functioning linear production model will continue to exist. Since there is currently no easy or cheap way to dispose of a recreational boat, a continuation of the contemporary model will result in ever more vessels that end up abandoned in harbors, canals and ditches (Waterrecreatieadvies, 2014). Because these recreational boats oftentimes cannot be linked to a responsible owner, the costs of removal and disposal will continue to fall on harbor or local authorities (Marsh, 2013). Outside harbors, local municipalities will become the problem owner, with the consequence of having to pick up the tab when boats are abandoned ashore. Rijkswaterstaat, as the administrator of the Dutch water systems, could continue to bear the costs whenever boats are abandoned in waterways, canals or ditches. Thus, outside private harbors, ultimately it is the local taxpayers who pay (Marsh, 2013; WaterrecreatieAdvies, 2014).

#### 4.4 Recommendations to policymakers

Policy strategies to stimulate drivers and help overcome obstacles to the development of the Innovation System around the recycling and/or re-use of composite boats follow directly from the above.

According to Weber and Rohrer (2012) a clear and shared vision supports systematic change by directing, aligning and inspiring a large number of actors. To overcome the directionality failure, policymakers are advised to establish a shared vision in collaboration with industry associations, governments at various levels and private companies. A clear vision for the future could contribute to kick starting market formation (F5), which in turn, may lead to the attraction of more financial resources (F6) in order to stimulate further development of a circular production model.

In addition to this soft instrument, laws and regulations can influence the behavior of citizens and businesses (McManus, 2009). To overcome hard institutional failures, it is recommended to policymakers that *Registration Fast Motorboats and Wrakkenwet* laws are to be revised and modified. To resolve issues with the former, it would be possible to document *every* recreational boat in a central register. This could, for example, help linking boats to owners, and make these owners feel more accountable for the adequate disposal. Whenever a boat and owner are linked, it could discourage boat abandonment and simultaneously facilitate clarity about the age and docking location of boats. This clarification may contribute to overcoming hindering factors with respect to waste stream uncertainties that surround recreational boats (F6).

Furthermore, as an unintended consequence of ambiguity in the *Wrakkenwet*, it is currently often unclear what actor or organization is (financially) responsible for the disposal of composite boats that are abandoned. Policymakers are therefore advised to revise this law, so that in the future it does become clear *who* is legally responsible for the disposal of abandoned boats. At present, local municipalities or Rijkswaterstaat become the problem owners. To ensure that these taxpayer funded governmental

bodies do not have to pick up the tab, one possibility would be to implement a disposal fee on newly purchased boats. With the funding that is generated from such a fee, disposal issues of abandoned boats can, at least in the short run, be settled financially. For example, governmental agencies can use these generated funds to either pay a third party for removal of a boat, or offer a financial incentive to boat owners that dispose of their boat in an adequate way.

Suggested modifications to the *Wrakkenwet* and *Registration Fast Motorboats* do need to be in line with other laws and regulations at various levels of government. Weber and Rohrer (2012) argue that it is important for system development to coordinate policymaking at the sectoral, national and EU level. To overcome the policy coordination failure, policymakers are therefore advised to align the shared vision and revised regulations at the system level with national (e.g. “*Waste to Resources*”) and EU (e.g. “*Circular Economy Package*”) legislation. This may settle potential conflicts between various levels of government in the future as a result of legislative changes.

Although the previous strategies are aimed at a reduction of boat abandonment, they do, however, not necessarily stimulate the development of recycling and/or re-use activities over the incineration of composite boats. In order for the recreational boating system to be able to support such activities, there is a need for physical recycling facilities and a disposal infrastructure to close material loops. At present, the non-existent physical infrastructure is the result of a market failure; there is a lack of niche market formation where the stability and profitability of recycling technologies is guaranteed. Policymakers of governments have the ability to address market and demand articulation failures that are at the basis of systematic under-investment in the physical infrastructure (F6).

Namely, governments are major investors that can use their procurement power to stimulate novel solutions from the demand side, by acting as a ‘launching customer’ (Weber & Rohrer, 2012). This could, for example, include a public procurement contract with suppliers of goods that are made from recycled composites to ensure sufficient and stable demand. In this way market failures can be addressed by forming a niche market (Kemp et al., 1998), so that recycling and/or re-use activities are offered a protected space wherein related technologies do not have to compete with incineration. This means that composite recycling technologies are (initially) shielded from price based market selection, which hampers market formation (F5).

Whenever a market for composite recycle forms, waste processors and recyclers are, in turn, more inclined to mobilize the necessary financial resources (F6) to develop the physical disposal and recycling infrastructure. Besides the previously mentioned measures on the demand side, policymaker may additionally assist in overcoming resource mobilization barriers by implementing a subsidy scheme or tax exemption for investing in specific technologies (Hekkert & Negro, 2009). This could make return on investment more interesting for activities related to recycling and/or re-use technologies that are otherwise too expensive.

Another barrier for the mobilization of financial resources is the uncertain composite waste stream from recreational boats. Van Mierlo et al. (2010) suggest that by establishing reflexivity instruments such as monitoring activities, actor interactions or experiments, a smoother development process is acquired. By providing a platform for

network meetings with key stakeholder groups, feedback discussions and monitoring activities can be stimulated by policymakers. For example, by setting-up a procedure to measure and quantify the composite waste stream from recreational boats. To ensure proper monitoring it makes sense to use the network of established industry associations, such as the VKCN, NRK and NWEA (Krebbekx & Lintmeijer, 2015), to provide insight into the yearly waste stream. Obtained results from the monitoring activities can then subsequently be discussed during stakeholder meeting to reflect on transition outcomes.

In sum, in order to strengthen the system's functionality with respect to the development of a circular production model, in this section several examples of policy instruments are outlined that can be used to address the previously identified system weaknesses. From the above it can be concluded that policymakers may need to primarily focus on the market and institutional environment. Namely, most barriers for the development of a circular production model were identified in relation to the market for composite recycling (e.g. market and demand articulation failures; and functions 5 and 6) and non-functioning or absent institutions (e.g. hard institutional, policy coordination and directionality failures; and function 4).

## 5.0 Discussion

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This discussion section first offers a comprehensive account of this thesis' main objective, empirical findings and theoretical implications for Technological Innovation Systems (section 5.1). Subsequently research limitations and recommendations for future research are presented (section 5.2).

### 5.1 Theoretical implications

This thesis was set out to explore sustainable industrial transformations in the context of accelerating the development towards a Circular Economy. The central proposition of this thesis is that a TIS-approach can be used as a building block to explain the development processes of sustainable industrial transformations, and to suggest innovation policies to direct this development towards a particular goal. From the literature review a conceptual framework was derived that both combines and interlinks the main theoretical concepts in TIS-studies to explain what factors – structure, functions and failures – drive or block the development of an innovation system (figure 3). This framework is subsequently used to map and analyze system failures, expressed in functional terms, which block the development of the Innovation System around the recycling and/or re-use of composite boats in the period 2015-2016. In doing so, it is one the first times a TIS-approach is used in empirical research to go beyond the diffusion of a specific sustainable technology to address the challenge of transforming industrial production and consumption models.

The proposed functions and failures of the conceptual framework agree well with the empirical data and appear to confirm that these factors are indeed appropriate for identifying drivers and barriers of the systemic development process. The findings suggest that most functions, as proposed by Hekkert et al. (2007), are also recognized key processes in the context of a transition from a linear to a circular production model. One possible exception is the creation of legitimacy (F7) function, since 4 interviewees did not consider vested interests in the status quo to be relevant for the system. An explanation for this discrepancy may be that it is too early, development phase wise, for vested interests to perceive the development of a circular production model as a threat.

The empirical findings of the functional analysis moreover show that the first three functions are positively fulfilled, in contrast to successive functions (F4-F6). This pattern confirms the predictive framework as accurate; specifically, the findings concur with the literature (Luo et al., 2012) in that functions 1-3 are expected to be critical in a *predevelopment* stage, whereas poor performance of functions 4-6 blocks further system development. This implies that the transition from a linear to a circular production model in the Innovation System around the recycling and/or re-use of composite boats follows a distinct functional interaction pattern, consistent with that presented by Luo et al. (2012). It should be noted, however, that there is no optimal functional pattern or 'ideal way' in which a system develops (Bergek & Lindmark, 2008; Hekkert & Negro, 2009). Recognizing the needs of functions 4-6 does, however, allow policymakers to distinguish the processes and structures of the system where policy intervention is likely to matter most (Jacobsson & Bergek, 2011).

Based on the evaluated system functions, 3 out of 5 structural failures and all transformational failures were identified in the recreational boating system. The fact that all transformational weaknesses were recognized implies that these novel failures,



presented by Weber and Rohrer (2012), are indeed complementary to the already established structural failures in innovation systems literature (Klein Woolthuis et al., 2005). This system condition where most failures were identified is not unique; other TIS-research (Negro et al., 2007) also indicates that multiple system failures can occur at the same time. This implies that policy strategies may need to simultaneously overcome all the barriers that the structural and transformational elements face (Jacobsson & Bergek, 2011).

All in all, this thesis showed that a TIS-approach is indeed useful as a building block for explaining the development of a circular production model in the analyzed system. The examination of system functions, failures and structure assisted in identifying what the needs of the Innovation System around the recycling and/or re-use of composite boats are, and *how* the system has to change in order to accommodate the transition from a linear to a circular production model. These insights are not only serving the objective of this research, but are also a first empirical attempt at extending the TIS-approach towards sustainability transitions – a novel research field aimed the transformation of industries towards more sustainable modes of production and consumption (Markard et al., 2015). Although no new functions or failures were identified in this new context, this thesis shows that a TIS-framework indeed appears suitable for identifying drivers and barriers to the sustainability transition in the recreational boating system. In practice, this research thereby demonstrated its value for policymakers in determining appropriate policy strategies aimed at overcoming transition obstacles, a topic that has not been prominent in transition management literature yet (Weber & Rohrer, 2012).

## 5.2 Research limitations and suggestions for future research

Although the empirical findings provide an evaluative perspective on the drivers and barriers to shift from a linear to a circular production model in the recreational boating system, several limitations exist that should be taken into account, particularly when considering using the conceptual framework or findings in future research.

A first consideration is related to the unfolding of the system development in the selected case study. Since a circular production model is not fully entrenched in the recreational boating system, the object of analysis has not yet moved through all the development phases (as outlined by Rotmans et al., 2001). As a direct consequence, later phases of this ongoing development process - the take-off, acceleration and stabilization stages - are not part of the analysis. This means that it cannot be established whether policy instruments, aimed at diminishing system failures by strengthening the functional needs of later phases, will actually take the transition from a linear to a circular production model in the recreational boating system forward. This progress may, for example, also depend on the response of businesses to governmental encouragement; which in nature varies per sector, industry structure and cross-national considerations (Moon, 2004).

In case the system advances, it is furthermore unclear from the interviews which of the competing recycling technologies would be most viable and who is responsible for the development and employment of this technique. Van de Ven (2005) suggests that knowledge-intensive technologies are often more successful when entrepreneurs 'run in packs'. This means that the development and commercialization of competing

technologies in an emerging industry have a greater chance of success when entrepreneurial firms collaborate in networks to bundle resources, power and legitimacy. The practical implications of such collective action would be that, in order to compete successfully with waste management through incineration, entrepreneurs should collaborate and concentrate on one preferred recycling technology to commercialize. How actors collaborate and coordinate their actions in 'shaping' further development of a system, as well as the role of competition and conflicts therein is not discussed in TIS-literature (Farla et al., 2012; Markard & Truffer, 2008) or in the conceptual framework, but may also prove to be a determining factor that triggers or hampers the development of a circular production model in the recreational boating system.

Moreover, it should also be considered that this research has taken an 'inward' oriented perspective. This means that successful development is perceived as a consequence of the system's performance (Markard et al., 2015), thereby (largely) excluding the external environment of the recreational boating system. Fluctuating oil prices are, for example, very important for the circular production process of composites. Namely, Schrama (personal communication, 2015) argued that when oil prices drop, the incentives to recycle and/or re-use composites decrease. Thus, the exogenous environment of the system (i.e. rising oil prices) can also influence the transition from a linear to a circular production model, but cannot be allocated in the used framework or influenced by policy intervention at the system level. Other imaginable changes in the exogenous environment that may influence the system development process are: economic growth and support from political coalitions (Geels & Schot, 2007). Socio-technological transition approaches (e.g. MLP) that do include a macro-level perspective of the socio-technical landscape (Geels & Schot, 2007; Rotmans et al., 2001) may therefore identify different factors that trigger or hamper further development of the analyzed innovation system.

In summary, exclusion of the business response to governmental encouragement, the role of collective action by actors and the system's external environment are considerations that decrease the internal validity of this research.

The previously mentioned considerations demonstrate that, although the conceptual framework proved to be a practical instrument to analyze where system development obstacles occur, it is not asserted that a TIS-framework addresses all the relevant drivers and barriers to shift from a linear to a circular production model. Future research may therefore attempt to widen the conceptual framework by expanding it with additional concepts and theories; for example, by incorporating previously described factors such as the commercialization of competing technologies (van de Ven, 2005), actor collaboration and collective action (Farla et al., 2012; Markard & Truffer, 2008) and the exogenous environment (Geels & Schot, 2007; Markard et al., 2015). By taking a more actor-oriented perspective that includes the exogenous environment in future research, previously mentioned limitations of this research can be addressed. Thereby complementary insights may be generated that enhance the explanatory power of the proposed conceptual framework.

In addition to a theoretical expansion, it is recognized that the examined case study – the recreational boating system – is quite particular in that it involves a CE challenge for which solutions are largely dependent on multiple distinct recycling technologies. For

further testing of the conceptual model in the studied context, a stronger case could be made by performing a comparative case study (Kaarbo & Beasley, 1999). In this way a systematic comparison can be made between similar systems developed elsewhere, or to compare different industries. For example, this may include other applications in the composites industry, such as: windmill blades, car frames, sluice gates and aircraft parts (Witten, 2012).

It is furthermore necessary to determine if the conceptual framework is also applicable in context of other system characteristics and challenges. From the analysis it became apparent that non-technology related services, such as new business models (online boat-sharing), do not easily match with the functional processes. This implies that the conceptual framework may not be suitable for every CE challenge. Future research may therefore be directed at determining what kind of CE challenges the framework can approach, and under which conditions these challenges can be addressed.

## 6.0 Conclusion

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Within the context of a CE it is recognized that the linear ‘take-make-dispose’ model needs rethinking, so that waste materials are not disposed of by incineration or landfill but are re-introduced as input for the same or another production process, i.e. a circular production model. An industry where a circular production model offers economic and environmental opportunities, but where there is a large gap between aspirations and practice, is in the composites industry. Consequently this thesis sought to answer main research question: “*What factors trigger or hamper the transition to a circular production model in composites industry, and how can Dutch policymakers accelerate drivers and overcome barriers?*” through the use of an Innovation Systems approach.

To provide an answer to the main question, this thesis analyzed a case study: the Innovation System around the recycling and/or re-use of composite boats. This system consists of a variety of experienced industrial actors, SMEs, entrepreneurial start-ups, knowledge institutes and support organizations that are involved with the production, use, collection, recycling and/or re-use of composite boats in the period 2015-2016.

From the case study it was found that the main triggers for moving materials in closed-loops are related to social and environmental benefits, which were expressed for the first time in the *Waste to Resources* (“Van Afval Naar Grondstof”) programme of the Dutch government in 2013. Within the examined innovation system, knowledge and information about the ambition to develop a circular production model is widespread; this shows, for example, through announcements in various industry reports and during ‘recycling’ conferences. Drivers for the development of a circular production model are related to the acknowledgement that the production of more sustainable products and services is desirable from an environmental perspective, and that it can potentially result in advertisement benefits for individual firms. However, although these factors drive the development of a circular production model, at present the system has not moved beyond a *predevelopment* phase. The functional analysis shows that this stagnation is caused by a problematic functional pattern, in which barriers block further development of activities related to recycling and/or re-use technologies in the innovation system.

Currently, the institutional environment in which the innovation system needs to function is not providing any guidance of the search (F4) to stimulate the development of a circular production model. This is demonstrated by the lack of a clear and long-term vision for the system (i.e. *directionality failure*), in combination with regulative policies at the system level that are unaligned with national and EU objectives of creating a CE (i.e. *policy coordination failure*). The latter is specifically shown by deficiencies in *Registration Fast Motorboats* and *Wrakkenwet* regulations (i.e. *hard institutional failure*). To overcome these barriers, policymakers could establish a shared vision for the innovation system in collaboration with industry associations, governments at various levels and private companies. A clear vision for the system that is aligned with (supra)national legislation could contribute to kick starting market formation (F5), which in turn, may lead to the attraction of more financial resources (F6) in order to stimulate further system development.

In the market environment the main barrier is that, due to the overall associated costs of composite recycling; the recycle is unable to compete with cheap and qualitatively superior virgin materials (i.e. *market failure*). This competition hinders demand for recycled composites (i.e. *demand articulation failure*) and consequently forms a barrier to market formation (F5). To overcome these barriers, policymakers could develop protected niche markets to ensure that activities related to recycling and/or re-use technologies are (initially) shielded from price based market selection. This offers a possibility for these technologies to improve and reduce their associated costs. The government could subsequently articulate demand for composite recycle, by acting as a launching customer.

Since there is currently little demand for recycled and/or re-used composites, investors are not inclined to mobilize financial resources (F6) for a disposal and recycling infrastructure (i.e. *physical infrastructure failure*). At present it is economically unfeasible for recyclers and waste processors to opt for recycling and/or re-use activities as long as the different technologies remain more expensive than the incumbent substitute: incineration. This economic unfeasibility, combined with waste stream monitoring issues (i.e. *reflexivity failure*) and legal ambiguity about the actor that is financially responsible for the disposal of recreational boats, hinders the mobilization of financial resources.

To overcome the physical infrastructure failure, policymakers could fuel the mobilization of financial resources by implementing subsidy schemes or tax exemptions for investing in composite recycling technologies. This could make return on investment more interesting for projects related to recycling and/or re-use technologies that would otherwise be too expensive. To overcome the reflexivity barrier, policymakers could establish a procedure to measure and quantify the composite waste stream. This may ensure that stakeholders can reflect on system development outcomes.

In conclusion, the TIS-approach proved to be useful in providing an answer to the main question. Although general benefits of a circular production model trigger systemic development, the framework pointed to institutional, economic, technological, structural and transformational barriers that block this development process through negatively fulfilled guidance of the search, market formation and resource mobilization functions. Overcoming these barriers is not an easy task, but policymakers may attempt to influence development of the recreational boating system by for example: institutionalizing a clear and shared vision, developing protected niche markets, implementing tax exemptions or subsidy schemes, and by monitoring the composite waste stream.

## 7.0 Recommendations for the client

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In the conclusion several general policy instruments were advised to policymakers. In this section more practical recommendations to Rijkswaterstaat are provided, subdivided in advice for the short and long term. These recommendations mostly stem from the interviews that were conducted with relevant stakeholders in the research field. The recommendations below are not intended to pose as a definitive solution for the development challenge that the Innovation System around the recycling and/or re-use of composite boats faces, since it is not within the power of one actor (Rijkswaterstaat in this case) to influence key processes in the entire innovation system. Rather, advice for action and/or further investigation that falls under the control of Rijkswaterstaat is provided that may stimulate the development of a circular production model.

### Short term

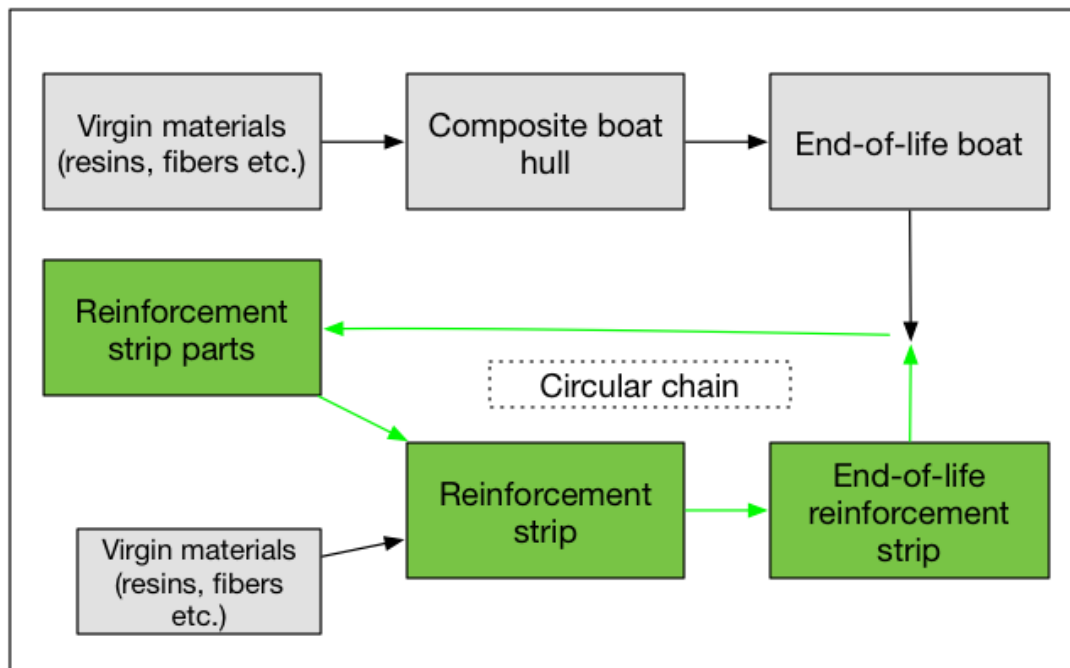
- The analysis showed that it is currently difficult to make activities related to recycling and/or re-use technologies economically viable. This is on the one hand initiated by technological deficiencies, which causes the recycle to be of inferior quality to virgin composites with higher associated costs; and on the other hand by uncertainty about the composite waste stream from end-of-life boats. Although the former is difficult to influence by Rijkswaterstaat, it is possible to set-up measurement and monitoring activities to gain insight into *when* boats become available for recycling and/or re-use purposes and *where* they are located. For example, by implementing a *'vignette with chip'* ("vignet met chip"). The implementation of such a vignette, the use of which has already been demonstrated in Amsterdam (WaterrecreatieAdvies, 2014), allows the local authorities to scan from a distance whether boat owners have paid their docking fees in a central register. It is therefore recommended to Rijkswaterstaat to investigate whether a similar system, where boats are traceable and their owners are registered, could be employed nationwide to provide additional insight into the end-of-life boat waste stream.
- Whenever a central register is established, it simultaneously becomes possible for Rijkswaterstaat (or another governmental body) to introduce a funding system for the dismantling and recycling of recreational boats. One could think of a system where, at the time of purchase, consumers pay a recycling fee into a common fund that is managed by Rijkswaterstaat. Another way to complement the fund would be through the establishment of a small yearly contribution from boat-owners. The financial resources that are gathered in this fund can subsequently be used for the disposal and recycling of recreational boats. The fund could also be used by Rijkswaterstaat to start a tender. One interviewee suggested for example: *"Start a tender: who has the best idea to remove and recycle the boats that are currently in the water in need of disposal?"*
- With regard to continuity of the composite waste stream, it is furthermore advised to Rijkswaterstaat to further investigate whether different composite waste streams can be merged. Whenever the composite waste stream is more predictable and bigger in volume, it becomes more interesting for investors to mobilize financial resources to set-up a recycling and/or re-use infrastructure. Compared with other composite markets such as wind-energy, composite waste from recreational boats represents only a tiny fraction (Witten, 2012). Hence one interviewee indicated that: *"To*



achieve a continuous input, combining composite waste streams of boats and windmill blades could be a possibility". Another potential waste stream stems from the automotive segment of the composites industry. According to the Dutch Polymer Institute (2015) it is expected that the use of composites in the automotive market will grow exponentially in the coming years. Because the timeframe of this thesis did not permit to examine whether merging the composite waste streams of cars, windmill blades and recreational boats is technically and/or economically feasible, it is therefore advised to Rijkswaterstaat to further pursue this prospect.

### Long term

- The analysis showed that contemporary recycling technologies for composite boats will never be able to ensure a fully closed-loop. Mechanical grinding, chemical solvents and pyrolysis all reduce the fiber strength of the composites boat-hulls, thereby making it impossible to re-introduce these materials in the production process of new products (boats) with the same properties. A different approach that was encountered during this research is: not to recycle a boat by reducing it to the basic elements (resin, glass fiber and filler), but instead use the positive attributes of composites - high strength to weight ratio, corrosion resistive, rigid and a long lifespan - in new applications or 'semi-products' made from composites. An example of such an application that is particularly interesting for Rijkswaterstaat is a proto-type 'reinforcement strip' that has been developed by the Windesheim Hogeschool in the context of the *Waste to Resources* programme. The idea is that these reinforcement strips can be used in the construction of civil infrastructure (e.g. bridges, sluices), and whenever these strips reach an end-of-life stadium they can be entirely re-used and/or recycled. So, in this case a circular production model is not established for a recreational boat, but for a 'semi-product' that is composed of re-used materials that originate from the boat hull. An example of what such a circular product chain could look like is depicted in figure 12 below.



**Figure 12** – Example of a circular product sequence (ten Busschen, 2016).

Although these reinforcement strips are still a proto-type, and their functionality and economic feasibility is still uncertain, it is recommended to Rijkswaterstaat to further examine whether these strips could provide a solution to the challenges that end-of-life boats face. For Rijkswaterstaat it could be interesting to study whether these strips, or another product that adheres to the circular product sequence as described in figure 12, could be of use for one of Rijkswaterstaat's prime tasks: the design, construction, management and maintenance of the main road and waterway infrastructures in the Netherlands (Rijkswaterstaat, 2015b). In the long term, this could possibly provide an elegant link between the waste challenge of composite boats and Rijkswaterstaat's main responsibilities.

- In order to facilitate the process as described in figure 12, it is essential in the long run that products and components of composite boats are re-designed in such a way that they are easier to deconstruct, re-use and recycle at the end of product life. In the context of a CE, this consideration during the design phase of a product is referred to as 'design for recycling' or 'design for re-use' (Kok et al., 2013). Although Rijkswaterstaat is of course not responsible for the design of recreational boats, it is possible for governmental bodies to put additional pressure on solving composite waste management challenges. For example, EU directives such as the End-of-Life Vehicle (ELV) require that vehicles have to be re-used or recycled (excluding energy recovery from incineration) for 85% since 2015 (Dutch Polymer Institute, 2014). Similarly a target for recreational boats could be imposed, so that boat builders have to incorporate the end-of-life phase in their design. In the long run, for the next generation of recreational boats this could make it easier re-introduce composite materials into the production processes at the end of product (boat) life.

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## Appendices

### Appendix A: Description of Rijkswaterstaat

Rijkswaterstaat, currently employing 8.483 fte's, is part of the Ministry of Infrastructure and Environment in the Netherlands (Rijksoverheid, 2015b). Its main responsibility lies in the design, construction, management and maintenance of the Dutch infrastructure facilities (Rijkswaterstaat, 2015b). These facilities include road and waterway networks and the main water systems. Besides these prime tasks, Rijkswaterstaat is responsible for the implementation of European and national legislation regarding waste management and prevention. In order to meet the challenges in the traditional waste management field, there is currently the long-term ambition to achieve a Circular Economy in the Netherlands (Rijkswaterstaat 2015a). To meet this challenge, Rijkswaterstaat aims to prevent and reduce waste streams, but also to minimize the environmental impact of waste treatment and material chains through integrated chain management. Therefore Rijkswaterstaat assists companies in interpreting end-of-waste criteria and is responsible for the green public procurement (Rijkswaterstaat, 2015a).

### Appendix B: Overview of system failures

Table 8: Overview of structural failures.

Type of failure	Failure mechanism	Description
Structural system failures	Market failure	A market failure can be the result of the competition with incumbent substitutes. New products or services tend to be associated with high prices and poorer performance (Negro et al., 2012). So, when the bridge between an incumbent linear and circular production model is too large, a transition may never have to chance to resolve these initial disadvantages.
	Capabilities failure	Actors can suffer of innovation problems due to: lack competences, capacity to learn or utilize resources (Klein Woolthuis et al., 2005). Smith (2000) argued that actors are likely to concentrate on 'what they know best'. This failure can prohibit the development of a circular production model, as actors may lack the capabilities to change their 'business as usual' (Kok et al., 2013).
	Institutional failure	Innovation can be stimulated or hindered by the wider political and social context (Smith, 2000). Hard institutional problems can result in an appropriability trap, favoring incumbent firms. Soft institutional problems can hinder innovation by a lack of support for new developments or processes (Wieczorek & Hekkert, 2012). This could for instance be the case when negative externalities are not adequately regulated in the conventional linear production model.



Interaction failure	Interaction failures can appear in different ways, there can be either too little or too much interaction between actors to accommodate the development of a circular production model. This is why Carlsson and Jacobsson (1997) differentiate between weak and strong network failures. Strong network problems may occur due to dominating actors, over involvement of incumbent actors or myopia, i.e. internal orientation that blocks the necessity to open up external forces (Wieczorek & Hekkert, 2012). On the other hand, problems caused by weak connectivity may hinder learning and innovation (Nooteboom et al., 2007).
Infrastructure failure	The quality of physical, knowledge and financial infrastructure may be inadequate to facilitate an innovation. Infrastructural elements are in general characterized by a large scale, indivisibility and a long-time horizon (Klein Woolthuis et al., 2005). For example, in the context of developing a circular production model, it may be that deficits in the existing physical collection or transportation infrastructure are needed to enable transition activities.

Source: adapted from Bergek & Lindmark (2008); Klein Woolthuis et al. (2005); Negro et al. (2012); Weber & Rohracher (2012).

## Appendix C: Failure indicators

The list of indicators below is used to identify system failures. Whenever a functional barrier, as taken by the interviewed stakeholders, contains one of the described indicators (table 9), it implies that a broader systemic problem is in effect.

Table 9: List of indicators to identify system failures.

Type of Failure	Indicator
Directionality failure	<i>A functional barrier is caused by a lack of direction from the government to stimulate the development of a circular production model.</i>  Keywords: <i>lack of direction, no collective orientation, no shared vision</i>
Demand articulation failure	<i>A functional barrier is caused by a lack of demand from the market for recycled or re-used composites, and consequently actors are not inclined to mobilize resource to supply the recycle.</i>  Keywords: <i>little demand for recycle, mismatch between supply and demand</i>
Policy coordination failure	<i>A functional barrier is caused by policies that are poorly aligned to warrant coherence between activities of (supra)national, sectoral and technological institutions.</i>

	Keywords: <i>conflicting, unaligned or incoherent policies</i>
Reflexivity failure	<i>A functional barrier is caused by the inability to identify and reflect on transition outcomes with respect to the development of a circular production model.</i>
	Keywords: <i>inability to monitor, no self-governance, no measurement tools, lack of anticipation by actors</i>
Market failure	<i>A functional barrier is caused by recycling and/or re-use activities that cannot compete with the incumbent substitute.</i>
	Keywords: <i>higher costs, poorer performance</i>
Capabilities failure	<i>A functional barrier is caused by actors that lack the appropriate competencies and resources to develop a circular production model.</i>
	Keywords: <i>lack of knowledge, inability to adapt to new circumstances, not open to opportunities</i>
Institutional failure	<i>A functional barrier is caused by hard and/or soft institutions that do not stimulate the development of a circular production model.</i>
	Keywords hard institutions: <i>absence or non-functioning laws, regulations and standards</i> Keywords soft institutions: <i>no or non-functioning social norms, lack of expectations</i>
Interaction failure	<i>A functional barrier is caused by actors that fail to interact and cooperate.</i>
	Keywords: <i>non-intensive cooperation, no exchange of resources, weak ties between actors</i>
Infrastructure failure	<i>A functional barrier is caused by the absence of the necessary physical, knowledge or financial infrastructure to develop a circular production model.</i>
	Keywords: <i>no physical infrastructure, little return on investment, insufficient technological knowledge</i>

## Appendix D: Semi-structured Interviews

### Appendix D.1: Overview of Interviewees

Below the carried out interviews with actors that are involved in the research field are listed.

Table 10: Overview of interviewees.

#	Actor	Company	Location	Date	Name
1	Governmental body	Rijkswaterstaat	Utrecht	17-12-2015	E. Schut
2	OEM	Poly Products B.V.	Werkendam	07-01-2016	J. Schrama
3	Raw material supplier/producer	Bouwmeester Advanced Composites	Amsterdam	11-01-2016	J. Bouwmeester

4	Recycling (prospective)	YF International	Duiven	12-01-2016	K. Hauwert
5	Consultant	BiinC	Skype call	13-01-2016	B. Drogst
6	Recycling (prospective)	Fibercare	Eemnes	18-01-2016	B-J. van der Woude
7	Market research consultant	Waterrecreatie Advies	Skype Call	21-01-2016	R. Steensma
8	Collector and Dismantler	Stichting Jacht Recycling	Nieuwkoop	22-01-2016	H. van Smoorenburg
9	Knowledge Institute	Windesheim Hogeschool	Almere	28-01-2016	A. ten Busschen
10	OEM	Jachtwerf Schaap Ship Care	Lelystad	02-02-2016	L. Schaap
11	Raw material supplier	Aliancys (DSM composites)	Breda	05-02-2016	T. Wegman
12	Waste Processor	Van Gansewinkel	Eindhoven	10-02-2016	M. van Eersel

#### Appendix D.2 Interview questions

Although different innovation systems may contain similar structural components, how they function can be entirely different. In order to provide an answer to the 'how' question, the functioning of the system needs to be assessed by expert or key stakeholders (Luo et al., 2012). Semi-structured interview questions will therefore be used to identify which functions, in the perception of the interviewee, drive or block the development of the Innovation System around the recycling and/or re-use of composite boats. Based on the answers, it is possible to distinguish structural or transformational failures based on negatively fulfilled (i.e. deficient) functions. Besides assisting in the identification of functions and failures, these questions are also meant to establish the current phase of development. The questions are ordered according to the seven system functions (F1-F7), which is part of the entire interview set-up as outlined below. Because some system functions are inter-related, an interviewee's answer can also address multiple functions at the same time.

At the end of the interview, the interviewee was requested to assess the functional performance of the system. By means of a survey form with a 5-tier scale - ranging from very weak (1) to weak (2), moderate (3), strong (4) and very strong (5)- the interviewees were requested to evaluate the performance of each function with respect to the development of a circular production model for recreational boats. All in all, the interview was structured as follows:

- i. Introduction of the researcher and description of the purpose of this thesis.
- ii. When necessary, a brief explanation of the CE concept is provided.

**F1: Entrepreneurial experimentation**

1. What is currently happening with end-of-life composite waste streams, and are there stations where the composites can be handed in?
2. Do you know of any entrepreneurs that are experimenting with new technologies or applications to work towards a more circular production model for composite waste from recreational boats?
3. At what stage of development are these experiments: are they fully commercial or still in an experimental phase?

**F2: Knowledge development**

1. How far are recycling and/or re-use technologies developed with regard to composite from recreational boats?
2. What is necessary to further develop this knowledge?

**F3: Knowledge diffusion through networks**

1. Who is currently responsible for the removal and processing of composite waste from recreational boats?
2. How conscious are companies and consumers of the recycling and/or re-use options for composite waste from recreational boats?
3. How do different stakeholders and actors exchange knowledge about this subject?

**F4: Guidance of the search**

1. How is the government influencing the development of a circular production model for composites from recreational boats?
2. What legislations, regulations or policies are blocking companies from adopting recycling and/or re-use methods for composite waste from recreational boats?

**F5: Market formation**

1. Is there a market for recycled and/or re-used composites from recreational boats?
2. If so, is the size of the market sufficient and are there adequate financial incentives?
3. If not, what is needed in order to develop such a market?

**F6: Resource mobilization**

1. What are the incentives to invest financial and human resources in the development a circular production model for composites from recreational boats?
2. If there are no incentives, what is needed in order to mobilize financial and human resources to instigate such a transition process?

**F7: Creation of legitimacy**

1. Do you see any resistance from vested interests towards circular solutions for composite waste from recreational boats?
2. If so, what would be needed to overcome their resistance to such a transition?

- **Recommendation: What should be done to facilitate the development of a more circular production model for composite waste from recreational boats?**

- **Is the government important in this process?**
- **What do you think Rijkswaterstaat can do in particular?**

<b><i>Evaluation*</i></b>	Very weak	Weak	Moderate	Strong	Very Strong
(F1) Entrepreneurial activities	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
(F2) Knowledge development	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
(F3) Knowledge diffusion through networks	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
(F4) Guidance of the search	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
(F5) Market formation	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
(F6) Resource mobilization	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
(F7) Creation of legitimacy	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

\*Whenever a function is deemed irrelevant for the development of a circular production model, no score should be assigned.

### Appendix E: Overview of actors in the recreational boating system.

The tables below provide an overview of the companies that are active in the supply chain of composite boats in the Netherlands. The actors are obtained from the company guidebook of the association for plastics and composites (“VKCN”) and the company index of the yachting industry in the Netherlands (JachtbouwActueel, 2015; VKCN, 2015). Every company in the VKCN (2015) index that is referenced to as in the shipbuilding and yachting sector is included in the tables below. Also, every company in the JachtActueel (2015) index that is connected to composite materials is incorporated in the lists. These indexes allow distinguishing raw material suppliers, composite producers and Original Equipment Manufacturers (OEMs), engineers and designers, dismantlers, recyclers and consultants (see appendix E.1). Additionally, in appendix E.2, knowledge and education institutes are provided.

Although it is aimed to provide the most extensive overview of the recreational boating system it possible that, due to the dispersed nature of a large amount of (small) actors, important stakeholders are unintentionally left out. Because there are more than 200 original equipment manufacturers (OEMs), only the interviewed actors are listed by name.

#### E.1: Industrial Actors

Raw Material Supplier (4)				
#	Company	Location	Name	Email

1	Chromaflo Technologies B.V.	Maastricht	E. Beckers	Europe@chromaflo.com
2	Aliancys (DSM composites)	Zwolle	R. van de Laarschot	Rob.laarschot-van-de@dsm.com
3	Advanced Plastics	Zeewolde	R. van Esch	r.vanesch@advancedplastics.nl
4	Brands Structural Products B.V.	Stellendam	J. Struik	Hansstruik@brandscomposiet.nl

#### Composite Producer/ Original Equipment Manufacturer (270)

#	Company	Location	Name	Email
10	Poly Products B.V.	Werkendam	J. Schrama	info@polyproducts.nl
16	Schaap Composites B.V.	Lelystad	L. Schaap	info@schaapcomposites.nl
19	Bouwmeester Advanced Composites	Amsterdam	J. Bouwmeester	sp-bac@planet.nl

#### Engineering/design (5)

#	Company	Location	Name	Email
1.	Lightweight Structures B.V.	Delft	A. Verheus	info@lightweight-structures.com
2.	CEEMO Engineering	Maarssen	C. Mollema	info@ceemo.nl
3.	Composite Technology Centre B.V.	Hengelo	J. ter Laak	info@ctcgroup.nl
4.	Solico B.V.	Oosterhout	H. Muller	hm@solico.nl
5.	Lightweight Structures B.V.	Delft	A. Verheus	info@lightweight-structures.com

#### End-of-life Boat Collectors and Dismantling (3)

#	Company	Location	Name	Email
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1.	Stichting Jacht Recycling	Nieuwkoop	H. van Smoorenburg	hans@jacht-recycling.com
2.	Marine Recycling Goossens	Hijen	R. Goossens	info@marinerecycling.nl
3.	'T Harpje	Enkhuizen	B. van der Pijll	info@bootsloperij.nl

Waste Processors (5)				
#	Company	Location	Name	Email
1.	Fiber Care (prospective)	Almere	B-J. van der Woude	info@fibercr.nl
2.	YF International	Duiven	K. Hauwert	klaas@yfint.nl
3.	ExtremeEcosolutions (prospective)	Nijkerk	S. Verheijen	info@extreme-ecosolutions.com
4.	Van Gansewinkel	Eindhoven	M. van Eersel	Marthien.van.Eersel@vangansewinkel.com
5.	Sita	?	H. Schoemaker	Henk.Schoemaker@sit.nl

Support Organizations (3)				
#	Company	Location	Name	Email
1.	BiinC (consultant)	Zwolle	B. Drog	info@biinc.nl
2.	WA Yachting Consultants	Lelystad	R. Steensma	info@wa-yachtingconsultants.com
3.	Rijkswaterstaat	Utrecht	E. Schut	evert.schut@rws.nl

## E.2: Knowledge Institutes

Knowledge Institutes (5)				
#	Company	Location	Name	Email

1.	TU Delft	Delft	A. Beukers	a.beukers@lr.tudelft.nl
2.	Instituut voor Composietontwikkeling (ICO)	Emmeloord	A. Zandstra	a.zandstra@icobv.nl
3.	Noordelijke Hogeschool Leeuwarden, Kenniscentrum Jachtbouw	Leeuwarden	J. Steenmeijer	kenniscentrumjacht bouw@nhl.nl
4.	Universiteit Twente	Enschede	R. Akkerman	r.akkerman@utwen te.nl
5.	Windesheim Flevoland	Almere	A. ten Busschen	a.ten.busschen@win desheim.nl