Informing systemic policies to promote emerging technologies

Fostering the Brazilian biogas innovation system

Luiz Gustavo Silva de Oliveira

Informing systemic policies to promote emerging technologies

Fostering the Brazilian biogas innovation system

Informeren van systemisch beleid om opkomende technologieën te promoten
Bevordering van het Braziliaanse biogasinnovatiesysteem
(met een samenvatting in het Nederlands)

Proefschrift

ter verkrijging van de graad van doctor aan de
Universiteit Utrecht
op gezag van de
rector magnificus, prof.dr. H.R.B.M. Kummeling,
ingevolge het besluit van het college voor promoties
in het openbaar te verdedigen op

vrijdag 20 mei 2022 des middags te 4.15 uur

door

Luiz Gustavo Silva De Oliveira

geboren op 17 december 1984
te Rio de Janeiro, Brazilië

Promotor:

Prof. dr. M.P. Hekkert

Copromotoren:

Dr. S.O. Negro
Dr. Fünfschilling

Dit proefschrift werd (mede) mogelijk gemaakt met financiële steun van CNPq–Brasil (National Council for Scientific and Technological development- Brazil) binnen het 'Science without Borders' programma.

Cover design: ProefschriftMaken
Cover Photo: Olivier Le Moal
Layout: ProefschriftMaken
Print: ProefschriftMaken | www.proefschriftmaken.nl
ISBN/EAN: 978-94-6423-837-2
Cite as: De Oliveira (2022). Informing systemic policies to promote emerging technologies – Fostering the Brazilian biogas innovation system

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1 - INTRODUCTION

1.1 CONDITIONS FOR THE DEVELOPMENT OF RENEWABLE ENERGY TECHNOLOGIES

Current societal challenges—such as those translated into the Sustainable Development Goals (SDG)—pose a multitude of problems for which solutions will require the introduction of new practices and technologies. In the energy sector, the transition from systems based on fossil fuels and expanding access to affordable energy requires developing and adopting renewable energy technologies (RET) across different contexts (Grubler et al., 2016; Sovacool, 2016; Strunz, 2018).

However, expanding the use of RET in energy systems is far from being an easy task, as there are distinct technological, economic, institutional and cultural barriers (Mignon & Bergek, 2016b; Negro et al., 2012; Painuly, 2001; Reddy & Painuly, 2004; Yaqoot et al., 2016). Among these, high costs and financial-economic hurdles are the most widely known; however, technological issues such as variability and integration into the grid are highly relevant challenges constraining RET adoption and users' preferences, regulatory conditions, and vested interests comprise obstacles for broader diffusion.

Another critical aspect of these problems concerns their manifestations in different contexts. The severity of economic and financial barriers varies depending on the situation of each country or region. Technological issues can be more manageable depending on a country's knowledge base and engineering capacity, and adaptations or changes in policies and regulations rely on the institutional framework and its respective political structures and actors.

Different contexts also bring distinct conditions for users' adoption of RET, and interactions among these conditions create an intricate situation for these technologies. For instance, a region's high availability of renewable resources may be useless when actors lack technological capabilities and insufficient funding. Similarly, a high level of technological development can be undermined by an inadequate institutional framework lacking legitimacy.

This situation shows that the debate about actions to mitigate these problems and promote RET is not a trivial one. Actions can be privately or publicly oriented, leading to corporate strategies or public policies (e.g. Mignon and Bergek, 2016b; Planko et al., 2015). Actions can focus on different stages of the value chain of the technology (e.g. van Welie et al., 2019), targeting a single technology or a group of them (e.g. Azar and Sandén, 2011). Actions can be attached to one or several sectors or policy domains and can reinforce or undermine established measures (e.g. del Río and Mir-Artigues, 2014), impacting a single region or several regions (e.g. Mastroeni et al., 2013). Thus, deciding which actions to take requires an in-depth understanding of the technologies and their application contexts. In other words, to propose actions to foster RET, analysts have to scrutinise the intricate setting of conditions in which the RET operates and is implemented.

1.2 Systems explanation of conditions and problems for emerging technological fields

Studying problems of emerging technologies has been a focus of various disciplines that take distinct perspectives on technological development and change, including market failure analyses (Arrow, 1962), evolutionary economy (Dosi, 1982; Nelson & Winter, 1982), science and technology studies (Garud & Karnøe, 2003; Garud & Rappa, 1994; Pinch & Bijker, 1984; Rip & Kemp, 1998), innovation studies (Arrow, 1962; Carlsson & Stankiewicz, 1991; Dosi, 1982; Garud & Karnøe, 2003; Garud & Rappa, 1994; Godin & Lane, 2013; Nelson & Winter, 1982; Perez & Soete, 1988; Pinch & Bijker, 1984; Rip & Kemp, 1998; Rotolo et al., 2015; Suarez & Utterback, 1993; Unruh, 2000). These different analytical approaches have led to several frameworks to explain technological change and explain it through innovation processes.

The innovation studies literature has explained such processes through two main rationales: the linear and systems models[1]. The linear model understands innovation as a consequence of a sequence of activities that can be pushed by developing basic research (technology push) or pulled by societal needs (demand-pull; Godin and Lane, 2013). The linear model's assumptions are often associated with the neoclassic economics perspective (Laranja et al., 2008), which understands knowledge production as a public good whereby private stakeholders do not totally capture benefits. This fact leads to a downturn in investment in R&D, which is characterised as a market failure (Frenken, 2017; Schot & Steinmueller, 2018).

In contrast, the systems model understands innovations as consequences of distinct configurations and interactions of system elements and describes the properties that emerge from these configurations at the system level. This model highlights that several interactions of different activities from basic science to marketing occur according to specific features of the actors involved, including their practices and places as well as the institutional frameworks and material aspects where technologies are developed and applied (Edquist, 1997; Jacobsson & Bergek, 2011). Unlike the linear model, the pathways studied by system models do not have a particular direction. Although the linear model continues to be widely applied, the system model of innovation provides a more comprehensive explanation of the various conditions (or determinants) that technologies face to achieve a high level of development and diffusion.

The development of the system model of innovation emerged from specific questions and disciplinary backgrounds, which has led to two leading families of frameworks. The first group is the innovation systems approach, which primarily originated from the field of evolutionary economics, institutional theories and organisation studies (Edquist, 1997). The first frameworks in this group

[1] There are other models, such as the chain-link model (Kline & Rosenberg, 1986). However, these two are the most representative.

addressed questions about the distinct conditions of countries for technological innovations, thereby giving birth to the National Innovation System (Freeman, 1987; Lundvall, 1992; Lundvall et al., 2002).

Later, other frameworks emerged to investigate issues not covered by focusing on national conditions. The Regional Innovation System argues for the relevance of studying specific regional conditions (Asheim & Isaksen, 1997; Cooke et al., 1997), the Sectoral Systems of Innovations focuses on the particularities of sectors (Malerba, 2002), and the Technological Innovation System attempts to explain the systemic conditions that influence technologies or knowledge fields (Carlsson & Stankiewicz, 1991).

Although innovation system frameworks differ in their definitions of boundaries, they initially largely focused on how configurations of system elements—mostly actors/networks, rules/institutions and materials/infrastructures (Carlsson et al., 2002; Wieczorek & Hekkert, 2012)—enabled or constrained innovations. Later, these studies began incorporating elements of system dynamics into their analysis. The approach that most explicitly deals with system dynamics is the Technological Innovation System (TIS) framework. TIS scholars have formulated varying system processes to explain how configurations of elements influence system dynamics (Bergek, Jacobsson, & Sandén, 2008; M. P. Hekkert et al., 2007). These processes are called 'functions' and comprise entrepreneurial activity, knowledge creation and exchange, the guidance of search, market creation, resource allocation, creation of legitimacy and positive externalities.

The second group of system frameworks refers to socio-technical systems and is focused on explaining transitions. This group mainly originated in science and technology studies, social constructions of technology, evolutionary economics and institutional theory (Frank W. Geels, 2010). Moreover, studies emphasise the embeddedness of technologies in society, i.e., conditions for technological change are the material and economic aspects of technologies and their institutional, political and cultural environment and the actors involved. Although sociotechnical systems and innovation systems share similar elements, the former's primary goal is to provide societal services rather than innovation (e.g. energy supply, transportation and health services).

Transition studies have endeavoured to explain large socio-technical transitions but have also analysed emerging technologies. The Multilevel Perspective (MLP) claims that changes in socio-technical systems—and consequently in how the societal services are provided—can only be understood by analysing interactions among processes across three levels of aggregation, namely landscape, regime and niche (Frank W. Geels & Schot, 2010). Regimes represent the main institutional conditions for the system functioning (F. W. Geels, 2005; Frank W. Geels, 2002, 2004), whereas niches serve as spaces for generating new socio-technical configurations that can evolve to new systems or adapt to the existent ones (Kemp et al., 1998; Schot & Geels, 2008), and landscapes encompass broader and macro influences to the system, i.e. beyond system and regime boundaries (F. W. Geels, 2005; van Driel & Schot, 2005). Although the initial conceptualisations are not clear about the differences between socio-technical regimes, systems and niches (Sorrell, 2018;

Svensson & Nikoleris, 2018), MLP has greatly enriched the understanding of system transition processes, including the conditions engendering the development and diffusion of new technologies (Frank W Geels, 2017).

Another prominent transition framework for analysing emerging technologies is Strategic Niche Management (SNM) theory (Markard et al., 2012). SNM argues that emerging technologies demand a protective space to mature to the extent that they can withstand the selection pressures of broader regimes (Kemp et al., 1998; Schot & Geels, 2008). Through learning, network formation and articulation of expectations, emerging socio-technical configurations are empowered to compete with more established technologies (Smith & Raven, 2012). Thus, SNM directly dialogues with MLP but focuses on understanding niche processes.

Although both innovation systems and transition studies inform policymaking (Bergek et al., 2010; Loorbach, 2014; Rotmans & Loorbach, 2010), only the former have explored the conditions and problems that influence system development. For example, scholars have devised the concepts of systemic problems/failures and blocking mechanisms to explain how systemic conditions hinder the development of innovations (Bergek et al., 2010; Wieczorek & Hekkert, 2012; Woolthuis et al., 2005). Systemic problems are analysed differently according to the innovation system framework; however, they are generally viewed as negative attributes of system elements (actors, networks, institutions and infrastructures; Wieczorek and Hekkert, 2012). Blocking mechanisms represent how systems processes are hampered (Bergek, Jacobsson, Carlsson, et al., 2008).

The rationale behind these concepts is that systems present problems, failures or mechanisms that hinder system development and must be addressed. Thus, by explaining system structure and functioning, these analytical frameworks extend beyond market structures to inform intervention actions to foster or govern the evolution of emerging technologies and provide evidence of where and how to intervene to promote emerging technologies.

The main idea behind identifying failures and problems is to identify activities and mechanisms that would create conditions for sociotechnical change or guide the system's transformation (Bergek et al., 2010; Wieczorek & Hekkert, 2012; Woolthuis et al., 2005). Such explanations have become a popular rationale to inform policymaking (Frenken, 2017; Mazzucato, 2016; Schot & Steinmueller, 2018); for example, path dependence and lock-in (e.g. Arthur, 1989; Garud et al., 2010) are widely incorporated in policy recommendations, counterposing the dominant market failure rationale. Informing the actions of different types of players is mainly a consequence of the type of research inquiry. Systemic failure frameworks have provided valuable insights to various kinds of policy instruments, the most prominent of which are systemic instruments.

Thus, systemic frameworks provide valuable and comprehensive analyses of how emerging technologies come about, whether through innovation or transitions processes (both with a socio-technical perspective). However, as discussed, different frameworks focus on distinct research inquiries, and among these frameworks, TIS concentrates on explaining emerging technologies or technological fields. By understanding innovation processes through a socio-technical lens, this approach provides a comprehensive analysis backed by concepts to explain system structure, system dynamics and system problems, and inform policy design. As TIS aims to inform policy design, understanding the role of policies in hindering or promoting emerging technologies is critical.

1.3 POLICY MIXES TO PROVIDE ADEQUATE CONDITIONS AND MITIGATE PROBLEMS OF EMERGING TECHNOLOGIES

The relevance of public policies to establishing supportive conditions for or mitigating the problems of RET is widely acknowledged among scholars and practitioners (del Río & Mir-Artigues, 2014; IRENA, 2018; Menanteau et al., 2003; Negro et al., 2008; Polzin et al., 2015). Furthermore, innovation studies have also emphasised how innovation policies are used to improve and stimulate capabilities, interactions and infrastructures, adapt institutional settings, coordinate actions and steer directions (Boon & Edler, 2018; Coenen et al., 2015; Edler & Fagerberg, 2017; Frenken, 2017; Laranja et al., 2008; Mazzucato, 2016; Schot & Steinmueller, 2018). Therefore, the elements needed for an adequate set of policies comprise important debate in both RET (e.g. del Río, 2014; del Río and Mir-Artigues, 2014) and innovation studies (e.g. Borrás and Edquist, 2013; Flanagan and Uyarra, 2016; Lindberg et al., 2018; Rogge et al., 2017; Rogge and Reichardt, 2016).

The debate mentioned above raises important issues. First, as emerging technologies are embedded in socio-technical systems, related policies encompass several domains. Both innovation and socio-technical systems analyses have demonstrated that such systems—even when defined for a specific sector or technology—comprise distinct knowledge, resource and production structures, which range from the production to use of artefacts, education to scientific development, and allocation of financial resources to the regulation of natural resources (Frank W. Geels, 2004). Therefore, emerging technologies are directly or indirectly influenced by many policies, which is also highlighted by the amplified scope of innovation policies. The innovation policy domain is not a homogenous field, and it encompasses varying interpretations (Edler & Fagerberg, 2017), which result from the different framings of what innovation problems are being addressed. For instance, innovation policies have included a plethora of issues, including but not limited to stimulating R&D activities, improving system coordination and tackling societal challenges (Edler & Fagerberg, 2017; Frenken, 2017; Kuhlmann & Rip, 2018; Laranja et al., 2008; Schot & Steinmueller, 2018)

Second, policies comprise several elements and can be understood as policy mixes. Policy design studies evince that policies cannot be analysed as single elements but are composed of goals and instruments (Michael Howlett & Rayner, 2007). Depending on their design features and application contexts, these goals and instruments interact in distinct fashions to influence the addressed problem (Kern & Howlett, 2009). Furthermore, as new policies are designed and implemented amidst pre-existing policies, changing policy mixes also becomes a relevant consideration (Michael Howlett & Rayner, 2013). Studies have demonstrated how different policy elements, their interactions and the resulting policy mix evolution influence the development and diffusion of emerging technologies (del Río, 2014; del Río & Mir-Artigues, 2014; Edmondson et al., 2018; Kivimaa & Kern, 2015; Mir-Artigues & del Río, 2014; Reichardt et al., 2016).

A third important point concerning the role of policies in fostering emerging technologies relates to how analytical innovation frameworks can inform policy design, which partly results from the core part of their analysis being institutional[2] (Fuenfschilling & Truffer, 2014, 2016; Frank W. Geels, 2004; Lundvall et al., 2002; Weber & Truffer, 2017). In recent years such analyses have more explicitly examined the role of policies and policy mixes as essential topics of innovation processes (Kivimaa & Kern, 2015; Reichardt et al., 2016; Rogge et al., 2017; Rogge & Reichardt, 2013). Analytical frameworks commonly try to explain problems in the socio-technical system and recommend policy instruments (Borrás & Edquist, 2013; Wieczorek & Hekkert, 2012). However, this scheme for informing policymaking has been criticised for being idealised and overly rational (Flanagan et al., 2011; Flanagan & Uyarra, 2016). Issues such as the roles of actors, target populations, varying rationales, policy environments and the distinct framing of instruments and problems play crucial roles in designing and implementing policies (Bacchi, 2009; Flanagan et al., 2011; Flanagan & Uyarra, 2016; Hoppe, 2010; Michael Howlett & Rayner, 2013; Schneider & Sidney, 2009).

In sum, multiple policies influence emerging technologies with numerous goals and instruments and across varying policy domains. Consequently, these policies interact with each other to create specific ‘policyscapes’ in which new policies are proposed (Mettler, 2016). Therefore, efforts to inform policy design must account for these policy spaces and respective interactions.

1.4 Informing policies with Technological Innovation Systems

As discussed above, although distinct system frameworks provide valuable insights into understanding the conditions in which technologies prosper, there is no single framework that covers all conditions. However, the TIS framework is widely cited as being most appropriate when the goal is to understand the specific conditions and problems of emerging technologies and technological fields (Carlsson & Stankiewicz, 1991; Markard et al., 2012).

TIS scholars have developed a robust framework to examine the structural configurations and the processes that enable or constrain the development and diffusion of these technologies (Bergek, Jacobsson, Carlsson, et al., 2008). The great innovation of the TIS framework lies in its functional approach to examining system dynamics. This functional approach states that system dynamics are a consequence of the fulfilment of system-level processes—i.e. system functions (Bergek, Jacobsson, Carlsson, et al., 2008; M. P. Hekkert et al., 2007). In addition, the fulfilment and

[2] “The institutional base of the TIS regulates interactions between actors. Institutions may come in the form of hard regulations (controlled by juridical systems) and in the form of norms and cognitive rules (controlled by social systems)” (Bergek et al., 2008b:577).

interaction of distinct processes are more relevant than others depending on the phase of system development (Bergek, Jacobsson, Carlsson, et al., 2008; Suurs & Hekkert, 2009b).

The structural-functional framework enables the identification of systemic problems and blocking mechanisms, thereby informing policy design goals and issues (Bergek, Jacobsson, Carlsson, et al., 2008; Wieczorek & Hekkert, 2012), which makes TIS a very straightforward framework for analysing innovation processes and recommending policies. This approach explains the structuration of innovation systems through key processes, systemic problems, blocking and inducement mechanisms. TIS analytical elements provide evidence organised through conceptual lenses to inform policy decisions.

However, like all analytical frameworks, TIS falls short in critical areas, which can be classified into the same two groups described above: innovation analysis and informing policy. Concerning innovation analysis, criticisms of TIS commonly cite the limited study of contexts, the delimitation of boundaries and issues of spatiality (Markard et al., 2015). Another criticism is the normative departure point on particular technologies (Bening et al., 2015). However, the latter criticism can be understood as an analytical choice, requiring only that scholars be aware of the issue from the outset and make it explicit.

The delimitation of boundaries on specific technologies or technological fields may neglect aspects such as TIS embeddedness in sectors and regions and the macroeconomic and political contexts. However, this is not necessarily a conceptual weakness. First, it can be viewed as an analytical choice. Second, TIS presents analytical tools to account for exogenous influences on the mechanisms that explain system dynamics (Bergek, Jacobsson, Carlsson, et al., 2008). Nonetheless, this limitation is highlighted when empirical studies have not sufficiently been explicit in identifying and analysing these exogenous influences.

The issue mentioned above is closely linked to criticisms concerning boundary definitions and the superficial analysis of spatial aspects. As definitions of technology and technological fields may vary (Sandén & Hillman, 2011), the TIS boundary is always dependent on the particular research enquiry, which makes the comparison of studies and the systematic inclusion of contextual influences a complicated task. Hence, several empirical studies focus on national cases (e.g. Tigabu et al., 2015; Wieczorek et al., 2014), facilitating the boundary definition.

To address the above criticisms, TIS scholars have proposed four typical contextual structures, namely sectoral, geographic, technological and political, as analytical tools to organise what TIS studies should consider (Bergek et al., 2015). In addition, they have recommended understanding contextual influences according to the proximity of the structures. Structural coupling is the primary approach to analysing closer structures, which also comprise TIS structures, whereas external links are examined in the case of distant structures, which directly influence TIS. Although some examples are presented—for instance, sectoral regulations as structural couplings and international price shocks as an external link, the very issue of boundary definitions and how to analyse these influences remain points of contention.

Criticisms on informing policy focus on unclear or superficial recommendations, the lack of contextualisation of recommendations and the need for more accurate evidence (Bening et al., 2015; Kern, 2015; Markard et al., 2015). These criticisms relate to conceptualisations of the role of actors and the low awareness of policy context. The TIS conceptual framework does afford an examination of the role of actors; its origins focused on agent networks, institutional settings, and the system level processes of guidance of search and creation of legitimacy constitute the conceptual foundations for analysis. Nevertheless, although TIS empirical studies explore configurations of actors and networks and how system processes are fulfilled, they rarely provide a detailed examination of how and why actors engage in activities. In other words, empirical analyses may not explain actors' motivations and power relations. Therefore, subsequent analyses of systemic problems and blocking mechanisms from which policy recommendations are derived may not cover the specificities of these problems. This issue is related to questions concerning the accuracy of the information produced by TIS studies and their validity in informing policies (Kern, 2015).

Furthermore, the context in which policies are proposed, changed and implemented is highly relevant. For example, policy studies demonstrate how coalitions, windows of opportunity and political systems have enormous impacts on the making and implementing new policies (Weible & Sabatier, 2017). Although some recent TIS studies include policy mix analyses (e.g. Kivimaa and Virkamäki, 2014; Reichardt et al., 2017, 2016), these advances are yet to be implemented in TIS policy recommendations. Therefore, neglecting the contexts in which policy recommendations are made may lead to innocuous or superficial recommendations.

The analytical toolset that TIS provides is commonly used to inform policy design, and the framework focuses on understating problematic factors and situations and proposing interventions. However, limitations of this analytical framework and the contextualisation of evidence to inform policy are two significant areas for improvement. About the former issue, despite recent advancements in considering contexts, TIS remains limited in its consideration of exogenous influences, and it faces some difficulties in explaining how and why actors engage in specific activities that fulfil innovation processes. About the latter criticism, these analytical limitations are carried to policy recommendations. Put simply, as some analyses may lack important information, policy recommendations may be superficial or even insufficient, and they tend not to be sufficiently contextualised, making TIS policies recommendations challenging to absorb by decision-makers.

1.5 BIOGAS TECHNOLOGIES IN BRAZIL AS THE MAIN CASE STUDY

The case of biogas technologies in Brazil illustrates how multiple conditions (different sectors, policy domains, technologies and geographies) play pivotal roles in the development and diffusion of RET. Bioenergy technologies in Brazil are widely known for achieving a high share in the energy matrix

(MME/EPE, 2019). The most successful case is the use of bioethanol produced from sugarcane in flex-fuel cars; however, biodiesel has also achieved high legitimacy and a significant market share (Furtado et al., 2011; Rico & Sauer, 2015). On the other hand, despite their long history, biogas technologies still struggle to find successful pathways (Jende & et. al, 2016).

Several scholars have already explained the technological features and the contextual conditions that hampered or promoted bioethanol and biodiesel (Andersen, 2015; Furtado et al., 2011, 2020; Goldemberg et al., 2008; Moreira et al., 2014; Moreira & Goldemberg, 1999; Padula et al., 2012; Rathmann et al., 2012; Rico & Sauer, 2015; Rocha et al., 2014; Salles-Filho et al., 2017). In contrast, studies of biogas technologies in Brazil remain limited to technological issues and specific cases, which makes understanding the problems that hamper and support these technologies a complicated mission (e.g. Coimbra-Araújo et al., 2014; Lobato et al., 2013; Melegari de Souza et al., 2012; Novak et al., 2016; Pasini, 2011).

Biogas in Brazil is mainly sourced from residues and wastes from different sectors, viz., agriculture, livestock, sanitation, waste management and industry, which entails several possibilities of scale and types of technologies for biogas production (Coelho et al., 2018). Furthermore, as biogas is a flexible fuel, there are several possibilities for its use, such as power generation, cooking gas, compressed gas, injection into the natural gas grid, and replacing liquid fuels as diesel oil. Consequently, the types of biogas treatment and logistics technologies employed depend upon the choices of feedstock type and biogas use. Due to this variety of technological routes, it is not difficult to realise that biogas projects' development encompasses various actors, policies, and infrastructures that cut across distinct sectors and regions.

The factors mentioned above create specific contexts within Brazil that enable or constrain biogas activities in multiple ways. For instance, the southern region presents an excellent availability of swine manure at small-scale farms and an existing constellation of biogas actors and networks; however, the latter has minimal policy incentives. In São Paulo State, great biogas potential lies in the sugarcane industry, and the state also has biogas and biofuel specific policies that provide some market mechanisms. Big cities focus their biogas plans on waste management and sanitation sectors for power generation; however, they have the little financial capacity and are dependent on the logistics systems for waste management. Moreover, in both cases, potential developers must contend with national rules for power commercialisation, biofuel production, and national technologies' low availability.

Another vital aspect of biogas technologies in Brazil is the positive impacts of related projects. The use of residues as primary substrates, the energy recovery of biogas and the use of by-products of the biodigestion process yield benefits across the sectors and stages of the value chain. Biodigestion technologies—particularly livestock residues—are understood by environmental bodies and farmers as important technical schemes to mitigate local pollution. In addition, the mitigation of greenhouse gases (GHG) due to more sustainable uses of residues is another critical benefit. The latter is also important for other sectors such as waste management and sanitation. GHG mitigation is also achieved via energy production and use when biogas replaces fossil fuels. The potential for biomethane applications to replace diesel consumption may also positively impact diesel importation.

Moreover, decentralised energy production could induce local economic development. For instance, regions with no access to natural gas grids or expensive power tariffs might benefit from local energy from biogas. Additionally, given that a major part of biogas potential is in rural areas, the treatment and utilisation of digestate as biofertiliser is an attractive option. Thus, as higher diffusion levels and a larger market share of biogas technologies yield several public benefits, it is reasonable to advocate for public actions to promote these technologies in the country, i.e. to advocate for biogas fostering policies.

However, suppose one wants to inform or design policies for fostering biogas technologies in Brazil. In that case, it is necessary to investigate the conditions that enable or constrain the development of the biogas field. In particular, it is needed to understand the current technological routes, how they evolved, their interactions with other technologies and infrastructures, their embeddedness in different sectors and regions and how these factors create barriers to further development and diffusion. It is also essential to understand how fostering these technologies may interact with existing policies, which actors are involved in the design and implementation of these policies and what possible conflicts these policies may introduce.

1.6 RESEARCH PROBLEMS AND QUESTIONS

Addressing the need for increasing diffusion and implementation of emerging technologies aligned with societal challenges requires analysing which type of policies promote the development and diffusion of these technologies. A compulsory initial step is to understand and explain the pathways, necessary conditions and problems experienced by emerging technologies so that policy problems can be framed and respective solutions evaluated. Investigating how sociotechnical analyses can inform policies is the main aim of this thesis. In other words, this research advances the debate on how analytical frameworks of innovation can inform policies to foster technological fields.

By examining this broad research problem through a focus on the case of biogas technologies in Brazil, this research aims to uncover ways to inform policies that establish adequate conditions for biogas technologies in Brazil. The study investigates the pathways, contexts and problems of biogas technologies as a Technological Innovation System. The above-presented discussion sets the analytical boundaries on the possibilities and limitations of TIS conceptual frameworks to explain these conditions and problems. Thus, the main research question defines the research problem: *How can we inform policies that support adequate conditions and mitigate problems to foster the Brazilian Biogas Innovation System (BBIS)?*

This research question will be answered by exploring four more specific research questions (Figure 1). The first problem explores the historical evolution of biogas technologies in Brazil and the possibilities of using a TIS framework to examine contextual influences (Chapter 2). This problem is summarised by the following question: *How did endogenous and exogenous influences affect the development of the Brazilian Biogas Innovation System between 1979 and 2016?* The main goal is to understand the evolution of biogas technologies in Brazil, considering not only endogenous aspects of the technologies but also how contextual influences affected the development of BBIS. This chapter also proposes an analytical framework that systematically investigates contextual influences on TIS.

Next, it is necessary to examine the current problems hampering the development of BBIS. The initial step is to explore the conceptual possibilities and limitations of a TIS framework to explain these problems. Therefore, Chapter 3 answers the question *How are the current systemic problems and blocking mechanism frameworks limited in explaining how and why certain activities lead to poor system functioning?* The chapter provides conceptual clarity on problematic factors at the system level by developing a causal explanation for systemic problems and blocking mechanisms for TIS studies. The following step, presented in Chapter 4, applies this conceptual framework to answer the question *What are the systemic problems and blocking mechanisms of BBIS?* This chapter provides an in-depth discussion of Brazil's systemic problems and blocking mechanisms experienced by biogas technologies. Thus, these three chapters examine the conceptual and analytical limitations of the TIS framework and discuss the historical evolution and current systemic problems and blocking mechanism of BBIS.

The investigation of how to improve policy recommendations based on the TIS analysis is the main task of Chapter 5. Given that evolution and problems of BBIS have already been discussed, the research problem here is to elucidate the possibilities for and limitations of informing policies deriving from the developed analytical framework. To do so, Chapter 5 answers the question *How does a mechanism-based explanation of blocking mechanisms influence the policy recommendations for biogas technologies in Brazil?* In addition, this chapter discusses how mechanism-based frameworks broaden the types of recommendations by expanding the kinds of policy goals.

Finally, Chapter 6 discusses possible conflicts deriving from the recommendations given the established policy mix and involved actors and political structures. This chapter aims to increase the awareness of the possibilities and limitations of the proposed policy recommendations. The chapter ends by summarising the main conceptual and empirical findings and discussing the limitations of the research and avenues for future research.

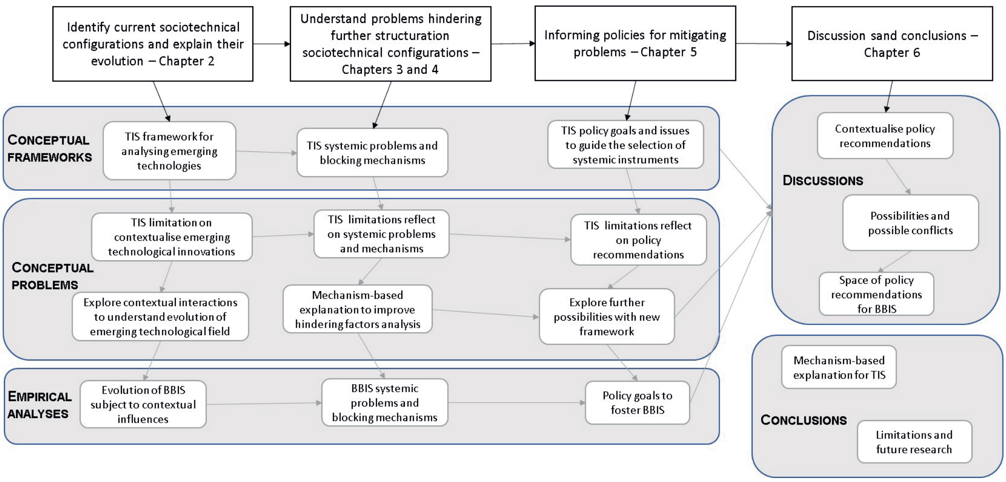


Figure 1 – Research framework

CHAPTER 2 - CONTEXTUAL STRUCTURES AND INTERACTION DYNAMICS IN THE BRAZILIAN BIOGAS INNOVATION SYSTEM[3]

- Shows the historical evolution of biogas field in Brazil using the TIS framework
- Proposes to examine activities and actors of value chains to identify TIS contexts
- Explains how sectoral and geographic contexts shaped biogas field in Brazil
- Advances the debate on TIS contexts suggesting patterns of contextual influences

ABSTRACT

Although biogas technologies in Brazil have a huge potential and a long history few studies have examined biogas in Brazil as a technological field. Accordingly, this paper aims to understand which conditions enabled or constrained the diffusion of biogas technologies. More specifically, this research applies and adapts the Technological Innovation System (TIS) framework to examine biogas-specific and context-related conditions as well as their interplay. Data were collected by performing an event history analysis from 1979 to 2016 along with 24 in-depth expert interviews. Our findings indicate that the evolution of geographically embedded sectoral regulations and infrastructures as well as their interactions have been responsible for major changes in the biogas field in Brazil. By demonstrating how this occurred, this research has opened up new possibilities to promote biogas technologies in Brazil. This study also provides an important analytical method that focuses on exploring activities and their background conditions to consider contextual influences in TIS. Consequently, three major ways of contextual influences for TIS studies are suggested – evolution of contextual structures, interaction of contextual structures and translation of external events by these interactions.

KEYWORDS

Biogas, Brazil, Sustainability transitions, Technological Innovation System, TIS contexts

[3] This chapter was published as De Oliveira, L.G.S., Negro, S.O., 2019. Contextual structures and interaction dynamics in the Brazilian Biogas Innovation System. Renew. Sustain. Energy Rev. 107, 462–481. https://doi.org/10.1016/j.rser.2019.02.030

2.1 INTRODUCTION

The energy transition towards more sustainable energy systems represents a relevant societal challenge(IRENA, 2018, 2019). This transition requires sharp increases on the share of modern forms of renewable energy technologies (IRENA, 2018, 2019; Strunz, 2018). However, technological development and diffusion are far from being easy processes (Negro et al., 2012). New renewable energy technological fields are subject to different conditions and determinants (Sovacool, 2016). These conditions can be national policy frameworks, international energy prices, local conditions for entrepreneurship and availability of resources and technological characteristics (Fouquet, 2016; Gabriel, 2016; Smil, 2016; Zeng et al., 2017). This fact emphasises the need to investigate the broader contexts that enable or constrain new renewable energy technologies.

A good example of these different conditions and their interplay is the case of bioenergy technologies in Brazil. First, the fact of being a global south country indicates specific socioeconomic conditions and forms of access to the global knowledge networks and financing which direct affects technological development (Lundvall et al., 2009; Wieczorek, 2017). Second, Brazil presents successful experiences of bioethanol and biodiesel technologies (Furtado et al., 2011; Rico & Sauer, 2015). These technologies have a long history of experimentation and development in Brazil and achieved high shares on fuel consumption matrix and institutionalisation level. However, other bioenergy technologies such as biogas technologies could not reach the same success level.

Biogas in Brazil has a large potential and several possibilities for its production and use. Recent studies present the potential ranging from 23 (ABiogas, 2015) to 40 (EPE, 2016) million m³ per day based on agricultural, livestock, industrial and urban residues. Among their benefits in Brazil, biogas technologies reduce carbon emissions, mitigate local pollution and promote local development (Bley Jr., 2015; Bley Jr. et al., 2009; Bruna S Moraes et al., 2015; Nadaletti et al., 2015; M. P. Querol et al., 2015). Moreover, experimentation with biogas technologies dates back from the late 1970s and comprises distinct technological schemes, e.g. for power generation and vehicle fuel and from manure and sugarcane residues. However, only few studies have taken a comprehensive perspective of the history of biogas projects (Bley Jr., 2015; Palhares, 2008) and the diffusion hurdles of biogas technologies (Jende & et. al, 2016). Therefore, nonetheless the high potential and its successful implementation in other countries, the reasons why biogas is not diffused and implemented on large-scale in Brazil needs to be investigated.

In order to understand the development of renewable energy technological fields, scholars have been applying the technological innovation system (TIS) framework (e.g. Bento and Fontes, 2019; Huang et al., 2016; Jacobsson et al., 2009; Aschalew Demeke Tigabu et al., 2015; Wieczorek et al., 2013). The TIS framework (Bergek, Jacobsson, Carlsson, et al., 2008; M. P. Hekkert et al.,

2007) recognises innovation as the outcome of interactions between innovators and supportive actors, infrastructures and the institutional environment. The innovation processes benefit from a well-functioning innovation system. Analysts apply the TIS framework and focus on revealing the systemic structural and dynamic conditions for developing and diffusing technologies (Wieczorek & Hekkert, 2012). These studies have provided valuable policy recommendations on how to foster renewable energy fields (Bento & Fontes, 2015; Jacobsson & Bergek, 2004; Negro et al., 2012; Aschalew Demeke Tigabu et al., 2015).

Nevertheless, criticisms say that TIS studies may be myopic and insufficient in accounting for exogenous or contextual influences (Bergek et al., 2015). In other words, TIS analyses may overestimate the innovation system functioning and underestimate external influences to the innovation system on the success or failure of innovations. For instance, competing innovation systems, generic political processes and sectoral dynamics and differences between global north and south countries are commonly pointed out as important factors. Recent studies have attempted to address this issue (Bergek et al., 2015; Gosens et al., 2015; Schmidt & Dabur, 2014; Wieczorek et al., 2014); however, it remains a point of contention.

This paper combines this conceptual line of reasoning with the empirical analysis of the biogas technological field in Brazil and raises the following research question: *'How did endogenous and exogenous influences affect the development of the Brazilian Biogas Innovation System between 1979 and 2016?* The primary goal of this paper is to explain how both endogenous (biogas-specific) and exogenous (contextual-related) influences have affected the development of biogas technological field in Brazil[4]. The secondary goal is to discuss how to examine contextual influences within TIS studies. For this, the methodology is based on event history analysis (Negro et al., 2007) supplemented with 24 in-depth interviews with key stakeholders in the Brazilian Biogas Innovation System (BBIS).

The paper yields two important outcomes. Firstly, it demonstrates how the interactions of sectoral and geographic institutions, actors and infrastructures defined the development of BBIS. Given the low level of institutionalisation, throughout the period biogas projects were subjected to the (mis)alignment of sectoral policies and regulations. Also, favourable regional conditions of feedstocks for biogas production were an advantage only when positive sectoral and macro influences occurred. Finally, broader macroeconomic conditions have determined sectoral contexts and indirectly influenced biogas activities. Thus, these findings improve the understanding of successful conditions for the Brazilian Biogas Innovation System.

Secondly, the adaptation of TIS framework (as developed by Wieczorek and Hekkert (Wieczorek & Hekkert, 2012)) advances the debate on TIS contexts by proposing an analytical

[4] It is important to explain that this paper does not intend to present an overview of biogas plants nor legislations.

framework that systematically examines contextual influences. This framework understands technologies as 'bundle' of value chains (Sandén & Hillman, 2011), enabling the identification of interaction points between technologies and their context (as suggested by Bergek et al. (Bergek et al., 2015)). Consequently, analysts can study how the engagement of actors towards specific activities under specific conditions posed by contexts influences TIS activities and processes. Lastly, the evolution of contextual structures, the interaction of contextual structures and the translation of external events by these structures are suggested as patterns of contextual influences are also suggested.

2.2 TECHNOLOGICAL INNOVATION SYSTEMS AND CONTEXTS

Innovation systems' frameworks have evolved in response to the linear model of innovation and the dominance of neoclassical economics in policy arenas (Sharif, 2006). These frameworks consider innovation as a result of interactions within networks of different actors embedded in institutional contexts (Edquist, 1997). The TIS framework focuses on explaining the emergence and dynamics of a particular technological field. The TIS approach combines a structural and a functional analysis of the innovation system (Bergek, Jacobsson, Carlsson, et al., 2008).

The structural analysis aims to examine which different system components are present. These components are often classified into actors (private, public, research agents, universities, consumers, etc.), institutions (legislation, norms, standards, values, etc), interactions/networks (formal networks, social communities, social relationships, etc) and infrastructure/materials (physical systems, material artefacts, financial systems, etc) (Wieczorek & Hekkert, 2012). The functional analysis (Bergek, Jacobsson, Carlsson, et al., 2008; M. P. Hekkert et al., 2007), identifies key processes (functions) necessary for proper system functioning, i.e. to promote the development and diffusion of a focal technology.

Here, the key processes adopted follow (M. P. Hekkert et al., 2007; Wieczorek & Hekkert, 2012) and comprise entrepreneurial activities (F1) – development of risky activities by entrepreneurs (new companies or incumbents) that are responsible for implementing new products and services; knowledge production (F2) – expansion of technological knowledge base through learning mechanisms; knowledge exchange (F3) – diffusion and exchange of new knowledge through different players and channels; guidance of search (F4) – alignment of visions, expectations, formal targets and goals to steer efforts of different players to common goals; market creation (F5) – need to create proper (protected) spaces for technological development due to incipient character of new technologies; resource allocation (F6) – allocation of adequate type and volume of resources for system activities; and creation of legitimacy (F7) – improvement of legitimacy and acceptance of new technologies and counteraction to possible resistance to changes. Several empirical studies have shown that the importance of these key processes differs across different phases of development (Hillman et al., 2008; Suurs et al., 2010; Suurs & Hekkert, 2009a, 2009b). These two concepts provide valuable information for theory development, the identification of problems and policy recommendations (Bergek, Jacobsson, Carlsson, et al., 2008).

Moreover, an innovation system does not operate in a vacuum. Instead, a TIS is embedded and nested in other socio-technical systems or contextual structures (Markard & Truffer, 2008; Stephan et al., 2017). The embeddedness of a TIS in other contextual structures calls for a better understanding of their influences on TIS development (Bergek et al., 2015; Markard & Truffer, 2008; Sandén & Hillman, 2011). Recently, TIS scholars proposed a number of relevant contextual structures which TIS analyses should examine (Bergek et al., 2015): technological, sectoral, political and geographical. However, typical analyses (e.g. Kebede and Mitsufuji, 2014; Wieczorek et al., 2013) identify system evolution by focusing only on what happens within the TIS, which results in a superficial perspective on TIS contexts[5]. This lack of systematic analysis of TIS contexts is a common criticism of TIS studies (Markard et al., 2015). Additionally, the application of the TIS framework in developing countries has demonstrated the amplified relevance of context for the development of technological fields [e.g. 49,50]. Examples of important contextual factors are the lack of a well-structured national innovation system (Chaminade et al., 2009), poor initial conditions (Intarakumnerd et al., 2002), weak positions in global value chains (Pietrobelli & Rabellotti, 2009) and a larger role of implicit policies (Cassiolato, 2015; Lastres et al., 2014).

2.2.1 Analytical framework to explore contextual influences on Technological Innovation Systems

For TIS scholars (Bergek et al., 2015), contextual influences vary according to the degree of interdependence between contexts and TIS. In close interactions, structural couplings – i.e. shared elements – are present. In distant interactions, external links – i.e. aspects that influence TIS but are not affected by it – are the main form of influence. For instance, the former can be a power utility that operates in several TISs (solar, wind biogas, etc), while the latter can be an important event, such as a political crisis. Moreover, these influences must be investigated not only as static specific factors, but as factors possessing intrinsic dynamics that affect the focal TIS.

[5] It is noteworthy to discuss that the conceptualisation of TIS as developed by Anna Bergek and her colleagues includes taking into consideration some exogenous factors. This fact is noted in two main points. First, her set of functions includes the process of *development of positive externalities,* which accounts for the interdependence of TIS development and external structures. Second, her consideration of inducement and blocking mechanisms provides room for analysing exogenous influences (Bergek, Jacobsson, & Sandén, 2008; Bergek, Jacobsson, Carlsson, et al., 2008; Jacobsson & Bergek, 2004; Jacobsson & Johnson, 2000; Johnson, 1998; Johnson & Jacobsson, 2001). However, the understanding is that the identification of external structures and factors of influence are made in an *ad hoc* manner.

TIS scholars [33:54] have also suggested some “generic types of contextual structures”, namely other TISs, sectors, specific geographic and political contexts. Although these categories are useful, TIS analysts still struggle to define the range of what is a structural coupling and an external link for each of these contextual categories. These authors also admit that “the distinction between a focal TIS and different context structures is often “blurred” and, therefore, not a straightforward exercise” (Bergek et al., 2015:54). Therefore, “the focal TIS and its contexts are always constructs of a specific analytical choice” (Bergek et al., 2015:54). One suggestion used to untangle this analytical trap is to apply a theory-guided research strategy (Falleti, 2016; Falleti & Lynch, 2009). In this way, analysts must explore the possible theoretical explanations to have a better picture of “what aspects of a context are likely to be relevant to the process and outcome under study” (Falleti and Lynch, 2009:1153).

Following this recommendation, this paper adopts the understanding of technologies as a ‘bundle of value chains’ (Sandén and Hillman, 2011:405) to delineate how biogas technologies interact with and overlap distinct contextual dimensions. In this model, these interactions “emanate[s] from [structural] overlaps’ (Sandén and Hillman, 2011:407). Structural overlaps – structural couplings for Bergek et al. (2015) – encompass material, organisational and institutional dimensions. Therefore, by explicitly describing the value chains of a specific TIS and examining their most relevant interactions with distinct structures of contextual categories as in Bergek et al. (2015), it is possible to select the relevant contextual structures to analyse. This approach addresses the analytical challenges of the boundary definition for contexts as pointed out previously. Thus, the TIS analytical framework as developed by Wieczorek and Hekkert (2012) is adapted (as in Figure 2[6]). The specific details of this adaptation are explained below.

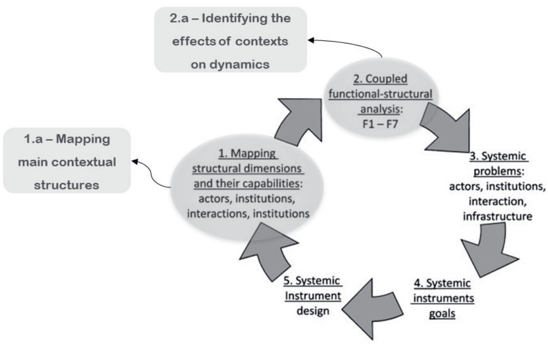


Figure 2 – Analytical framework–adapted from Wieczorek and Hekkert (2012)

[6] Because this research aims to explain the evolution of biogas history in Brazil, we focus on the structural and functional analysis rather than the full analytical cycle.

2.2.1.1 Defining the boundaries of analysis by exploring the value chains

The adaptation 1.a in Figure 2 refers to the definition of the boundaries of the analysis both for the focal TIS and for the contextual structures. According to Sandén and Hillman (Sandén and Hillman, 2011:404-405), "[a]ny specific technology […] is defined by a set of complementary and alternative value chains" and "is a combination of upstream and downstream hierarchies" of products and processes. Hence, analysts can delineate system boundaries in wider or narrower fashion. In the case of biogas, the analysis of innovation system may consider the biogas production for power generation, biogas production from swine manure for power generation or biogas production from different substrates for different uses. This choice is an analytical choice and depends on the particular research questions.

Nevertheless, this method of boundary definition is closely related to what is suggested in TIS literature (Bergek, Jacobsson, Carlsson, et al., 2008; Carlsson et al., 2002). It also refers to the TIS boundaries only and not to the contextual structures. However, the description of value chains made by specifying products and processes enables analysts to explore the exact activities and entities[7] for the different levels of the different value chains. Put simply, the specific activities in value chains are performed by certain agents under certain conditions, in which the conditions may be institutional, infrastructural, political or geographic.

The identification of these agents and conditions enables to determine how these value chains relate to contexts. For instance, the collection and treatment of substrates for biogas production may be performed by sanitation utilities or farmers embedded in different institutional, geographic and infrastructural conditions. Therefore, by applying this framework to the different streams of the delineated value chains and taking into consideration the main categories of contexts as in Bergek et al. (2015), TIS analysts can map the boundaries of contexts[8]. This is presented for our case in Section 2.4.

2.2.1.2 Exploring the contextual influence on Technological Innovation Systems dynamics

After defining the boundaries of contexts, it is necessary to examine how the contextual structures evolved. This means the analysis must investigate the dynamics of the elements of contexts and their influence on TIS (Bergek et al., 2015) (2.a in Figure 2). First, the analyst must consider the timeframe of the analysis. A good way to do this is to set the same timeframe as the

---

[7] We understand entities and activities as in Beach and Pedersen (2016:35), in which entities are engaged in certain activities that are responsible to produce changes or transmit causal forces.

[8] It is important to note that Sandén and Hillman (Sandén & Hillman, 2011) proposed this conceptualisation to explore the technological interactions. We do think that the presentation of a complete list of technological interactions across value chains is relevant. However, we do not present this list here because our main goal is to understand contextual influences and not the technological interactions.

TIS analysis[9]. Second, the analysis may be more theory-guided or more grounded-developed. With the former, the analyst can account for different disciplinary and conceptual explanations. For example, it is possible to explain the evolution of sectoral contexts using Sectoral System of Innovation (Malerba, 2002) or Industrial Dynamics (Carlsson, 2016) frameworks. On the other hand, grounded analyses, which are adopted for this research, requires extensive collection of data about the contextual elements mapped through the value chains.

The next step is to explain how this evolution of contexts affects TIS structure and dynamics. These effects are more evident in TIS structures. As the contextual structures are mapped through the couplings of entities, activities and conditions in value chains, changes in these entities, activities and conditions lead to changes in the couplings. For instance, if new important players appear in sectoral contexts, or if there is any significant institutional change through time in sectors that interact with a focal TIS, the changes will very likely affect the actors and institutions in the TIS. Therefore, it is possible to detect these effects by exploring the evolution of contextual structures and their interactions with TIS structural elements.

The contextual effects on TIS dynamics are less obvious. Analysis of TIS dynamics, or the functional analysis, is generally performed by examining indicators that would be proxies for several activities (Bergek, Jacobsson, Carlsson, et al., 2008; Negro et al., 2007). For example, one way of tracing the fulfilment of knowledge production in TIS is to analyse R&D indicators that are expected to represent knowledge production activities. Although this may be a reasonable strategy for gaining a broader understanding of TIS functioning, it is necessary to really check the activities, i.e. who is engaged and under what conditions, to analyse contextual influences. This is exactly the outcome of the value chain analysis and the mapping of contextual structures. For example, for R&D activities analysts must map the main actors, their sectoral embeddedness, region and stream of value chain, among other possible factors. By exploring these activities in TIS, analysts can trace the influence of contexts. In the following section, data collection is explained.

2.3 METHODOLOGY

The analyses of the biogas value chains and contextual influences (Section 2.4) and the structural–functional analysis (Section 2.5) were conducted with desk-based research and verified with interviews. The main sources used for the desk-based research were documents (scientific, professional and public reports). Scientific literature databases, such as Web of Knowledge, Periódicos Capes and selected Brazilian universities, were used to retrieve scientific papers on

[9] The timeframes of TIS and contextual analysis may not match because they may not be synchronised (e.g. see Falleti and Lynch (2009)).

biogas experiences in Brazil. Electronic files of the Lexis-Nexis® database, selected newspapers[10] and websites of sectoral media were the main type of media documents collected.

This research also comprised the collection of reports of activities, public consultations, research reports, technical reports and official government documents for selected organisations. For the structural-functional analysis, it was developed an event history analysis from 1979 to 2016 (Negro et al., 2007). The event history analysis is a type of process method (Poole et al., 2000; Van de Ven & Poole, 1990) for mapping the sequence of events[11] that have taken place. This mapping aims to construct a narrative for a particular process (Suurs & Hekkert, 2009b) from data of events of the literature and of interviews (Negro, 2007:37-43; Suurs, 2009:67-73). The events are stored in a database and allocated to the system functions.

However, to identify the contextual influences, it was necessary to go beyond the mapping of events and their sequences by collecting detailed data about the events. To construct a large database, data collection also comprised specific information about the events' main actors, place and sector, main activities and motivations and exchanged products. This information was used in the coding process to describe the functional pattern of BBIS. This method allowed us to make inferences about contextual influences because it could relate the system functions to specific details, such as engaged actors, their sectoral and geographic embeddedness, and their explicit motivations.

Subsequently, researchers conducted 24 semi-structured expert interviews to confirm the constructed narrative. The questions were grouped into the following categories: the identification of system elements, system functioning, sectoral contexts, regional aspects and the Brazilian national environment. The existing TIS literature, which presents main indicators and follow-up questions (Bergek, Jacobsson, Carlsson, et al., 2008; M. P. Hekkert et al., 2007; Marko P. Hekkert et al., 2011; Marko P. Hekkert & Negro, 2011; Negro, 2007; Wieczorek & Hekkert, 2012), was the main reference to define the questions. The interviews were recorded, transcribed and analysed. Among the interviewees listed in Table 1 were consultants and representatives of governmental bodies, private and state-owned companies, industry associations, intermediary organisations, universities, farmers and researchers of the BBIS.

The TIS dynamics and contextual influences are represented in figures (see Section 2.5). Grey boxes represent the most relevant functions for each period. These figures also indicate the most relevant events or clusters/groups of events from the BBIS and its contexts. The selection of events or clusters followed the coding process that comprised specific categories derived from TIS

---

[10] We searched for 'biogás', 'biodigestor' and 'digestão anaeróbica' in the digital archives of *O Globo* and *Folha de São Paulo*.
[11] Events are the basic analytical construction done by the analysts in order to relate the empirical fact and the theoretical (Van de Ven & Poole, 1990).

functions and from empirical data. These categories included the following: expectation, interaction/network, international context, knowledge, legitimacy, lobby, local context, market creation, national context, projects, research group, resource allocation, sectoral context, state-level context and technological context. These categories allowed us to identify which cluster of events was most relevant for each period.

Additionally, these figures included single events when they directly affected BBIS structures, or when they were crucial for the fulfilment of BBIS functions. These events or clusters of events could be from the BBIS or from its contexts. For the representation of the functions, as these functions can be fulfilled by different types of activities[12], boxes were named according to the most relevant activities for the period. The respective subsections present the explanations of these activities. Lastly, the arrows between events or cluster of events indicate which events preceded other events. The arrows linking events or cluster of events and boxes indicate the relevance of these events to the fulfilment of certain function, and the arrows connecting boxes and events indicate the effect of this function fulfilment to other events.

Table 1 – List of Interviewees

Category of Players	Number of Interviewees	Acronyms
Governmental bodies (G)	6	G1 to G6
Utilities (Ut)	5	Ut1 to Ut5
Private companies (P)	3	P1., P2 and P3
Intermediary organisations (I)	3	I1, I2 and I3
Research centre/company (R)	3	R1, R2 and R3
Financial organisation (Fin)	2	Fin1 and Fin2
University (Un)	1	Un1
Farmer (F)	1	F1

2.4 BIOGAS VALUE CHAIN AND ITS CONTEXTS IN BRAZIL

Biogas is generated by a biochemical reaction, in which organic matter is degraded by microorganisms in the absence of oxygen. The main products are methane, carbon dioxide and digestate, which is the residue of anaerobic digestion (Balat & Balat, 2009; Da Costa Gomez, 2013).

[12] See Section 2.

Like natural gas, biogas is a flexible fuel with several applications (Holm-Nielsen et al., 2009). The set of technologies related to biogas ranges from biomass treatment to biogas logistics and use. However, the core of biogas technological innovation lies in the production and treatment technologies, which require specific biodigesters, yeast strains and technologies for removal of water, sulphur, siloxanes and carbon dioxide (Wellinger et al., 2013). Therefore, the different combinations of feedstocks and technologies yield a plethora of possibilities in biogas value chains in Brazil[13].

2.4.1 Biogas value chain, technological trajectories and Brazilian Biogas Innovation System boundaries

Biogas activities can be placed into three main categories: feedstock supply and logistics, biogas production and treatment and biogas uses and logistics. Given Brazil's large potential to produce biomass and the flexibility of biogas applications, biogas technologies involve a profusion of institutions, actors and materials. From the upstream side, this situation introduces several categories of actors, such as sanitation utilities, farmers and agroindustry; different type of rules, e.g. sanitation regulations, agricultural market rules and environmental legislations; and a variety of material aspects, such as sewage, organic fraction of Municipal Solid Waste (MSW), manure, vinasse, UASB[14] reactors, landfills and dunghill lagoons. The downstream side introduces energy utilities, engineering companies, power and natural gas sectors regulations, ICE[15] generators, compressors and power and natural gas systems to name some actors, institutions and materials (FEAM et al., 2015; Jende and et. al, 2016; Moraes et al., 2015; Nadaletti et al., 2015; Novak et al., 2016; Querol et al., 2015; Strassburg et al., 2015). Consequently, biogas technologies have evolved across different technological trajectories or technical routes.

A series of recent publications (Berns et al., 2015; Cabral et al., 2015; Coelho et al., 2018; Schnicke, 2015; B. Silveira et al., 2015) have contextualised biogas technologies for Brazil. The choice of anaerobic reactor for biogas production (CSTR[16], UASB, anaerobic lagoons, plugflow and batch dry fermentation reactors) depends mostly on the geographic density, quantity, seasonality and characteristic feedstocks (livestock manure, agro-industrial residues, sewage and sludge and organic fraction of MSW) (Cabral et al., 2015; Coelho et al., 2018). These factors influence the type of biogas treatment[17] and the scale of biogas production. Therefore, the scale of biogas production varies according to regional and sectoral activities. For instance, livestock production tends to involve

[13] The study of Paraná state case (Novak et al., 2016) illustrates the possibilities of developing the biogas value chain.
[14] Up-flow Anaerobic Sludge Blanket Reactor.
[15] Internal combustion engines.
[16] Continuous Stirred Tank Reactors.
[17] For instance, biogas from vinasse has a much higher concentration of sulphur than biogas from livestock manure (Colturato, 2015).

small or medium-scale biodigesters, whereas industrial residues, such as those from ethanol production, may be handled on larger scales.

Conversely, the scale of biogas production in urban areas depends on the population, the related waste and residue concentrations and infrastructural systems. Technical infrastructure plays an important role in urban biogas projects. Because urban sanitation and waste management projects are capital-intensive investments, the selection of technical schemes influences the availability of either the substrates or the biogas. The case of UASB reactors in sanitation systems and landfills illustrates this dependence on technical infrastructures.

Additionally, the selection of biogas-use technologies, mostly power generation, substitution of thermal or automotive fuels or injection into gas grids, is influenced by the scale of biogas production. The selection of biogas-use technologies has also a strong influence on the choice of biogas treatment technologies. For example, biomethane production requires a more intensive biogas treatment technology than power generation or cooking fuel use. These treatment technologies have distinct scales, placing technical or economic constrains on the choice of other technologies in a biogas project.

With this set of conditions, it is possible to highlight four main technological trajectories for biogas related to the feedstock sector (see Figure 3). The first (T1) is based on livestock manure comprised mostly of the residues from swine production. T1 leads to small or medium-scale projects in rural areas, primarily in the southern region. Biogas production occurs mainly in anaerobic lagoons; however, more modern biodigesters like CSTR are also used for production. Power generation and heating fuel are the predominant uses of biogas in this scheme. Consequently, biogas treatment technologies in T1 are simpler than those for other trajectories and involve mostly the removal of water and sulphur content.

The second trajectory (T2) is also based on residues; however, these come from industrial processes, mainly related to the food, beverage and sugarcane industries. The main difference between industrial and livestock residues is the concentration and quantity of residues that can be much higher. Therefore, the scale of biogas projects goes from small to very large. Projects in this trajectory tend to apply CSTR types of biodigesters and use biogas in different ways; however, power generation is still dominant. This use depends on local demand and infrastructure. These two trajectories require different types of technological development, such as the scaling-down of biogas production and treatment technologies and the adaptation of biogas production technologies for a very large scale, e.g. the sugarcane sector.

Residues from the sanitation sector (sewage and sludge) lead to the third trajectory (T3). Biogas production for this trajectory relies heavily on the type of infrastructure in the sewage systems. If these systems employ UASB type reactors for sewage treatment (anaerobic treatment), there is a possibility of capturing biogas produced during the treatment of waste water and use sludge (output of the treatment) in a different biodigester. If sanitation systems apply a chemical treatment procedure, then the only possibility is use of the sludge. In general, biogas projects for this trajectory are small and medium-scale projects that apply power generation schemes for self-consumption. Therefore, these biogas treatment technologies are similar to those in previous trajectories.

The fourth trajectory (T4) refers to biogas production in the waste management sector. The dominant technical route is based on the capture of landfill gas. This dominance entails the higher relevance of biogas treatment technologies as no digester is needed in this case. Power generation is the dominant use of biogas; however, biomethane projects have been proposed recently. The scale of such projects is a direct outcome of the size of landfills. Important technological development must be achieved for this trajectory, particularly the development of biogas treatment technologies that remove siloxanes and assure the quality of biomethane.

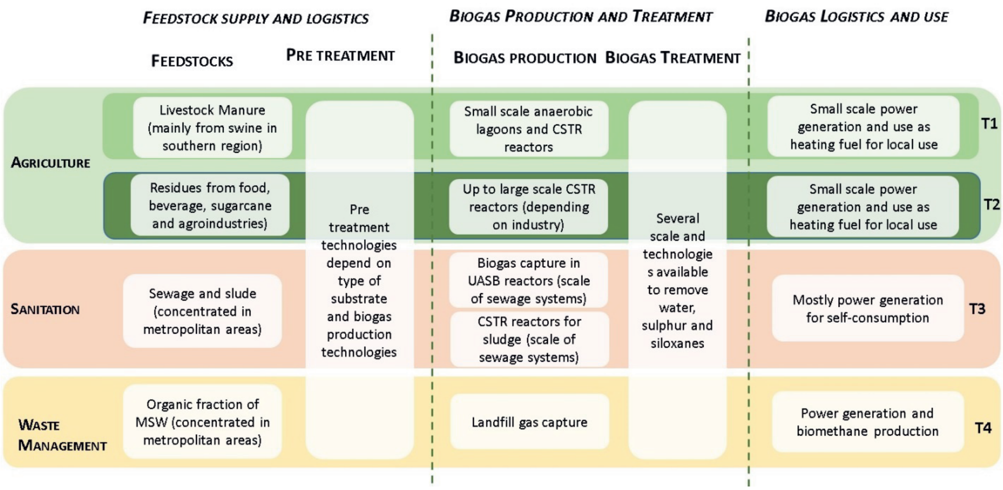


Figure 3 – Main technological trajectories of biogas production in Brazil

The investigation led to other projects in which these trajectories overlap with each other, e.g. co-digestion of residues, biomethane production from livestock manure and dry processes for MSW. However, the selection of these trajectories represents the majority of projects that have been developed during the period analysed. These trajectories also indicate where contextual influences may be expected in the biogas value chain. They highlight the relevance of feedstock sectors, of sectors that use the biogas produced and of most propitious regions and places for biogas projects. However, future development of biogas technologies in Brazil may encounter other trajectories.

2.4.2 Main contexts for Brazilian Biogas Innovation System analysis

This section aims to present the main contextual aspects to investigate so that TIS analysis can account for the influences of contexts on the dynamics of BBIS. From the description of technological trajectories, it was possible to detect contextual influences of the four categories presented in Bergek et al. (2015). However, the discussion in next sections grouped these influences into sectoral and geographic contexts This is consequence of several interactions between contextual structures. Therefore, technological and political factors and structures can be analysed through the lens of sectoral and geographic contexts. Moreover, for readers that are not familiar with the Brazilian conditions, some general aspects of sectoral and geographic contexts in Brazil are presented.

2.4.2.1 Sectoral contexts

Sectoral structures emerged as the most important contextual influences on biogas technological trajectories. Biogas projects are engaged mostly in activities within the *Agriculture* sector (including agriculture, livestock and agroindustry), the *Energy* sector (mainly power and natural gas) and the *Sanitation* sector (including water and sewage treatment and waste management sectors). The *Environmental* and C*limate Change* policy fields[18] also influenced these trajectories. The strongest influences came from specific actors and institutional, physical and resource infrastructures.

For institutional structures, the first focus of investigation was how their evolution has influenced the BBIS. This was a crucial point because the research covered 37 years, and sectoral institutions have changed several times due to several institutional reforms. For example, the power sector has faced two large institutional reforms within the last 25 years. Our second focus was on how sectoral institutional overlaps, voids and interactions create both barriers and opportunities for biogas projects. For instance, agricultural activities must comply with environmental regulations and market structures, due to the commodity market feature, whereas the sanitation sector has specific regulatory frameworks in addition to environmental rules. Another example is the low-carbon agricultural plan (climate change field and agriculture sector) which has enabled several biogas projects.

Sectoral institutional structures also interact with the political system. The interactions with different governance levels, given by the Brazilian federative political system (Souza, 2005), provide distinct governance structures across sectors. For example, national environmental policies define

[18] Here, there is an implicit understanding of sectors as organisational fields (DiMaggio & Powell, 1983) and as policy fields (Rogge & Reichardt, 2016).

the macro guidelines that regional and local bodies must follow and adapt to local conditions. The fields of climate change and the sanitation sectors follow the same shared governance structure, national guidelines and targets and regional and local rules. In contrast, the agricultural sectors are less regulated and more market-oriented[19].

On the downstream side, the power sector is regulated by national agencies[20] (ANEEL[21], CCEE[22] and ONS[23]), including the definition of tariffs. In contrast, the natural gas sector is subjected to regulation shared by national (ANP) and state-level (regulatory and executive agencies) bodies. This situation involves not only diverse rules but also the need for vertical and horizontal coordination among these governance levels. Therefore, understanding how this interaction affects BBIS dynamics seems to be crucial.

These governance structures lead to a distinct set of actors, such as utilities, private companies and national and local governmental bodies according to sectors. It is essential to analyse what are the roles of these sectoral actors in the development of biogas projects and technologies since they bring different logics into BBIS. It is also essential to investigate how these actors interact with other actors in a cross-sectoral context. For instance, while environmental agencies may support and push biogas technologies by enacting regulations for waste and residues treatment, these regulations may also be too strict and constrain the development of biogas projects.

These governance structures may also hinder important interactions. As biogas projects deal with players and regulations of distinct sectors, horizontal and vertical knowledge exchange is vital. For example, if centralised energy regulatory agencies have to interact with agricultural players, it may be very difficult to find common solutions for biogas projects since they have few spaces for interactions.

Physical infrastructures represent other relevant sectoral influences. They have a strong impact on the development of biogas projects because each sector has distinct infrastructural conditions. Sanitation sectors have low numbers of adequate treatment systems. Sewage systems collect only 80% of effluents and treat 40% only, whereas MSW management collects 98% of solid waste but still has around 30% of dumps[24]. As discussed, the choice of anaerobic or chemical processes for sewage treatment and the choice of landfills or other schemes have direct impacts on biogas decisions for these sectors. In recent years, the agricultural sectors have been improving their residues management through tillage in agriculture and the expansion of livestock manure

[19] Although state players are also important, such as the national supply company, Embrapa and Banco do Brasil.
[20] Although there are state-level agencies, the relevance of these for the power sector compared with natural sector is minimal.
[21] Power sector regulatory agency
[22] Electricity National Chamber of Commercialisation
[23] National Power System Operator
[24] SNIS (National Sanitation Information System) – www.snis.gov.br

treatment. However, the expansion of confined livestock production systems increases the need for new rural sanitation systems.

On the downstream side the power sector is the most universal in Brazil in terms of physical infrastructure, while the natural gas grid is concentrated in a few cities only. Furthermore, physical infrastructures are territorially embedded, meaning that quality and accessibility vary among regions. For instance, there are differences in quality between urban and rural power networks and sanitation systems, and access to a natural gas grid is more limited in country cities.

Furthermore, the main driver for BBIS technological interactions is the interaction between institutional and physical infrastructure. While the formal rules influence the definition of business models, accessibility and quality, the types of infrastructure enable or constrain different technologies. Therefore, possible influences of other technologies can be investigated by focusing on these interactions. On the upstream side, the primary example comes from the sanitation sectors. The choice for landfills in waste management results in no development of biogas production technologies, but only biogas treatment and use technologies. In sanitation, the development of biogas projects is either planned with expansion of the system or has to rely on anaerobic systems[25].

On the downstream side, power sector regulations and grids define which and how distinct types of distributed generation technologies can access the grid and trade electricity. This creates an important type of competition between these technologies. Still, biogas projects that aim to use biogas as fuel must comply with fuel regulations and natural gas grid conditions.

Finally, as resources are crucial for any TIS development, it is crucial to examine how sectoral resource structures act upon BBIS resources. Despite having a successful agricultural innovation system, Brazil concentrates R&D&I in the public research company, Embrapa, and in universities with low private investment and no mandatory rules for private companies (OECD, 2015). For the sanitation sectors, R&D&I resources are scarcer. Because there is no mandatory investment in R&D&I, and because there has been a long period without significant investments in infrastructure, research and innovation activities depend mostly on the inner motivation of single actors (Heller & Nascimento, 2005; Leoneti et al., 2011).

In contrast, the energy sector possesses abundant funds for R&D&I activities, which is a consequence of mandatory regulations that force investments in R&D. Moreover, combined R&D&I projects are not common across sectors, which would be crucial for the biogas field. Another important resource is human, i.e. skilled labour. The availability and quality of human resources is hugely disparate across sectors, because the qualifications of labour vary according to sectors.

[25] In general lines, chemical sanitation treatment makes biogas projects unfeasible.

2.4.2.2 Geographic aspects and influences

Recently, TIS studies tried to capture geographic influences beyond the national level (e.g. Binz et al., 2014; Gosens et al., 2015; Schmidt and Dabur, 2014; Aschalew D. Tigabu et al., 2015; Wieczorek et al., 2014), even though most scholars still concentrate on national influences (Coenen et al., 2012). At the international level, TIS studies have focused on technology transfer activities and financial resource allocation (e.g. Schmidt and Dabur, 2014; Tigabu et al., 2015). However, other factors, such as shocks in international prices and international crises, are important as well (Markard & Truffer, 2008). For BBIS, there are three main factors to be mapped. The international development of biogas technologies is the first relevant factor because of the possible technology and policy transfers. Then, it is necessary to investigate the interactions with and roles of international players that facilitate these transfers. Third, changes in international prices of agricultural, mineral and energy commodities are relevant because they directly affect the Brazilian economy and biogas-related sectors.

At the national level, analyses must account for the interrelationships of BBIS and the Brazilian National Innovation System (BNIS) and political structures, more specifically understand how macro national conditions affect both sectoral and TIS dynamics. Since the broad definition of NIS (Lundvall et al., 2002) already accounts for some political issues, and because a detailed description of political factors goes far beyond the scope of this paper, this study borrows from two recent studies on BNIS (Cassiolato, 2015; Mazzucato & Penna, 2016). These studies presented the historical development of BNIS, its current strengths and weaknesses as well as the role of macroeconomic policies by examining four macro groups: Education and Research, Production and Innovation, Finance and Funding and Government (regulations and policies).

Lastly, sectoral contexts have already discussed regional and local actors, institutional settings, resources and material aspects play important roles for biogas in Brazil. This fact is consequence of the interactions between regional features and sectoral conditions create specific situations that influence biogas activities. Therefore, the singular geographic factor to examine is the evolution of substrate availability. Availability of substrates is consistently distributed with regional edaphoclimatic characteristics and consequent agricultural production. It also results from the urban population concentration that determines the differentiation of urban from rural areas. This situation yields regions that are more suitable for certain feedstock, which leads to different sorts of technologies. For example, the concentration of sewage and sludge treatment systems is higher in big cities, swine manure is produced mainly in rural areas of southern states, as sugarcane and ethanol production take place mostly in São Paulo state.

2.5 BRAZILIAN BIOGAS INNOVATION SYSTEM

The historical analysis documents four main phases[26] of biogas development in Brazil (see Figure 4 for temporal and geographical distribution of events in which the height of the bars represent the number of events per year, and the circles represent the total number of events per city. See also Figure 5 for an overview of phases).

The first phase is the period of 1979–1986. The initial event of biogas promotion in Brazil usually is pointed out as the inauguration of the '*Granja do Torto'*[27] biodigester (Bley Jr., 2015; Palhares, 2008) in 1979, and the first incentives for biogas production in Brazil in the 1980s. These incentives were a direct consequence of the oil crises in 1973 and 1979 and public pressure for improved sanitation services. This phase achieved some success as about 3,000 biodigesters were installed. Nevertheless, the oil prices drop in 1986 and the deterioration of Brazilian macroeconomic conditions discontinued the positive cycle of biogas activities.

The following phase (1987–2002) represents the recession of biogas experimentation and the decline of the BBIS. Meanwhile, several macro institutional changes happened to create a turbulent environment for the BBIS. During the third phase (2003–2011), CDM[28] projects stimulated biogas technologies. During this period, the BBIS was resurrected and experienced important structuration. Contextual events marked the end of this phase, such as the decline of CDM projects and the consequences of international economic crisis.

The last phase (2012–2016), started with the development of important milestones for biogas, such as state-level biogas policies, the creation of national associations and research networks. However, the current economic and political crises in Brazil may have a negative impact on the BBIS's future activities. In the following sections, the detailed description of these phase is presented, starting from the initial contextual conditions, development of BBIS activities, changes in contexts and impacts on BBIS activities.

[26] The end of each phase was chosen on the basis of change in activities or key events; therefore, not all periods are equal in length (Negro et al., 2007).
[27] One of the official residences of Brazilian presidents.
[28] Clean Development Mechanism of the Kyoto Protocol.

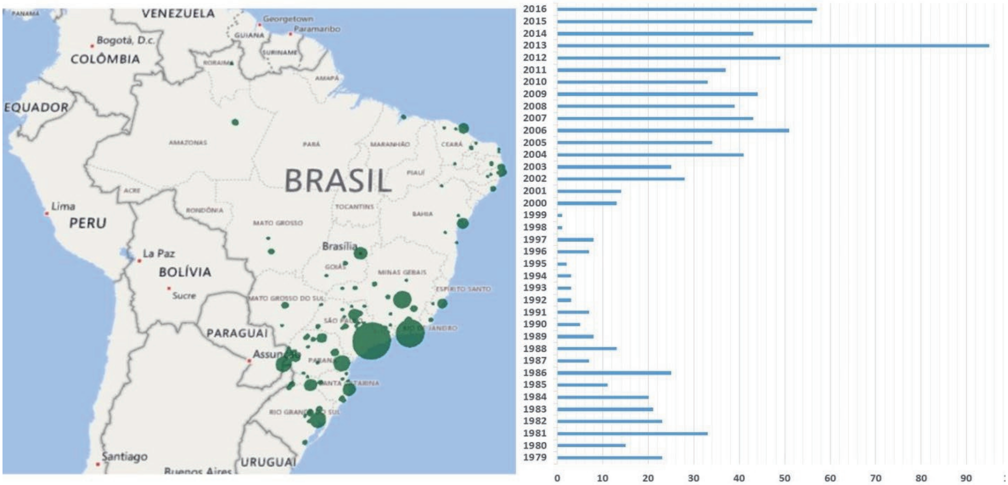


Figure 4 – Geographic and time overview of mapped events

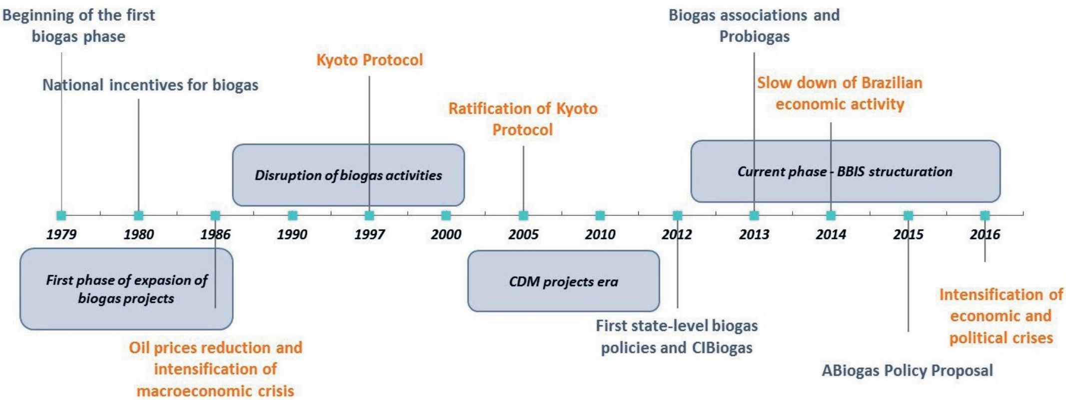


Figure 5 – Timeline of main phases of biogas activities in Brazil

2.5.1 Biogas kick-off (1979–1986)

This period started under the pressure of two global oil crises in 1973 and 1979, which led to the search for reducing oil dependence. Coinciding with these events was the growing concern for environmental issues, such as resource depletion and local pollution, and the diffusion of biogas technologies in other developing countries like China and India (Bond & Templeton, 2011).

In Brazil, high oil prices were translated into macroeconomic pressures and consequent actions to reduce external oil dependency. During this period, the Brazilian government decided to intensify the promotion of alternative energy and several measures were implemented. For instance, the famous *PROALCOOL* programme to promote the expansion of ethanol production from sugarcane (Furtado et al., 2011). In addition, the initial effects of intensification of livestock production and the increasing urbanisation started to pressure the environment and demand more sanitation services.

This situation set the contextual environment for BBIS development by enabling the *convergence of the visions of biogas* as one of the solutions for these contextual problems among different types of actors and promoting the initial fulfilment of guidance of the search and engagement of key players. This set of activities comprised the first relevant process that triggered the BBIS's development (see Figure 6). First, the engagement of researchers, for instance the UNESP[29]'s biogas research project funded by CNPq[30] in January 1979 and practitioners, for example from Embrater[31], led to the *Granja do Torto* biogas project (trajectory T1), which was launched in November 1979. These initial events aligned the expectations of searching for alternative energies and the need for better sanitation in rural and urban areas around the biogas technologies as a convergent solution for these problems.

Then, a series of events started to shape the BBIS and led to the second important process based on the *resource allocation* by the incumbents, which intensified the engagement of other actors and the development of projects. Financial resources were provided by national and state-level bodies (including state-owned companies). Knowledge was provided by sectoral utilities and private companies established in Brazil. Feedstocks were dependent on regional and local players.

National government bodies created funding lines to biogas solutions through the development bank and research agencies. State-level bodies stimulated projects through state-level banks and state-owned companies. Energy and sanitation state-owned companies had fundamental roles on both the supply and demand sides of biogas technologies and actively participated in R&D projects. Rural development agencies and the Brazilian Agricultural Research Corporation (Embrapa) mobilised not only farmers and, consequently, the supply of substrates, but also provided important knowledge resources through operational and research activities. Universities and some private companies complemented the knowledge infrastructure of this period, with private companies participating later on and more on biogas treatment and use technologies.

The outcome of this resource allocation was the development of several projects. Initially, the majority of projects occurred in rural areas (trajectory T1), especially in the southern states of Paraná and Santa Catarina, where rural sanitation along with biofertiliser production were the main motivations, and biogas energy use was to be a by-product[32]. The most diffused biodigester

[29] University of the state of São Paulo
[30] National Research Council
[31] Brazilian technical enterprise of rural extension
[32] These projects created a huge cycle of positive expectations due to the possibility of cost reduction with biofertilizer mainly but also energy. For instance, the expansion of Liquefied Petroleum Gas in replacement of firewood raised the costs for farm production. However, the share of chemical fertilizer costs and the possibility of replacement with

technology was the Indian biodigester model since it was relatively cheap and easy to adapt (Palhares, 2008). Research projects concentrated in areas where there were already strong research groups on rural- and agriculture-related topics such as in São Paulo's universities (UNESP and Unicamp) and the southern region (with Embrapa and universities like UEL and UFSC).

The combination of convergence of visions around biogas as solution for oil dependence and local environmental problems, resource allocation by important incumbents and development of several projects brought about the increase of legitimacy of biogas technologies and experimentation with other technological trajectories. This *increasing of legitimacy* became the third relevant process of BBIS expansion, reinforcing the pressure for resource allocation.

The energy use of biogas from landfills was more relevant in São Paulo, Rio de Janeiro, Minas Gerais and Ceará states (trajectory T4). The necessary set of resources (knowledge and financial) was also mostly provided by sanitation and energy utilities that already experimented with digestion technologies. Besides, since the landfills produce gas without any additional technology needed, technological development concentrated on the biogas treatment and use technologies. Meanwhile, also because of the search for reducing oil dependence, the promotion of natural gas vehicles in some urban areas motivated experimentation with biogas from landfills in these vehicles[33]. For this, the engagement of car manufacturing companies was crucial in developing automotive technological solutions for specific projects[34].

Other important experiences occurred as a consequence of ethanol production expansion (trajectory T2). The increased legitimacy of biogas technologies fitted very well the problems of surplus of vinasse[35] production and shortage of diesel supply in the sugarcane sector. Players were able to develop specific biodigestion and biogas treatment technologies targeting the treatment of vinasse and automotive uses of biogas. However, these experiences presented technological limitations[36]. Lastly, another avenue of biogas experimentation, less explored, was the combination with other energy technologies[37].

Nevertheless, after this positive cycle, and although BBIS underwent a noticeable development, changes in contexts along with technical problems negatively affected BBIS functioning. First, the intensification of the national macroeconomic crisis, which had already started

biofertilizer was more relevant for rural areas. Lastly, the compliance with better environmental manure treatment was also relevant.

[33] Landfill projects in Belo Horizonte, Rio de Janeiro and São Paulo for vehicles (1983–1986), as well as R&D projects in Londrina with biogas tests for tractors (1984) and the fuel station of UNESP and Mangels in Jaboticabal (1985), are relevant examples.

[34] Projects for automotive biogas happened in different cities, such as Londrina for tractors (Sanepar, Mangels, MWM and Valmet) and for taxis and trucks in Rio de Janeiro (CEDAE, Comlurb, CEG and Marsh).

[35] Liquid residue of ethanol production

[36] Several players were involved, such as Dedini, IPT, Unesp, Comgás, UEL and PEM-Engenharia; however, there were persistent technical problems, mainly for controlling biodigestion reactions and biogas treatment technologies.

[37] For instance, projects like Piraí do Sul (PR) and Cedro (PE) attempted to create 'sustainable cities' models through the integration of different technological solutions, including biogas.

in 1982 (Cassiolato, 2015), and the plunge in international oil prices reduced the availability of resources extremely reduced the contextual pressure for searching for *alternative* energies. These changes, therefore, affected the convergence of problems and the resource allocation processes.

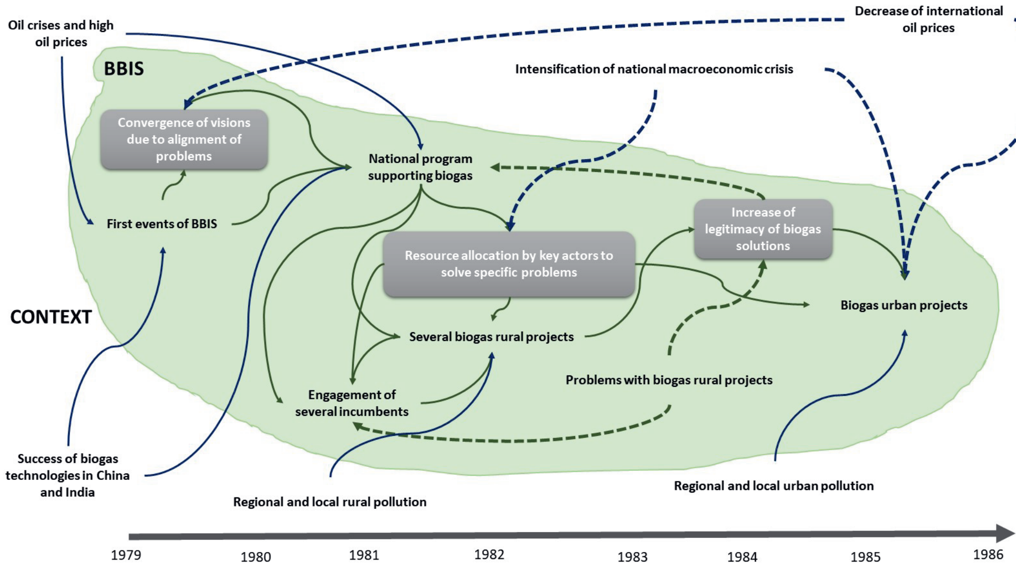
Key actors, such as national governmental bodies and state-owned companies, altered their strategies or lost their financial capacities, cutting off financial support for biogas projects. Second, technical problems of biogas projects triggered a vicious cycle for biogas activities. These technical problems, e.g. inadequate material specification and incorrect operation of biodigesters, were primarily due to a lack of knowledge related to operating and designing projects of both companies and users, particularly in rural areas.

Other important issues were the lack of regulations for biogas projects and the quality and accessibility of technical infrastructure. The former allowed the development of poorly designed projects. Although there was the engagement of incumbents, virtually no biogas-specific regulation or standard was enacted during this period. Infrastructure, such as the power and natural gas grids and sanitation systems, were less accessible, restricting the production and capture of biogas values.

This issue also entailed higher relevance of sectoral regulations. By that time, these regulations were too strict and hampered the development of important biogas activities. For instance, the role of distributed generation (DG) in the power sector and fuel use of biogas for either transportation or injection into the gas grid. Hence, several projects could not fulfil the high expectations they raised in terms of environmental solutions and cost reduction, which contributed to the downturn of legitimacy.

In sum, contextual influences were central for this phase in both positive and negative ways (see Figure 6). International contexts provided pressure on the existing regimes (through the oil crises), which were translated by national and sectoral actors into several problems (e.g. the need to reduce oil dependence and improve energy efficiency) and solutions (e.g. the promotion of alternative energies, including biogas) according to regional and local conditions. After this initial alignment of contextual conditions, key incumbents allocated resources and the resulting development of projects increased legitimacy.

The vicious cycle of this first phase also started with changes in macroeconomic contexts and international oil prices, and then intensified through the internal problems of biogas activities. International and national factors affected mainly the alignment of contextual conditions and the resource allocation, whereas technical problems undermined the legitimacy of biogas technologies. Thus, the coupling of processes that promoted BBIS development was severely weakened.



Continuous line -> positive influence; Dashed line -> negative influence; Blue line -> contextual influence; Green line -> BBIS internal influence

Figure 6 – Interaction of BBIS activities and their contexts for the first phase

2.5.2 Biogas tumble (1986–2002)

This phase was marked by the great dismantling of basic BBIS structures due to the continuation of negative cycles present in the previous phase. At the international level, low oil prices continued. On the environmental front, during the whole period there was increasing legitimation of climate change problems. Important events, such as the Brundtland report (1987), the establishment of IPCC in 1988, the Rio de Janeiro Earth Summit in 1992 and to the Kyoto Protocol in 1997 strengthened the process of increasing legitimation for carbon emissions reduction. On the political economy front, the internationalisation of neoliberal policies converged to the standardisation of macroeconomic policies[38].

Domestically, the period started with the continuation of macroeconomic crises that lasted until the stabilisation of the Brazilian economy in 1994. Consequently, the main actors aborted most biogas activities. Only a few experiments were left, e.g. some urban biogas projects, particularly in landfills. However, by the beginning of 1990s these were also terminated. The only elements of the BBIS that remained were some isolated knowledge development projects.

[38] Particularly for Latin America, neoliberal policies were highly promoted by international organisations through the Washington Consensus (Williamson, 1990) (for further discussion see (Babb, 2013)).

With economic crises continuing throughout the period, by the end another economic crisis took place (1999); thus, the negative influence of macroeconomic conditions continued during this phase. Moreover, this phase also showed a very turbulent environment, when significant macro institutional changes occurred, namely changes from a dictatorship regime to a democracy (1985), the establishment of a new constitution (1988) and the opening of the economy (1990). Sectoral contexts also presented important institutional changes, following the liberalisation manual. The law of concessions (1995)[39] was an important policy for the institutional changes of several sectors, such as the liberalisation of the oil and power sectors and the creation of regulatory bodies (in 1996 for the power sector[40] and 1997 for the oil and natural gas sectors[41]).

Industrial and innovation policies during this period were mostly based on a belief in liberalisation, leading to quick implementation of free-trade policy instruments and limited implementation of innovation policy instruments such as coordination and support mechanisms (Cassiolato, 2015). Noteworthy events also occurred in the power sector: the deep crisis of the power sector in 2001, which was a consequence of the liberalisation processes and lack of planning (Goldenberg & Prado, 2003); the power sector R&D law enactment, which obliged power utilities to invest in energy efficiency and R&D projects (2000)[42]; and the PROINFA programme (2002)[43], which is the main RES-E[44] incentive program of Brazil (Dutra & Szklo, 2008).

In Brazil, other sectoral and geographic factors were also important. First, environmental laws and agricultural policies created the institutional contexts for the following phase[45]. Second, by the end of the period, during a new economic crisis, the government acknowledged the need for further intervention and created important Science, Technology and Innovation (STI) policies such as the sectoral innovation funds (1999–2002) and a national programme to support incubators and technological parks (1998–2002) (Cassiolato, 2015).

Third, there was continuous growth in population rates in the urban areas, from roughly 135 to 176 million, and urbanisation from 70% to 82% during that period[46]. In metropolitan areas, the huge concentration of population and resulting MSW led to conflicts between municipalities (e.g. in Rio de Janeiro state) as well as to important local and regional actions to improve waste management[47]. For sanitation systems, it also entailed the diffusion of UASB reactors. The expansion of Brazilian agriculture, in rural areas, entailed the need for better manure treatment and

[39] http://www.planalto.gov.br/ccivil_03/leis/L8987cons.htm#art30
[40] http://www.planalto.gov.br/ccivil_03/leis/L9427cons.htm
[41] http://www.planalto.gov.br/ccivil_03/leis/L9433.htm
[42] http://www.planalto.gov.br/ccivil_03/leis/L9991.htm
[43] http://www.planalto.gov.br/ccivil_03/leis/2002/L10438.htm
[44] Renewable energy sources for electricity.
[45] For example, http://www.planalto.gov.br/ccivil_03/leis/L7797.htm , http://www.planalto.gov.br/ccivil_03/leis/L7735.htm and http://www.planalto.gov.br/ccivil_03/leis/L9605.htm
[46] http://seriesestatisticas.ibge.gov.br/lista_tema.aspx?op=0&no=10
[47] The Bandeirantes Landfill initial actions and the promotion of dunghill lagoons for manure treatment date from the late 1990s.

consequent local initiatives in which local and regional environmental bodies, together with rural development agencies and Embrapa, started to promote the use of dunghill lagoon schemes.

These factors combined provided the institutional environment, problematic situations and the availability of feedstocks for BBIS in the following phase. Therefore, the end of this phase brought to some extent the convergence of contextual problems similar to the beginning of the first phase: the Kyoto Protocol, with the possibility of using CDM resources, and the intensification of local and regional pollution problems, with consequent actions to mitigate them such as regional environmental regulations and the diffusion of landfills and UASB reactors. Despite this, because there was no robust biogas activity within a turbulent macroeconomic environment, this phase could not produce a positive cycle of actions. In other words, projects were conducted as isolated actions and did not promote the engagement of actors during this period. Nonetheless, contextual events enabled the environment for another positive cycle of biogas activities.

2.5.3 The CDM era of biogas (2003–2011)

Once more, the convergence of contextual problems played out as the initial mechanism to activate the 'dormant' BBIS. Following the activities at the end of the previous phase, the increasing pressure for solving local and regional urban and rural pollution problems guided the actions of different actors towards better environmental management. Nationally, a series of CONAMA[48] resolutions provided the regulatory basis for water bodies and effluents, the use of sanitation sludge in agriculture, and the environmental licensing for sanitation facilities, as well as for small-scale agroindustries and landfills[49]. In urban areas, programmes of municipalities and states targeted the negative impact of waste dumps. In rural areas, the involvement of private companies, farmers and Embrapa aimed at the livestock manure problem.

Moreover, these local/regional problematic situations encountered a fertile environment in sectoral, national and international scenes. In 2003, the new Brazilian government initiated several sectoral institutional changes (presented in **Erro! Fonte de referência não encontrada.** in the Appendix). Important reforms were undertaken in STI, energy, bioenergy and sanitation policies. Later on in this phase, the promulgation of natural gas, climate change and waste management laws completed the large sectoral reforms during this period. Although one might assume this produced a turbulent environment, similar to what happened in the second phase, this was not the case.

New sectoral regulatory frameworks created a more propitious environment as they addressed important problems. For instance, in the new regulatory model of power sector introduced incentives for renewable and decentralised energy, and the sanitation policies provided important

[48] National Environmental Council.
[49] Table 3, in the appendix, presents these resolutions.

targets for system expansion. Additionally, the agricultural sectors in this period continued to show intense growth and expansion on international markets due to high commodities prices, the outcomes of intensive research and the diffusion of best practices. For sugarcane particularly, the introduction of flex-fuel cars boosted the ethanol market.

Two other factors made the environment more stable for biogas experimentation: the national macroeconomic and international contexts. During this period, macroeconomic conditions were relatively favourable[50] and constant economic growth was observed until the international crisis in 2008. After the slight recession in 2009, economic growth returned in 2010 and 2011. Internationally, validation of the Kyoto Protocol in 2005 boosted the market of CDM projects[51]. The latter became an interesting business model for biogas projects[52]. Thus, an increasing awareness for local/regional pollution problems, a relatively stable macroeconomic environment and the CDM instrument for mitigating GHG emissions characterised the process that reactivated the dormant BBIS by providing the *guidance of search*.

This process motivated the engagement of important players that foresaw financial return on investments with the trade of carbon certificates and started to allocate resources to biogas CDM projects (see the main projects for this phase in Table 2). Municipalities led landfill projects while agroindustries promoted rural projects. Intermediary actors, such as consultancies, played important roles by providing knowledge on the business model and bureaucratic procedures. This model also attracted the interest of international players (technology suppliers and consultancies) for the Brazilian market, and they supported important learning processes by contributing with technological solutions (e.g. manure management systems and biogas treatment systems) and organisational and market solutions (how to develop CDM projects)[53].

Table 2 – Main Biogas Projects in Phase 3

Project	Year	Trajectory	Main Business Model	Description
Ambev Project	2003	T2	Biogas with energy recovery	Biogas from industrial residues to promote energy efficiency
Nova Gerar landfill	2004	T4	Biogas burning	World's first registered CDM project
ETE Barueri	2004	T3	Biogas with energy recovery	Biogas recovery from sewage treatment
Sadia Sustainability Project	2004	T1	Biogas burning	Improvement of dunghill lagoons (swine manure) to anaerobic lagoon with biogas recovery through CDM

[50] However, Cassiolato (2015) presented the appreciation of exchange rates, from 2006 onwards, as a negative effect.
[51] The relevance of Brazil for CDM projects is illustrated in Watts et al. (2014).
[52] CDM allowed countries of Annex I (developed countries) investing in GHG mitigation projects in non-Annex I countries (developing countries) under specific conditions.
[53] See Dechezleprere et al. (20080 and Dechezleprêtre et al. (2009) for specific analyses of technology transfers.

Bandeirantes landfill	2006	T4	CDM	World's biggest CDM trade by the time
Start-up of Consórcio Verde project	2007	T2	Biogas with energy recovery	First activities of the project that would lead to important developments in the following phase
Itaipu biogas project	2008	T1	Biogas with energy recovery	Engaged small farmers and utilities for the swine manure treatment in the west of Paraná state
Geoenergética pilot projects	2004, 2008 and 2009	T2	Biogas with energy recovery	aimed the biodigestion of residues of the sugarcane industry for large-scale power generation
Geoenergética commercial project	2011	T2	Biogas with energy recovery	Larger scale biogas project in the sugarcane sector

Projects that applied the CDM business model achieved high level of legitimacy at the beginning of the phase, mainly in trajectories T1 and T4. After the success of Nova Gerar and Bandeirantes landfills (capturing and burning landfill gas to mitigate methane emissions), several municipalities tried to set up similar projects to use the CDM resource to improve waste management conditions–trajectory T4. The Sadia Sustainability programme[54] launched in 2004 promoted the improvement of dunghill lagoons (mostly swine manure) to anaerobic lagoons with biogas recovery through CDM–trajectory T1. This project influenced other food companies to take the same path, mainly in the states of Santa Catarina, Minas Gerais and Paraná.

In parallel, the biogas projects led by AMBEV (2003) were also important references to increase the legitimacy of biogas solutions–trajectory T2. They implemented biogas technologies into the industrial processes to increase energy and economic efficiency. Consequently, there was an increase in *entrepreneurial activities* with biogas solutions with two main business models: (i) anaerobic digestion mainly as an environmental treatment without energy recovery (biogas burning) and little technological development; and (ii) biogas recovery for power generation that required more efficient projects and technological adaptation.

In other words, the *resource allocation* at the beginning of the period resulted in successful projects, more knowledge about biogas solutions (important learning mechanism) and a *positive cycle for legitimacy.* For instance, the success of trajectory T4 projects led to the formation of an inter ministry committee to promote and diffuse this design. The same happened for projects in trajectory T1, which were supported by several state-level environmental bodies. This coupling of

[54] See Querol, (2011) for in-depth analysis.

processes (alignment of contextual conditions, resource allocation, learning as consequence of projects and increased legitimacy) led to a second period within this phase where key players, such as the energy incumbents Itaipu, Copel, Sanepar, Sulgás and the new entrant Geoenergética, were responsible for carrying out other models of biogas projects (Figure 7 presents the cycles and interactions for this phase).

The formalisation of the Itaipu biogas project led to the engagement of small farmers and utilities in swine manure treatment in the west of Paraná state. The presence of Itaipu, an important player of the power sector, and the creation of Itaipu Technological Park (2003) enabled the exploration of different types of innovations[55], promoted interaction with other agents and became one of the most known references of biogas projects in Brazil[56]. This project has achieved important institutional contributions as it was one of the first biogas DG projects to acquire authorisation from ANEEL (in 2008) for commercialisation. It represented an improved type of project for trajectory T1.

Geoenergética's projects are directed at the sugarcane sector (trajectory T2). The projects focused on the biodigestion of residues of sugarcane industry for power generation in scales larger than the traditional international large-scale biogas projects. The company is also one of the few national players investing in technological development with its own R&D centre. Lastly, in this phase, the first activities of Consórcio Verde project started, which is a partnership of a cooperative of agriculture producers (Ecocitrus), a livestock industry (Naturovos) company and a natural gas utility (Sulgás). In the following phase, this project would become the reference for biomethane production in the agricultural sector.

Once more, this engagement occurred because of sectoral contexts at local and regional levels. The Itaipu project promoted biogas technologies in alignment with state-level environmental regulation as a solution to the water pollution associated with swine production. The residues of swine production were deteriorating the water quality of the Itaipu hydropower reservoir. Reacting to the engagement of local players to improve manure treatment, Súlgas promoted the application of biogas technologies and producing biomethane. Besides, Geoenergética tried to couple with the development of the sugarcane industry. The commitment of these players entailed the development of new models for biogas projects other than the two mentioned above, and *knowledge production* about biogas solutions.

Meanwhile, a negative cycle of expectations also took place. First, the international crisis in 2008 changed the positive scenario of the international economy – particularly for Brazil due to the

[55] Itaipu Technological Park has different technological projects, such as biogas, solar PV and electric vehicle technologies. It can be understood as a contextual influence as the technological park was a consequence of STI policies.
[56] With the same motivation, local water pollution by swine production, players in Paraná developed a different type of biogas solution for small farmers, the so-called 'agroenergy condominium' (Coimbra-Araújo et al., 2014). This scheme comprises small properties that produce biogas in a decentralised way and then transport it through low-pressure pipelines to a central point.

discontinuation of the boost on commodities prices – and deteriorated the international carbon market. Additionally, UNFCCC[57] changed the rules for CDM projects related to the treatment of swine manure (2006–2007). It discouraged projects purely based on burning of methane without energy recovery, which was the most diffused model by that time.

Other contextual factors, to a lesser extent, acted negatively. Although biogas technologies achieved certain legitimacy, this was restricted to upstream sectors. Even in these sectors, biogas technologies were not at the centre of high-level discussions. One important illustration is the set of measures to promote agroenergy. These measures deliberately focused on bioethanol and biodiesel and not on biogas. As interviewee R3 said: '*In 2004, 2005 what was understood as agroenergy was basically biodiesel, sugarcane was already important, and both got many incentives'*. This situation explains the virtual absence of institutionalisation of the biogas sector during this period.

Along with these contextual issues, technical problems and unrealistic expectations with biogas projects undermined their legitimacy. For instance, Querol et al. (M. P. Querol et al., 2015), analysing the Sadia Sustainability Programme, pointed out that the different expectations through the different levels of biogas projects combined with the poor capability of farmers to operate and maintain biodigesters led to frustration of farmers and companies in rural areas. This situation was rather similar to what happened in the first phase, with the diffusion of inefficient projects combined with the lack of skills to design and operate biogas plants and low level of institutionalisation. Thus, the combination of contextual negative pressure and decreasing internal legitimacy negatively affected the resource allocation and development of new projects.

Nonetheless, differently from the first phase, the development of different models of biogas projects, exemplified by the projects of Itaipu, caused a second learning process. This learning process combined with the favourable national economic situation and sectoral institutional structures, along with the engagement of important players, maintained the BBIS structures. This would produce a positive cycle at the beginning of the next phase.

---

[57] United Nations Framework Convention on Climate Change

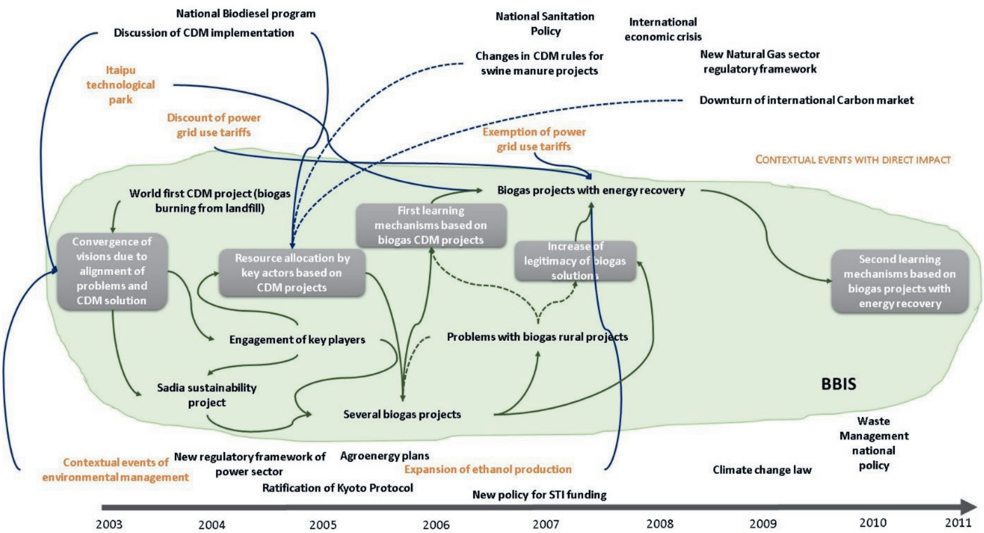


Figure 7 – Interaction of BBIS activities and their contexts for the third phase

2.5.4 Structuring the biogas field (2012–2016)

The beginning of this phase once more started with important contextual events. In the power sector, ANEEL implemented, in 2012, the rules for micro- and mini-DG, establishing a net metering scheme[58]. Two revisions have occurred since 2012[59]. The first had limited schemes of virtual net metering[60] to avoid state-level taxation and the second expands the allowed installed capacity, enabling the virtual net metering schemes again in 2016[61]. Then, because of high dependence of hydropower[62], the low rainfall led to a period of high electricity prices moderated only by the downturn of Brazilian economy by the end of 2015. Meanwhile, by the end of the period, a new national programme was established to promote DG in 2016, the PRO-GD programme[63].

The agricultural sectors continued to thrive mainly because agricultural commodities sustained their high price levels. Furthermore, the national climate change law led to significant events in the agricultural sector, mainly the low-carbon agriculture plan in 2012[64] in which manure treatment was one of the seven main target actions. Particularly for the case of biogas, the international installed capacity of biogas plants experienced intense growth during this period, with

[58] http://www2.aneel.gov.br/cedoc/ren2012482.pdf
[59] http://www2.aneel.gov.br/cedoc/ren2012517.pdf and http://www2.aneel.gov.br/cedoc/ren2015687.pdf
[60] Possibility to allocate energy credits to other power meters (see http://www.cpuc.ca.gov/general.aspx?id=5408).
[61] The second revision came up as consequence of many different lobbies and the waiver of added-value tax by many important states.
[62] Hydropower comprises 70% of power generation installed capacity in Brazil.
[63] http://pesquisa.in.gov.br/imprensa/jsp/visualiza/index.jsp?jornal=1&pagina=96&data=16/12/2015
[64] http://www.agricultura.gov.br/desenvolvimento-sustentavel/plano-abc

Germany leading the world development of the technology[65], which would increase the relevance of German players.

In parallel, from the end of the previous phase, the learning processes yielded important structuration for the BBIS. This phase showed a more intense institutional evolution compared with previous periods. The states of São Paulo and Rio de Janeiro were the first two to settle biogas-specific policies, both in 2012. The policies were a consequence of distinct contexts and projects. Whereas in São Paulo the huge potential of biogas in sugarcane industry was the main driver, Rio de Janeiro focused on landfill potential. In the following year, the partnership between the Brazilian and German governments, through the Brazilian ministry of the cities and the German international cooperation agency (GIZ), started the National Programme of Biogas (PROBIOGÁS). The main objectives were to promote interaction, diffusion of information and support best-case projects.

Meanwhile, as a consequence of the entrance of important biogas players who emerged at the end of the previous phase and developed important projects[66], new intermediary actors and networks appeared. The creation of the international centre of biogas (CIBiogás) in 2012, located in the state of Paraná, was the result of many interactions that happened in the region and supported mainly by Itaipu. Its main goal is the professionalisation of the biogas sector through the diffusion of information and standardisation (laboratories, projects, etc.). Additionally, the creation of two biogas associations, ABiogás (December 2013) and ABBM (January 2014), represented an important step towards more integration and interaction in the sector[67].

Likewise, for networks, the Strategic R&D biogas project, promoted by ANEEL (2012) and supported by GIZ, intended to apply the R&D resources of the power sector to develop replicable commercial models of biogas projects. It promoted the interaction of different agents from different sectors, even though the results were somewhat lower than expected[68]. Then, the launching of BiogasFerti, research network for biofertiliser, led by Itaipu and Embrapa, aimed at developing knowledge and models to improve the value of the 'digestate'. The relevance of the digestate was evidenced by its inclusion in the discussions of a Ministry of Environment's task group (2016) that aimed to propose a new regulation on the usage of organic matter as fertilizer. In addition, the ABBM proposed the creation of NPDs (decentralised Research and Development centres) to promote an increase in university–industry interactions; however, it is still newly emerging and with few experiences.

---

[65] http://european-biogas.eu/2015/12/16/biogasreport2015/
[66] Projects such as the large-scale biodigester of Geoenergética, Dois Arcos Landfill of Ecometano and Consórcio Verde project were cited many times during the interviews.
[67] ABiogás congregates the big players of the sector and aims at the creation of a national agenda for biogas, whereas ABBM is more locally oriented and gathers professionals and researchers with the aim to create a critical mass to spark innovation.
[68] While some interviewees were very critical of the programme (they said there was no strategic vision aligned to Brazilian reality), others realised the relevance for promoting interactions and allocating resources. However, the majority of the interviewees agreed that the outcomes are and will be lower than initial expectations.

These chains of events illustrate the structuration of the BBIS. The expansion of networks tried to influence high-level decision-makers, promoted institutional development and produced information about biogas potential, types of projects, technologies, services and policy advices. Consequently, these activities fulfilled the *guidance for search* and the *legitimacy* of biogas activities. Therefore, biogas players started to counterbalance contextual influences for the first time in Brazil. Pragmatically, the organisation of biogas players has led to several outcomes.

First, important institutional development for biogas at the national level in the natural gas sector. In 2015, because of interactions with different players[69], the ANP established the regulation for the specification of biomethane fuel[70], filling in an important gap for biomethane commercialisation. However, this regulation restricted the trade of biomethane from urban substrates due to the issue of measurement of siloxanes content[71]. In 2017, this controversy was solved through the publication of a specific regulation for biomethane from urban substrates[72].

Moreover, the biogas-specific policy proposal (ABiogas, 2015) and a series of technical publications by PROBIOGÁS can be also understood as the results of such a sectoral organisation of biogas players. This organisation has also influenced institutional development. Other states have recently established biogas policies, such as Rio Grande do Sul (2016)[73], or are in the process of establishing them, such as the case of Santa Catarina, whereas some relied on renewable energy promotion policies such as the states of Paraná, Minas Gerais and Pernambuco.

Thus, these new system elements (intermediary organisations, networks and institutions) stimulated *knowledge diffusion* processes. As said by one interviewee (Fin1), '*previously, biogas was only a word, without meaning. Nowadays, it is so much easier to talk to utilities and governmental bodies about biogas, they know minimally about the process, possibilities and benefits'*. Intermediary players and networks developed actions from knowledge diffusion of small rural biogas projects to the creation and presentation of policy proposals for national governmental bodies.

Besides, both *entrepreneurial and research activities* were more assertive for BBIS-specific problems; they addressed specific struggle points of biogas field and were the result of many interactions and important projects[74]. It means that although new projects were not the main

[69] Particularly, because of the success of Consórcio Verde Project and discussions with Sulgás, Natural Gas utility of Rio Grande do Sul state.
[70] http://pesquisa.in.gov.br/imprensa/jsp/visualiza/index.jsp?data=02/02/2015&jornal=1&pagina=100&totalArquivos=156
[71] These projects could be developed only on an experimental basis or for self-consumption.
[72] http://pesquisa.in.gov.br/imprensa/jsp/visualiza/index.jsp?data=30/06/2017&jornal=1&pagina=69&totalArquivos=272
[73] http://www.al.rs.gov.br/legis/M010/M0100099.ASP?Hid_Tipo=TEXTO&Hid_TodasNormas=63057&hTexto=&Hid_IDNorma=63057 as a consequence of Consórcio Verde project and Sulgás participation.
[74] PROBIOGAS could bring the biogas discussion to the high level of ministries, even though the ministry of energy has still very little influence, whereas CIBiogás and associations could cultivate and promote new networks, new standardisation projects and more lobbying activities. In addition, intermediary players promoted many interactions with international players, from specific projects in Brazil to visits to biogas plants in European countries.

developments in this phase, important projects, such as the Caieras landfill that is the largest conversion plant, were relevant for the legitimacy of biogas field.

Nevertheless, this phase presented hurdles as well. First, although the international economy presented slight improvements in this period, the level of mineral commodities prices remained low. The great difference happened in the oil markets, which faced a huge decline in the prices from 2014 onwards. This situation, combined with the aggravation of economic and political crises in Brazil, created a very turbulent environment by the end of the period. The Brazilian economy started to slow down until the severe recession in 2015 and 2016.

This macroeconomic situation negatively affected the sectoral contexts in two ways. It reduced the demand of energy sectors, restricting the markets and, consequently, diminished the resource allocation by important incumbent players, e.g. utilities. For instance, in the natural gas sector, the reduction of industrial activity slowed down the expansion of natural markets as well as the need for alternative gas supply. As one interviewee (Ut2) said: '*it is very challenging to justify new biogas projects to the board when the market is limited*'. A similar situation occurred in the power sector, leading to an important unbalance of financial conditions of the utilities.

Moreover, specific sectoral issues also played against investment in innovations. For the power sector, the success of wind energy in national auctions set a new low level for power generation prices, undermining competition from other sources. For the sanitation sectors, the possibility to invest in the expansion of infrastructure also decreased, reducing the level of investments for biogas projects. At last, this environment of crises affected regional governments[75], which experienced serious economic issues by the end of the period. These regional governments were responsible for the biogas-specific policies in the beginning of the period and for the few market creation mechanisms in place.

In addition, biogas-specific issues complemented these negative influences. Although this was a period of increasing legitimacy of biogas technologies and opening up of markets, as the power market with the net metering scheme, there were few new projects. This fact limited further knowledge production and cost reduction. Once more, an important exception was the launching of *Termoverde Caieras* project, which the biggest power landfill power plant in Brazil. The improvement of knowledge exchange over biogas solutions was not sufficient to solve important problems such as the lack of information by potential users of biogas technologies (including public decision-makers). Players continued to struggle to identify replicable business models and partnerships. This struggle led to the limited market creation mechanisms, negatively reinforcing the few numbers of new projects.

[75] Important states for biogas projects, such as Rio de Janeiro, Rio Grande do Sul, Paraná and São Paulo.

Here, financial and funding conditions were major issues. For rural projects, low-carbon agriculture funding lines have well attended the demand for small projects according to interviewees. Large-scale projects have the possibility of using existent funding lines, mainly from BNDES[76] and FINEP[77]. However, biogas players faced many difficulties to access them, specifically due to financial guarantees. In addition, the low level of technological development sustained the need for importation of technologies, which maintains the high project costs.

Another important issue was the lack of coordination of institutional development. The most representative case was the biomethane regulation that restricted the use of biomethane from urban substrates and impaired state-level policy of Rio de Janeiro[78]. This contest over the urban biomethane hindered resource allocation and the implementation of market creation mechanisms. What is more, although PROBIOGAS promoted knowledge exchange among some organisations and high-level national governmental bodies, biogas-specific issues were still too restricted to state-level agendas. This was mostly a consequence of more difficult interactions among sectoral players at higher levels associated with the different frames they had to biogas issues. As PROBIOGAS, which turned out to be an important development point ended in 2017, other forms of interaction with high level national bodies must be implemented. However, the proposal of RenovaBio policy, with initial discussion from the end of 2016, is seen as one of the ways to provide important resource allocation and room for interactions.

In summary, this phase presented important structural development of the BBIS and, for the first time, biogas players had an important role in influencing the direction of BBIS development. However, the turn in contextual conditions, particularly in the macroeconomic arena, and the permanency of uncoordinated activities in the BBIS's activities pose important struggles for further development of the field. The picture below presents the cycle of processes discussed above.

[76] Brazilian Economic and Social Development Bank
[77] Funding Agency for Research and Innovation
[78] The renewable natural gas (RNG) policy of the state of Rio de Janeiro, which establishes that RNG should supply 10% of the natural gas market excluding thermal plants, could not deliver due to lack of regulation of biomethane from urban substrates by the ANP regulation.

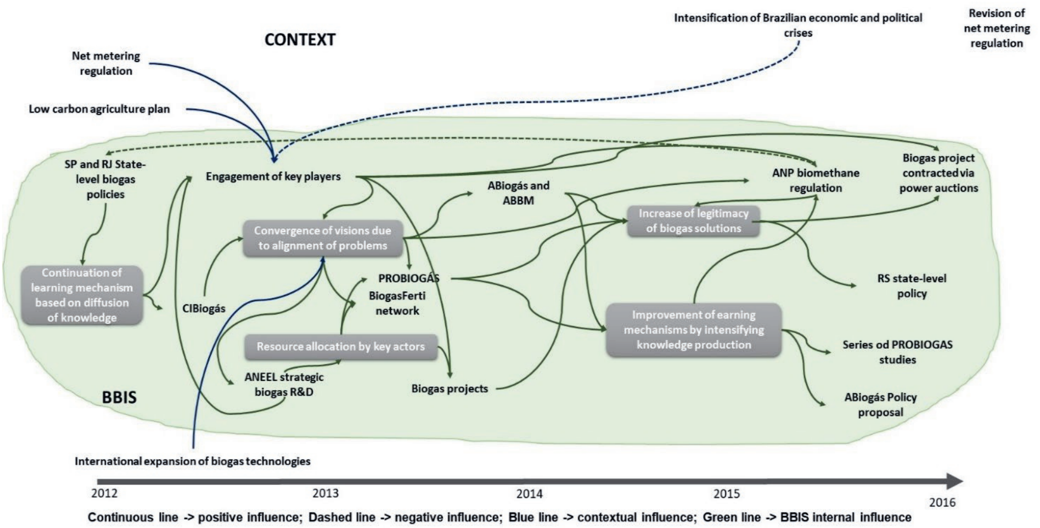


Figure 8 – Interaction of BBIS activities and their contexts for the fourth phase

2.6 DISCUSSION AND FUTURE PERSPECTIVES

The findings indicated four phases of development for biogas technologies in Brazil which showed a tortuous trajectory due to both endogenous and exogenous conditions. The first three phases were influenced mostly by exogenous conditions, such as sectoral institutions, geographic availability of resources and key national and international events. Biogas players were mostly reactive to contextual pressures. This does not undermine the role of biogas-specific conditions (e.g. the development of inefficient projects in the third phase). It only emphasises the need for attention to contextual background conditions. The last phase, in contrast, showed a more substantial influence of BBIS players because of more assertive activities related to knowledge diffusion and production. The articulation of intermediary structures (e.g. biogas associations) and guided activities for production and diffusion of knowledge (e.g. the series of studies of PROBIOGAS, CIBiogás, the policy proposal and biomethane regulation) led to a more intensive institutionalisation.

In the first phase, the initiation of biogas activities in Brazil occurred because of the oil crises and the resulting pressure to develop alternative energies. Additionally, the alignment of local sanitation problems with the successful international expansion of biogas projects triggered the promotion of biogas technologies as one of the alternative energies. Although important experimentation occurred, the absence of a regulatory framework for biogas projects and technological limitations to trade biogas energies resulted in difficulties to capture value with biogas energies and the development of inefficient projects respectively. The biogas field had virtually no formal institutionalisation and suffered from lack of trust due to inefficient projects. Consequently, changes in contextual conditions hardly affected it.

These adverse contextual conditions, deep economic crises and political reforms, lasted through most of the second phase, creating a very turbulent environment for any new experimentation. After a period of very little activity, a convergence of contextual conditions similar to those in the first phase brought biogas activities back for the third phase. Sanitation systems to treat residues and waste continued to be a problem, but CDM provided a convenient and feasible business model that was an important source of financial resources. Other contextual influences were crucial, viz. the institutional reforms in key sectors like energy and the huge expansion of agricultural commodities and investments in sanitation.

The reforms enabled the trade of biogas energies, a downstream condition in the value chain that did not exist in the 1st phase. The expansion of agricultural production and sanitation systems provided the environment for investment expansion on the upstream side of the biogas value chain. For example, the expansion of UASB and landfill systems caused biogas technologies to be considered in the sanitation sector. The expansion of swine and ethanol production intensified the search for solutions to treat manure and vinasse, and the regulation of distributed generation in the power sector allowed new business models to emerge. Therefore, the biogas field started to develop its own critical mass of projects and actors. However, the international financial crisis and the drop of carbon prices questioned the main business model based in CDM projects.

The most relevant development of biogas field occurred in the latest phase. São Paulo and Rio de Janeiro states enacted biogas-specific policies. Important stakeholders created two industry associations, one research centre and one formal RD&I network. Moreover, national initiatives to promote biogas knowledge and projects (PROBIOGÀS and strategic R&D call ANEEL) were launched. This series of initiatives increased momentum, which spread to other important activities, such as the regulation of biomethane by ANP and the promotion of biogas projects in national power auctions.

However, the different visions and logics of contextual players created divergences. In the case of biomethane regulation, this was a temporal mismatch. The initial biomethane regulation allowed agricultural residues only. This fact counteracted the promotion initiatives that relied on MSW substrates, such as the Rio de Janeiro policy. For the power auctions, modelling biogas sources with the same criteria used for centralised sources led to little participation of biogas projects in these auctions due to modelling specifications.

These events occurred in a relatively calm environment. The upcoming political crisis of 2013 and the intensification of economic crisis from 2014 onward posed threats that were similar to those observed at the end of the first phase. Therefore, although it was observed as an important evolution of the biogas field in the last phase, the contextual background conditions had a strong negative effect on the development of biogas projects and new policies.

2.6.1 Insights for contextual influences on Technological Innovation Systems

The outcomes of our investigations provided important insights for understanding contextual influences on TIS studies because they demonstrated how the interaction of different types of contexts enabled or constrained activities in the BBIS. The study suggested distinct forms of contextual influences: (i) evolution of contexts affecting TIS; (ii) interaction of contexts providing certain conditions for TIS activities; and (iii) the interactions of contexts playing out as translators of external events to conditions of TIS activities.

First, sectoral institutional frameworks changed enormously during the period analysed. Since the biogas value chains are cross-sectoral, they brought into the BBIS important structural elements from sectors. This fact is illustrated in our study by the regulations for decentralised electricity and fuels trade, and the expansion of infrastructural and production systems in the agriculture and sanitation sectors. The evolution of institutional frameworks has also influenced conditions for project development, market creation and resource allocation activities. As discussed in Section 2.5, energy sectors have dedicated R&D resources and were responsible for the most significant market creation mechanisms for biogas technologies. Additionally, the role of utilities and agricultural companies in developing projects was crucial. This first type of contextual influence is aligned with the hypothesis of spatially sticky TIS (Binz & Truffer, 2017), which states the higher relevance of local knowledge and markets.

Second, interactions of contexts yielded conditions for the development of BBIS activities. They provided positive background conditions when there was a convergence of contextual influences on downstream and upstream sides of the biogas value chains. For example, convergence of the increasing awareness of sanitation problems and high energy costs was an important driver for biogas activities. Put differently, contextual activities fulfilled the guidance of search process. Also, the convergence of the expansion of energy, sanitation and agricultural systems enabled the development of resource allocation for biogas projects. The evolution of environmental, climate and energy regulations created market opportunities for biogas projects and increased the legitimacy of biogas technologies.

However, these interactions also caused some difficulties. Actors possess distinct types of sectoral knowledge which affected how they dealt with different possibilities of biogas projects. Actors from different sectors had quite different visions and expectations about biogas technologies, which undermined development of common actions and knowledge exchange, maintaining these different visions on biogas. In addition, the contextual structures evolved at different rates. This led to a mismatch in timing and undermined project development, market creation and legitimacy of the technology, as observed in the last phase. These first two types of contextual influences relate more to what TIS literature names structural couplings.

Third, the last type of contextual influence relates to how interactions of contextual structures translated external links – events distant from TIS – to specific conditions that affected activities in the BBIS. Two main patterns were observed. Initially, there was a clear impact of negative macroeconomic conditions on resource allocation of key players. As consequence of several crises and adverse macroeconomic conditions, private actors retracted their investments and governmental agencies implemented budget cuts. These reductions of investments and budget cuts varied according to sectoral and regional embeddedness of actors. This movements occurred mainly at the end of first and last phases.

Moreover, findings demonstrated that external events intensified the perception of problems or solutions according to local realities affecting orientation of activities, resource allocation and legitimacy. The oil crises in the 1970s, the Kyoto Protocol and CDM discussions are good examples of such external events. The oil crises were responsible for the perceived intensification of the oil dependence problem and consequent triggered the search for solving it. The climate discussions enabled biogas technologies to be viewed as a feasible solution for sanitation problems, and the CDM increased legitimacy and provided resources for biogas activities.

2.6.2 Practical implications of this study

Pragmatically this study proposes a framework for studying the contextual influences in TIS studies. This is done by applying the conceptualisation of technology as a bundle of value chains (Sandén & Hillman, 2011) into the TIS framework (Wieczorek & Hekkert, 2012), taking into consideration the suggestions of including contextual aspects (Bergek et al., 2015). Hence, analysts can go beyond the ad-hoc definition of contextual influences and can explicitly identify and explain how activities and actors convey contextual influences into an emerging TIS. It improves the usage of TIS framework to inform the relationship between actors' behaviours, system conditions and external contexts. This framework enables to investigate the influences of different contexts such as geographic factors, sectoral infrastructures and national macroeconomic conditions.

For new renewable energy technological fields, this more detailed information can be particularly useful for both recommending strategic actions and for monitoring these actions. This is more visible for situations in which contexts play a more relevant role, such as conditions of developing countries (e.g. Edsand, 2017; Gosens et al., 2015; Schmidt and Dabur, 2014; Tigabu et al., 2015) and the case of renewable energy technologies that presents different types of contextual embeddedness (Binz & Truffer, 2017). The explanation of how actors engage in activities to bring in contextual influences into the development of new technologies provides knowledge of which actors are involved, for specific contexts and activity of field development. Moreover, after the description of these activities, it seems possible to use them to monitor and evaluate interventions. Therefore, analysts can discuss interventions not only for public policy but also or firm strategies. For example, the suggested patterns of contextual influences may lead to specific strategies depending on actors' positions.

Naturally, this research presents limitations that lead to future analyses. For tailor-made recommendations, it is still necessary to specify the main mechanisms that hamper continuity of positive cycles of TIS development. In other words, it is necessary to describe the exact activities by which a TIS problems, exogenous problems and interactions among them hamper the technological field. Additionally, for firms' strategy recommendations it seems necessary to deepen the understanding of organisational processes, while for policy recommendations seems necessary to understand the political structure and policy processes (Flanagan et al., 2011; Rogge & Reichardt, 2016). For instance, although this analysis improves the understanding about the conditions for successful development of biogas in Brazil, it is still necessary to examine how these conditions manifest themselves into specific problems and their interplay with policy mixes and organisational strategies.

Furthermore, our analysis is limited to understanding the conditions of our boundary definition: biogas technologies at national level. For specific regional policies or for interactions of regional and national policies, this analysis must be performed for local/regional conditions. Finally, the suggested types of contextual influences must be further researched. It is necessary to explore other cases with different conditions as well as to compare these cases. Distinct conditions to investigate can be defined according to the innovation and valuation modes as in (Binz & Truffer, 2017) or/and conditions of countries in global south and north (Hansen et al., 2017; Ramos-Mejía et al., 2017; Wieczorek, 2017).

2.7 CONCLUSIONS

This study investigated the history of biogas technologies in Brazil by applying the TIS framework while accounting for biogas-specific and context-related influences. It is the first systematic historical investigation of biogas activities in Brazil, which comprehensively covered 37 years. It is also one of the first attempts to include systematic analysis of contextual influences in TIS framework. Thus, this research explained the conditions in which biogas technologies thrived or dwindled, as well as proposed an analytical framework and patterns of contextual influences for TIS studies.

The explanation of how distinct set of sectoral and geographic conditions as well as specific events influenced the development of biogas field in Brazil goes beyond common analysis of barriers for renewable energies. It provides a comprehensive description of how Brazilian contextual conditions and actions of biogas players enabled or constrained biogas field development. Therefore, it opens a new avenue for private and policy actions for biogas in Brazil by shedding light on the need to recognise patterns of contextual influences. For instance, these findings may enlighten policy recommendations by focusing on contexts such as alignment and interaction of the macroeconomic and sectoral conditions, or by focusing on biogas-specific issues such as low number of new projects, lack of market creation mechanisms and few institutional developments.

For TIS studies, our research presented a framework for examining TIS structural–functional conditions subject to contextual influences. By employing the ‘bundle of value chains’ (Sandén & Hillman, 2011) perspective of technologies, instead of an *ad hoc* selection and description of contexts, the identification of the contexts that really mattered for the case was possible. Then, the specification of events, by including the search for agents, sectors, locality, motivations and resources, enabled to recognise the activities and their background conditions which explained contextual influences. Hence, this study went beyond a common structural–functional analysis focused only on endogenous conditions by incorporating exogenous conditions in the mechanisms of structuration and functional fulfilment of the BBIS.

Moreover, the empirical findings suggest important insights for TIS studies by going back to the discussion of TIS embeddedness in other structures like innovation systems or socio-technical structures (Bergek, Jacobsson, Carlsson, et al., 2008; M. P. Hekkert et al., 2007; Markard & Truffer, 2008; Stephan et al., 2017). The contextual conditions were demonstrated through the evolution of contextual structures, the interaction of contextual structures, and by the translation of external conditions by these interactions. Therefore, the mapping of contextual influences through the identification of specific activities – accounting for conditions and entities – that fulfil system processes seems very suitable to explain the role of structural couplings as a promising way of improving TIS analyses.

CHAPTER 3 - EXPLORING BLOCKING MECHANISMS AND INTERDEPENDENCE OF SYSTEMIC PROBLEMS IN TECHNOLOGICAL INNOVATION SYSTEMS[79]

- Discusses systemic problem and blocking mechanism concepts in TIS literature
- Uses a mechanism-based approach to explore these concepts and empirical application
- Defines blocking mechanism as causal mechanisms
- Discusses how blocking mechanism link systemic problems and poor system functioning
- Suggests a mechanism-based research avenue for TIS studies

ABSTRACT

Understanding "systemic problems" or "blocking mechanisms" in emerging technologies and industries has been a major issue in Technological Innovation Systems (TIS) research. Despite this literature's long tradition, we show that a more accurate definition enhances the TIS framework explanatory power for a higher diversity of empirical cases. We posit that conceptual improvement depends on addressing the unclear or incomplete definitions and the lack of explanation of interdependent systemic problems and blocking mechanisms. To this end, we apply a mechanism-based approach to explore these conceptual limitations. As a result, we propose a causal conceptual framework that understands blocking mechanisms as causal pathways linking systemic problems (causes) to poor system functioning (outcomes). We also argue that detailing the causal pathway in activities and respective actors better explains system malfunctioning. Finally, we discuss patterns of interdependencies among systemic problems and blocking mechanisms and implications for methodologies and for informing policy.

KEYWORDS

Systemic problems, blocking mechanisms, mechanism-based explanation, Technological Innovation Systems

[79] This chapter was published as De Oliveira et al. (2020) A mechanism-based explanation for blocking mechanisms in technological innovation systems. Environmental Innovation and Societal Transitions 37, 18–38. https://doi.org/10.1016/j.eist.2020.07.006

3.1 INTRODUCTION

The emergence of new technological fields is often studied by using the Technological Innovation System (TIS) framework (Bergek, Jacobsson, Carlsson, et al., 2008). This literature highlights how an innovation system supports or fails to support the development and diffusion of a specific technology or technological field. TIS studies focus on analysing an innovation system structures and functions (e.g. Jacobsson and Bergek, 2004; Turner et al., 2016; Wieczorek et al., 2013). Within this framework, previous studies have shown how structural and functional characteristics reflect different phases of the TIS maturity and functioning (Bergek, Jacobsson, Carlsson, et al., 2008; M. P. Hekkert et al., 2007; Markard, 2018; Suurs & Hekkert, 2009b). Throughout these phases, the causes of innovation systems malfunctioning have been attributed to either systemic problems or blocking mechanisms by different scholars; similar concepts that refer to hindering factors at the system level (Bergek, Jacobsson, Carlsson, et al., 2008; Wieczorek & Hekkert, 2012).

Both analyses of systemic problems and blocking mechanisms seek to inform how negative functional or structural conditions at the system level hinder innovation system operation and development (Bergek, Jacobsson, Carlsson, et al., 2008; Wieczorek & Hekkert, 2012). Systemic problems are understood as inadequate structural elements (Wieczorek & Hekkert, 2012) that hinder TIS functioning. Blocking mechanisms in turn have a broader definition and refer to inadequate endogenous and exogenous factors that lead to TIS malfunctioning (Bergek, Jacobsson, Carlsson, et al., 2008). Both concepts promise insights to guide policymaking in that they correct for systemic problems or dissolve blocking mechanisms.

Yet, while the analyses of systemic problems and blocking mechanisms have already provided valuable insights into conditions of innovation success or failure (Bergek et al., 2010; Weber & Truffer, 2017), they still suffer from at least two limitations. First, there is a lack of theoretical clarity regarding the definition of both concepts and their interrelationship. Often systemic problem and blocking mechanism are used interchangeably, leading to different empirical interpretations and consequent explanations of system malfunctioning. This fact occurs because the causes of this malfunctioning are not clearly distinguished from the causal pathways that lead to system malfunctioning (Kieft et al., 2016).

Second, empirical studies have highlighted that these system level hindering factors are often interdependent while still treated mostly as independent (Hellsmark et al., 2016; Negro et al., 2012; Patana et al., 2013). Strikingly, possible interdependencies between the concepts of systemic problems and blocking mechanisms remain unexplored. Together these two limitations hamper the explanatory power of TIS analysis substantially and therefore result in potentially biased policy recommendations. Recent criticisms on TIS studies regarding its effectiveness in generating policy advice provide further evidence of this explanatory weakness (Markard et al., 2015).

Recently, Kieft et al. (2016) analysed the conceptual interdependence between systemic problems and suggested the need of a new conceptualisation for blocking mechanisms. They proposed to understand blocking mechanism as emerging from the interaction between systemic problems. Here, blocking mechanism is understood as a sequence of problems and activities rather than the structural negative attributes of elements (Kieft et al., 2016). Yet, it remains unclear in their framework how the systemic problems and blocking mechanisms can be positioned in a causal explanatory framework.

Therefore, these concepts still do not enable analysts to fully answer questions such as 'why' or 'how' similar links between blocking mechanisms and systemic problems have divergent impacts across innovation systems. In other words, TIS analysis lacks a clear conceptualization of the interdependencies between systemic problems and blocking mechanisms, which creates room for confusion when mapping TIS malfunctioning. Hence, we aim to build a framework that fosters a clear view on how systemic problems, blocking mechanisms and system functioning are causally linked.

We propose a mechanism-based explanation to shed new light into these relationships (Bunge, 1997; Machamer et al., 2000; Mahoney, 2016). The mechanism-based explanation (hereafter MBE)[80] has gained ground in the social sciences in the last decades (Hedström & Ylikoski, 2010; Mahoney, 2001). The idea is that the description of mechanisms opens up the 'black-box' of causation (Gerring, 2007; Mcadam et al., 2008; Tilly, 2001) while the most commonly used analyses focus on correlations. MBE indicates that mechanisms are causal pathways between causes and outcomes under certain scope (or contextual) conditions. Hence, within the MBE framework, the conceptualisation, description and empirical examination of mechanisms are the crucial tasks to explain causation (D. Beach & Pedersen, 2016a; Falleti & Lynch, 2008; Hedström & Ylikoski, 2010).

Accordingly, our main goal is to answer *how does a mechanism-based causal analysis of systemic problems, blocking mechanisms and poor system functioning improve the explanation of TIS malfunctioning?* The secondary goal lies in understanding what are the implications for analysing the interdependence of hindering factors at system level. To this end, this paper is structured as follows: first we review the literature on systemic problems and blocking mechanisms to identify their conceptual limitations which imply weaknesses for explaining hindering factors at system level (Section 0). Next, we introduce the approach of MBE to elucidate why and how this is a useful framework for our study (Section 0). Section 0 discusses the analysis of blocking mechanism and systemic problem concepts as well as possible implications based on MBE. Section 5 presents an illustration of MBE application to demonstrate its advantages by analysing previous TIS studies. Lastly, we discuss how the proposed framework and concepts enhance the understanding of causal

[80] The literature on mechanisms presents distinct terminologies, for instance mechanismic, mechanistic and mechanism-based.

analysis in innovation systems, mitigate the discussed explanatory gaps and lead to more precise information for policymaking (Section 3.6).

3.2 INNOVATION SYSTEMS, SYSTEMIC PROBLEMS AND BLOCKING MECHANISMS

3.2.1 System level hindering factors in the Innovation System literature

The innovation systems literature has demonstrated the relevance of studying how actors behave, interact and engage in networks under specific institutional and infrastructural contexts to fulfil or not innovation processes and to understand system level innovations (Edquist, 1997; Weber & Truffer, 2017). These contexts can be countries, sectors, regions or technological fields (Asheim & Isaksen, 2002; Carlsson & Stankiewicz, 1991; Lundvall, 1992; Malerba, 2002). Innovation system studies have also provided a new innovation policy rationale: the systemic failure rationale (Laranja et al., 2008). The reasoning behind this rationale is twofold. First, the hindrance of innovation development occurs due to negative factors at system level, which affect the fulfilment of innovations processes and mechanisms (Edquist, 1997; Woolthuis et al., 2005). Second, understanding and explaining these hindering factors is the way to inform interventions (Bergek et al., 2010; Chaminade & Edquist, 2006; Woolthuis et al., 2005).

Innovation System literature presents different terminologies when trying to explain these hindering factors: system failures, weaknesses, imperfections and problems (Chaminade & Edquist, 2010; Edquist & Chaminade, 2006; Negro et al., 2012; Wieczorek, 2014). However, they present a common ground that refers to the idea that “structural causes of functional weaknesses” are present in a system (Jacobsson and Bergek, 2011:46). Hitherto, studies focused on the analysis of systemic problems have adopted diverse analytical frameworks mostly resulting in a categorisation based on structural elements of innovation systems (Chaminade & Edquist, 2010; Negro et al., 2012; Wieczorek & Hekkert, 2012; Woolthuis et al., 2005). We agree with Bergek et al. (2010:129-130) that “it is difficult, if not impossible, to evaluate the ‘goodness’ or ‘badness’ of a particular structural element or combination of elements without making reference to its effects on the innovation processes”.

Therefore, it becomes imperative to relate structural (elements) and dynamic conditions (processes). The analysis of system functions developed by Technological Innovation Systems scholars (TIS) (Bergek, Jacobsson, Carlsson, et al., 2008; M. P. Hekkert et al., 2007)[81] is the most prominent framework for this task. Functional analysis postulates that key processes at system level

[81] The processes studied by TIS focus on technology-specific innovation systems, which do not necessarily hold for other innovation system approaches (Bergek et al 2010). Most of the Innovation System frameworks focus only on structural analysis, leaving aside the dynamic features of systems and using comparisons to identify systemic problems (Chaminade and Edquist, 2006). Still, Chaminade et al (2012) have also developed a framework to measure systemic problems in National Innovation Systems.

must be fulfilled for the system to function. These processes include entrepreneurial activity, knowledge production and exchange, guidance of search, market creation, resource allocation, creation of legitimacy and development of positive externalities (Bergek, Jacobsson, Carlsson, et al., 2008; M. P. Hekkert et al., 2007).

3.2.2 System level hindering factors for Technological Innovation System

In TIS literature, hindering factors at system level are understood and explained by two concepts that are derived from distinct analytical frameworks: systemic problems (Wieczorek & Hekkert, 2012) and blocking mechanisms (Bergek, Jacobsson, Carlsson, et al., 2008). Instead of choosing one terminology over the other[82], below we explore how these concepts explain the hindrance of TIS functioning, their limitations as well as recent propositions to improve their explanatory strength.

Systemic problems in TIS literature are conceptualised as negative attributes of systems elements (Wieczorek & Hekkert, 2012). This understanding directly follows the broader literature on innovation systems (e.g. Woolthuis et al., 2005). Hence, hindering factors at system level are understood across categories and sub-categories. The main categories are the structural elements: actors, their interactions (including networks), institutions and infrastructures. To these categories, sub-categories are attributed, which are explained as negative attributes of structural elements: the presence and absence or adequacy and inadequacy of structural components (Wieczorek & Hekkert, 2012). Finally, systemic problems are considered to negatively affect the fulfilment of system level processes. Put simply, systemic problems are the causes (light grey box) of poor system functioning (dark grey box), as shown in Figure 9 below.

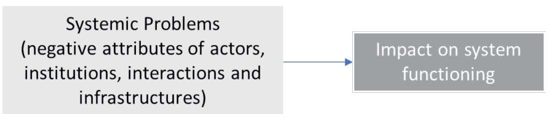


Figure 9 – Systemic problems' explanation for poor system functioning in TIS literature

In this framework, the analysis of systemic problems is an intermediary step to inform the interventions to promote the focal TIS. According to Wieczorek and Hekkert (2012), each sub category of a systemic problem may lead to a specific goal for systemic instruments. These goals are expected to guide the selection of policy instruments that stimulate the functioning of the focal TIS[83]. For instance, the lack of capabilities of actors indicate the goal of creating space for improving capabilities, while low quality physical infrastructures leads to the goal of ensuring the quality of

[82] Some scholars argue that the terminology of 'problems' avoid the implicit assumption of optimal or ideal structures, which are not observed in reality (Chaminade and Edquist, 2010:101-105; Negro et al., 2012; Wieczorek, 2014:26-31).
[83] Systemic instruments.

infrastructures (Wieczorek & Hekkert, 2012).

Blocking mechanism concept introduces a similar perspective to this discussion but is conceptualised differently in TIS literature. Blocking mechanisms derives from empirical studies on innovations mostly in Sweden (Johnson & Jacobsson, 2001). However, this literature (Bergek et al., 2010, 2008; Jacobsson and Bergek, 2004; Jacobsson and Johnson, 2000; Johnson and Jacobsson, 2001) does not present a clear definition for blocking (or inducement) mechanisms; it does not clearly state what the mechanisms are and their causes. For instance, these mechanisms are considered to originate from conditions internal or external to a focal TIS (Bergek, Jacobsson, Carlsson, et al., 2008). They are also considered to influence the functional dynamics of a TIS (Bergek et al., 2010; Bergek, Jacobsson, Carlsson, et al., 2008), as well as they are called structural weaknesses (Jacobsson & Bergek, 2011)[84].

Therefore, the blocking mechanism concept is not clearly defined. It seems that the blocking mechanism concepts may understand hindering factors at system level as a consequence of structural weaknesses, (endogenous or exogenous) attributes, or as other conditions such as broader exogenous factors. Figure 10 depicts the possible understandings according to this literature. One understanding suggests that blocking mechanism is an intermediary concept between structural weaknesses and exogenous conditions (causes – light grey boxes) and poor system functioning (outcomes – dark grey box). Another one suggests that blocking mechanisms are the structural weaknesses, being these endogenous or exogenous attributes, and consequently would be the causes of poor system functioning. This latter is similar to systemic problems but is broader because it includes exogenous influences.

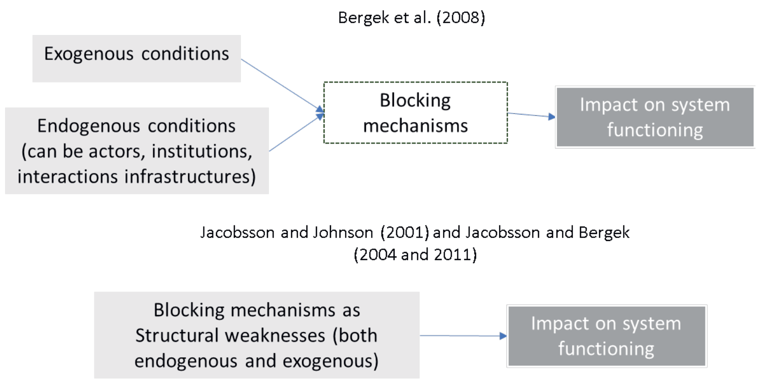


Figure 10 – Blocking mechanisms' explanation for poor system functioning in TIS literature

Similarly to systemic problems, the analysis of blocking mechanisms is an intermediary step to

[84] Jacobsson and Bergek (2011) refer to the Johnson and Jacobsson (2001) work in footnote 16.

inform interventions to stimulate TIS functioning. Here, instead of pre-defined goals, the existence of blocking mechanisms, as well as the absence of inducement mechanisms, are considered to produce functional system weaknesses (Bergek, Jacobsson, Carlsson, et al., 2008). Therefore, mitigating blocking, as well as promoting inducement mechanisms, becomes the key policy issues.

In sum, although systemic problem and blocking mechanism concepts aim to explain hindering factors at system level, they present distinct ways of explaining these phenomena. However, this conceptual difference is not always explicit nor understood because studies focused mostly on empirical explanations rather than conceptual clarifications. For the case of blocking mechanisms, their own conceptualisation is not clear. Hence, TIS analysts may have a hard time in choosing which of the two frameworks to use to explain hindering factors.

3.2.2.1 Conceptual and analytical limitations of systemic problems and blocking mechanisms

The comparison of these two concepts indicates the need to explore how their conceptual limitations constrain the understanding and explanation of TIS hindering factors. Both concepts have important shortcomings which are conveyed into empirical studies. A first issue is the lack of clarity of conceptualisation of the blocking mechanism, which leads to different empirical interpretations. As demonstrated in Figure 10, TIS analysts can interpret blocking mechanisms as an intervening concept between structural weaknesses and poor system functioning or as structural weaknesses. Usually empirical studies apply this concept in an interchangeable manner with systemic problems, i.e. as a structural weakness (e.g. Jacobsson and Bergek, 2004; Jacobsson and Karltorp, 2013). This fact is also acknowledged by Wieczorek and Hekkert (2012:81) which say that "[c]areful consideration of these mechanisms reveals that they can be categorised as systemic problems".

A second issue refers to the explanation of exogenous conditions (external to the focal TIS). Exogenous factors are important because of the recognition of TIS embeddedness in broader structures (Markard & Truffer, 2008). The recent discussions on the relevance of TIS contextual factors evidences the need to improve conceptualisations (Bergek et al., 2015). The systemic problem concept does not consider any type of exogenous influence. For Wieczorek and Hekkert (2012), negative attributes of structural elements of systemic problems refer only to internal conditions of the focal TIS. In contrast, blocking mechanisms do acknowledge that "[e]xogenous factors also come into play, influencing the internal dynamics" (Bergek et al., 2008a:421). However, these exogenous factors are still investigated and explained in an *ad hoc* manner due to the lack of conceptualisation[85] and the lack of clarity of conceptual explanations[86].

[85] More recently, TIS scholars have moved towards this direction (Bergek et al., 2015).
[86] For *ad hoc*, we mean case-by-case. De Oliveira and Negro (2019) is an exception in proposing an analytical method for this task.

A third issue refers to the interdependence of TIS hindering factors. Systemic problem and blocking mechanism concepts do not account for the explanation of possible interactions and interdependencies, although conceptual and empirical studies suggest that systemic problems are not independent (Hellsmark et al., 2016; Jacobsson & Johnson, 2000; Johnson & Jacobsson, 2001; Negro et al., 2012; Patana et al., 2013). For both cases, interactions are considered to occur only between system functions. Thus, these concepts still cannot explain what these interdependencies are and why and how they manifest themselves. These conceptual limitations – summarised in Table 3 – have direct implications on how to explain the phenomena of TIS hindering factors.

Table 3 – Conceptual limitations of systemic problems and blocking mechanisms

Limitations	Systemic Problem	Blocking Mechanism
Conceptual clarity	Well defined in terms of its nature (negative attributes of structural elements) but not clear in terms of how it affects system functioning	Lacks clear definition in terms of nature and how it affects system functioning
Role of exogenous factors	X Not included	Included but not clear what they are and how they perform
Interdependence	X Not included	X Not included

These limitations certainly relate to the criticisms on policy recommendations derived by TIS studies (Bening et al., 2015; Kern, 2015). These criticisms and limitations indicate the need to better explore the causes of and the role of actors on poor system functioning. TIS studies must account for why problems occur and how they unfold. Put differently, a complete explanation would need to disclose the causes of hindering factors, why and how they unfold or manifest themselves, how they may trigger or reinforce other hindering factors, and their impacts on system functioning. Therefore, it is necessary a conceptual framework to show these explanations.

In addition, as both frameworks present a clear goal to inform interventions, these conceptual limitations have implications for recommending policy. TIS policy recommendations are derived from the structural-functional analysis, but more specifically from the investigation of hindering factors. The TIS policy rationale lies in the mitigation of these hindering factors, differing according to the specific analytical framework. For systemic problems, the policy rationale is that systemic problems support the discussion of policy goals for systemic instruments (Wieczorek & Hekkert, 2012). For blocking mechanisms, system weaknesses that comprise the "strengthening/adding inducement mechanisms and weakening/removing blocking mechanisms" inform key policy issues (Bergek et al., 2008a:423)[87]. Thus, the criticisms of generic or oversimplified policy recommendations (Bening

[87] Lastly, these two policy rationales can be considered aligned with system policy rationales for innovation policy, often called systemic failures (Frenken, 2017; Laranja et al., 2008; Schot & Steinmueller, 2018). This is another example of

et al., 2015; Kern, 2015) can be understood as consequence of these conceptual limitations.

3.2.2.2 Recent proposals for improving systemic problem and blocking mechanism concepts

Recently, scholars have been discussing these issues of TIS hindering factors. The most assertive discussion is presented by Kieft et al. (2016). They proposed conceptual improvements that address both the confusion on empirical use of concepts, the role of exogenous factors and the explanation of interdependence of problems.

First, they provided a different categorisation for systemic problems other than structural conditions. They understand systemic problems as independent or interacting problems depending on their level of interdependency; and as endogenous or exogenous, referring to innovation system-specific or context-related problems. They explicitly aimed to create the conceptual foundations to explain interdependencies of hindering factors and exogenous influences for the systemic problem framework.

Second, they offered empirical evidence suggesting that blocking mechanisms result from interacting systemic problems. Blocking mechanisms are explicitly understood as having a different nature than systemic problems, i.e. different to negative or weak structural conditions. For the authors, blocking mechanism represent how systemic problems interact to hinder system functioning. This understanding suggests these concepts are interwoven, which is also suggested by recent empirical studies (Turner et al., 2016; Wesseling & Van Der Vooren, 2017). This proposition harmonises in a single conceptual framework the two frameworks for studying TIS hindering factors, aiming to mitigate the lack of explanation for interdependence of systemic problems. Figure 11 presents their proposition.

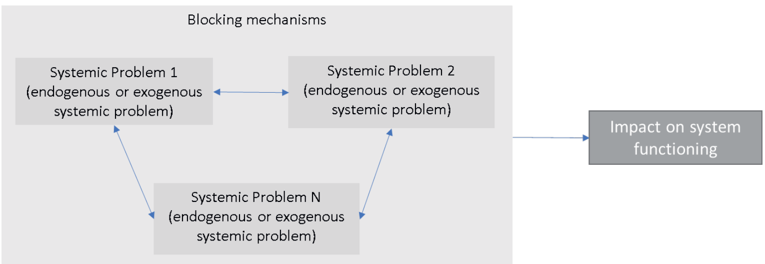


Figure 11 – Kieft et al. (2016) proposition to explain hindering factors in TIS

This proposition seems to follow one of the understandings of blocking mechanisms, which

different uses for the same nomenclature. As mentioned in Section 3.2.1, systemic failure is also used in innovation system literature for discussing the analytical hindering factors.

sees blocking mechanisms as the causes of poor system functioning (see Figure 10). However, this proposition states the need to specify the causal attributes in the form of interacting systemic problems, which is its main contribution. As Kieft et al. (2016:34) say "[i]nstead of using the term blocking mechanism to indicate a problematic 'factor', we use it to indicate a real 'mechanism'". For them, blocking mechanisms cannot be only attributes of structural elements, but consequence of the causal forces of attributes of different systemic problems. Hence, it starts to clarify the nature of blocking mechanisms.

Furthermore, this proposition brings the discussion of causation to the centre of the analysis of TIS hindering factors. Although previous frameworks implicitly pointed out the issue of causation, they have not focused on how this causation works. It remains an unexplored issue in TIS conceptual frameworks and empirical studies. To explore this issue, as well as to mitigate the limitations on explaining TIS hindering factors indicated before, we argue that the mechanism-based explanation (MBE) is a particularly suitable solution. Below, we explicitly examine the causal relationships of systemic problems and blocking mechanisms and system functioning based on the MBE approach. Before that we introduce the aspects of MBE in Section 3.3.

3.3 MECHANISM-BASED EXPLANATION

The MBE has gained attention from scholars from diverse scientific fields (e.g. natural sciences and philosophy) because of the limitations of the covering law and statistical explanations (Hedström & Ylikoski, 2010; Mayntz, 2004). This increased attention led to distinct framings of mechanisms (Bechtel & Abrahamsen, 2005; Bunge, 1997; Falleti & Lynch, 2009; Gerring, 2007; Glennan, 1996; Hedström & Ylikoski, 2010; Machamer et al., 2000; Mahoney, 2001; Tilly, 2001). However, there is broad consensus regarding MBE's main argument, namely: (i) correlational or variance explanations imply regular patterns of association between independent and dependent variables but do not explain the causal forces between them; and (ii) tracing causal mechanisms is the way to explain how causal forces are transmitted between causes and outcomes (Mahoney, 2001). Central to MBE is the notion of causal pathway between cause and outcome (D. Beach & Pedersen, 2016a; Falleti & Lynch, 2009; Hedström & Ylikoski, 2010). Although the literature shows that there is no consensus about what mechanisms are[88]; following Beach and Pedersen (2016a), it is possible to classify the different perspectives on mechanisms into those which have a minimalist understanding on mechanisms and those which see mechanisms as systems.

For the minimalist perspective, causal mechanisms (CM) that connect causes (C) and outcomes (O) are comprehended as intervening factors (C → CM → O), and the causal process is not totally 'unpacked' (D. Beach & Pedersen, 2016a; Falleti & Lynch, 2009; Mahoney, 2016). This

[88] See Hedström and Ylikoski (2010) and Mahoney (2001).

perspective enables analysts to claim the existence of the causal relationship between C and O and to explain it to some extent. In contrast, the system perspective aims to 'unpack' the causal process in detail. Following this view, mechanisms comprise "a series of interlocking parts that transmit the causal forces from C to O" in which these parts are "composed of entities engaging in activities" (Beach and Pedersen, 2016a:35), or the cogs and wheels of the casual process (Hedström & Ylikoski, 2010). One can conceptualise an entire causal process between C and O by focusing on entities (who is engaged – actors), activities which present connections between them without logical holes[89] and relevant contextual conditions. However, it does not mean that the system perspective is better than the minimalist. They just answer different types of research questions (D. Beach & Pedersen, 2016a).

Furthermore, it is important to emphasise that mechanisms are conceptual constructions. This means that the causal pathway between C and O must be explicitly based on theoretical explanations (D. Beach & Pedersen, 2016a). This also means that mechanisms are ontologically different from variables (Mahoney, 2001, 2016). Being conceptual constructions, mechanisms can be portable across a bounded population of cases that shares similar contextual conditions[90] (D. Beach & Pedersen, 2016a, 2016b; Falleti & Lynch, 2009). Contextual conditions are regarded as "enabling factors" (Beach and Pedersen, 2016a:89), "relevant aspects" or "initial conditions" (Falleti and Lynch, 2009:1152)[91] and are fundamental for the mechanism conceptualisation.

Lastly, mechanisms can be studied at different levels of aggregation depending on the research design (Gerring, 2007). This entails the need to accommodate the proper level of aggregation, i.e. proper level of conceptual extension and intension (Sartori, 1970) according to the research enquiry (Falleti & Lynch, 2008). However, this latter aspect represents a huge debate in mechanism's literature. Some scholars claim that is not possible to study macro mechanisms (Hedström & Ylikoski, 2010). For these scholars it is only possible to study macro-micro (situational), micro (action-formation) and micro-macro (transformational) mechanisms. For other scholars, there is no such restriction for macro mechanisms and this limitation would represent an unnecessary theoretical wed (Bunge, 1997; Mayntz, 2004; Tilly, 2001). Macro mechanisms, then, would attain to macro level theories (D. Beach & Pedersen, 2016a).

Thus, MBE focuses on conceptualising a causal relationship between a cause and an outcome under specific contextual conditions at a particular level of analysis. This conceptualisation can be focused on simply sketching a mechanism (minimalist), or on fully unpacking the causal process (systemic) at different levels of aggregation. For this study, the MBE brings three original

[89] Mechanisms' parts must present productive continuity, i.e. causal connection between each activity (D. Beach & Pedersen, 2016a; Machamer et al., 2000).
[90] This requires causal homogeneity across the population of cases (D. Beach & Pedersen, 2016b).
[91] Beach and Pedersen (2016a:89) give the example of a fuel burning and car movement with the presence of oxygen as a contextual condition; causes do something actively.

contributions. First it stresses the need to clearly define what are the causes and outcomes of a phenomenon, as well as to conceptualise the causal pathway between them. Second, it highlights the relevance of exploring contextual (or scope) conditions. Third, it enables to connect the meso system explanation to micro understandings of actors' behaviours and strategies. In the next section, we dive into the MBE conceptualisation of systemic problems and blocking mechanisms for TIS.

3.4 MECHANISM-BASED EXPLANATION (MBE) OF SYSTEMIC PROBLEMS AND BLOCKING MECHANISMS FOR TECHNOLOGICAL INNOVATION SYSTEMS

Recently the literature on innovation and transition studies have raised the debate around the explanatory power of systemic frameworks (Svensson & Nikoleris, 2018; Weber & Truffer, 2017). This debate questions the use of systemic frameworks as heuristics tools, i.e. focused more on description than on explanation. Although TIS studies provide already a more detailed explanation than other frameworks (Weber & Truffer, 2017), prior criticisms and propositions (Bergek et al., 2015; Markard et al., 2015) indicate that some explanatory gaps remain. For example, modelling studies (Holtz et al., 2015; Walrave & Raven, 2016) require more fine-grained information on how processes unfold and what are the necessary and contingent conditions. Moreover, for transition studies, there is already an explicit call for studying mechanisms (Papachristos, 2018; Sorrell, 2018; Svensson & Nikoleris, 2018) which corroborate with the need of focusing on causal explanations.

For TIS literature, this debate on mechanisms has not been explicitly brought to light yet. Arguably, the minimalist version of MBE underlies the TIS literature for system functioning – as it is possible to observe for hindering factors in Figures 1 and 2. TIS analyses explains system functioning either by presenting a longitudinal analysis of events (M. P. Hekkert et al., 2007; Negro et al., 2007) or by identifying the presence of inducement and blocking mechanisms (Bergek, Jacobsson, Carlsson, et al., 2008). Inducement and blocking mechanisms are concepts closely connected to the MBE, however are not clearly conceptualised and lack the explanation of the causal pathways – as discussed before.

The longitudinal analysis of events takes a processual approach on TIS functioning that connects past to present events to "understand how forces or influences initiated in one event, how they are transmitted or dissipated in subsequent events, and how conjunctions of events produce interactions among causal factors to build momentum or lead to collapse" (Negro, 2007:37). It does it through "[t]he narrative [that] captures the particular causal factors influencing the case" (Negro, 2007:37). Although for both cases the causality is described as a functional pattern at the system level, there is only an implicit description of causes and outcomes. No clear mechanism is conceptualised.

In parallel, some TIS studies focus on detailing how specific system functions are fulfilled. They also aim at understanding the interconnection of meso and micro conditions. For instance, Dewald and Truffer (2011) focus on explaining how different activities and actors create a market for solar PV TIS; Konrad et al. (2012) investigate how expectations influence activities that fulfil system functions for fuel cell technology; Binz et al. (2016) and Wirth et al. (2013) examine the institutional dynamics of technologies' legitimacy for water reuse and biogas technologies; Karltorp (2016) and Karltorp et al. (2017) study how different actors behave and influence activities of financial resource mobilisation for biomass gasification and wind power technologies; and Yap and Truffer (2018) analyse strategic actions that fulfil guidance of the search for water technologies in China. These empirical studies evidence the effort to understand the causes, mechanisms and pathways to system functioning. They also evidence the suitability of MBE for TIS framework because they specify activities, entities and contexts.

A mechanism-based explanation, even in its minimalist form, would require a clear description of initial causes, contextual/scope conditions and outcomes. For TIS, specific structural conditions can be framed as causes, patterns of system functioning can be framed as outcomes and contextual conditions can be understood as defined in Bergek et al. (2015). However, the goal of this paper is not to reconceptualise TIS, but rather to refine the conceptual framework of TIS hindering factors to improve the explanation of systemic malfunctioning and to discuss possible implications[92]. Therefore, we elaborate below how systemic problems and blocking mechanisms can be explained within a mechanism-based framework, arguing that it is necessary to specify entities and activities from a MBE system perspective[93].

3.4.1 Applying a mechanism-based approach to TIS hindering factors

As already discussed, conceptual frameworks must be clear in establishing which concept explains particular empirical phenomena and how concepts relate to each other. For this task the MBE provides an important direction. Causal concepts apply a narrower definition so that the causal effects can be generalised to a causal homogenous population of cases (D. Beach & Pedersen, 2016a). This fact entails that the causal attributes must be defined and be compatible with the causal claim made[94].

Obviously, TIS literature is the starting point for developing a mechanism-based framework for

---

[92] MBE may be applied broadly to TIS explanation. For instance, we see possibilities to explain the concepts of system builders (Hellsmark & Jacobsson, 2009; Musiolik et al., 2012), inducement mechanisms (Bergek, Jacobsson, Carlsson, et al., 2008) or motors of innovation (Suurs & Hekkert, 2009b).

[93] The most important distinction between events and activities is that activities represent a particular action of actors, such as decision-making, investing, buying, lobbying, exchanging knowledge, etc. Events may comprise these activities but may also encompass other type of actions not directly performed by actors, such as an infrastructural fault, or outcomes of actions, such as external price shocks. Therefore, they can be applied to other studies as well.

[94] See Chapter 4 of Beach and Pedersen (2016a) for a detailed discussion on defining causal concepts from a mechanism-based perspective.

TIS hindering factors. From Bergek et al. (2008a) and Wieczorek and Hekkert (2012), it is already clear that negative attributes of structural elements are important causes of poor system functioning. This understanding is shared by all TIS frameworks (see FiguresFigure 9,Figure 10 andFigure 11) and indicates a clear causal relationship between inadequate structural conditions (causes) and poor system functioning – given by the hindrance of system processes (outcomes). Although this understanding is already explained, the conceptual foundations for causes, causal pathways, outcomes and contexts – as required by the MBE – are not clearly described.

For the causes, among the TIS concepts, systemic problems are best defined in terms of its nature and attributes. It is clearly specified as a structural condition with specific attributes of presence or absence and of adequacy or inadequacy. However, as discussed, it falls short to consider exogenous conditions for these attributes, which TIS literature also indicates as important conditions (Bergek et al., 2015; Bergek, Jacobsson, Carlsson, et al., 2008; Kieft et al., 2016; Markard & Truffer, 2008). Here, our first conceptual refinement is to define systemic problems as “the negative attributes of structural elements which can originate both from endogenous or exogenous conditions”[95]. This definition not only allows us to explain clearly the causes in our causal framework, but also complies with the requirements of a causal concept (as explained in Beach and Pedersen (2016a)).

Following this, the MBE requires a clear conceptualisation of the causal pathway – causal mechanism – between causes and outcomes. TIS literature also indicates that blocking mechanisms can be understood as consequence of structural conditions (Figure 10 and Figure 11). However, the literature does not present a clear definition to explain what are or how blocking mechanisms are caused. Here, our second conceptual refinement is to explore how blocking mechanisms relate to systemic problems (causes), how they come up and manifest themselves and how they lead to poor system functioning.

Taking systemic problems as negative attributes of structural elements, it is reasonable to state, according to TIS literature, that these systemic problems manifest themselves distinctly conforming to the system configuration and contextual conditions. For instance, TIS literature, presents the lack of actors’ capabilities as a common problem (Negro et al., 2012). However, different types of actors (e.g. governmental agencies and technology suppliers) may lack different capabilities (e.g. organizational or technological).

Also, the lack of particular capability by a specific actor may influence a plethora of activities. For instance, the lack of technical know-how by entrepreneurs may affect the investments’ decision-

[95] Endogenous negative attributes are more commonly treated (e.g. innovations require capabilities or regulatory frameworks not necessarily developed) than exogenous ones (e.g. poor infrastructure quality and weak policy/regulatory alignment as a result of political parties’ bargains). Thus, it indicates that exogenous attributes must be better discussed. Here, it also seems necessary to explore in detail the definitions of structural couplings and external links, as proposed by (Bergek et al., 2015). However, it goes far beyond the scope of this paper.

making, by lowering interest to invest or by overestimating returns. It may affect how entrepreneurs foresee future pathways or may affect the project design. This fact is also valid for negative attributes originated from exogenous conditions. For instance, misalignment of policies from different sectors or governance levels may affect actors' decision-making and expectations or adequacy of institutions or network resources (Negro et al., 2012). It is also expected that the context influences how these specific capabilities affect specific activities. For example, in a moment of economic crisis, decision-making may be more susceptible to negative influences from lack of a capability.

Thus, specific negative attributes of structural elements create the conditions for the activities and actors to hinder the fulfilment of system processes. This discussion converges with mechanism-based understanding, particularly with the one of mechanisms as a system, which demands the description of the causal mechanisms. Once more, mechanisms are pathways connecting causes and outcomes; composed of activities and their entities (actors) that logically connected; and operate under specific contextual conditions.

Here, understanding blocking mechanisms as causal mechanisms not only adheres to the causal conceptual framework of TIS hindering factors, but also provides a clear and explicit account on their nature and avoids the different empirical interpretations. Put simply, blocking mechanisms represent how systemic problems manifest themselves to hinder the fulfilment of system functions. They are composed of activities and respective entities (actors) which convey the causal forces from systemic problems to poor system functioning.

At this point, we have discussed how to understand and explain the causes, the causal pathways and the connection to outcomes for TIS hindering factors and malfunctioning. A last issue refers to how accounting for contextual influences in a mechanism-based conceptual framework for TIS hindering factors. Contextual influences for a causal framework are not necessarily only exogenous influences, as discussed in TIS literature (Bergek et al., 2015). This difference occurs first because exogenous influences (external to the focal TIS) can be understood as causes or as contexts of the causal mechanisms.

Our proposition already accounts for part of the exogenous influences, when defining that causes of poor system functioning can be outside TIS boundaries. This fact is in line with previous literature (Bergek et al., 2015; Bergek, Jacobsson, Carlsson, et al., 2008; Kieft et al., 2016) and is captured by our conceptualisation of (exogenous) systemic problems. Moreover, exogenous influences can play a contextual role for causal mechanisms. As explained in Section 3, contextual influences of causal mechanisms do not convey causal force, but they enable or constrain how the mechanism operate. Put differently, conditions external to the focal TIS can have causal effect or contextual effect for a blocking mechanism.

What is more, TIS endogenous influences may also comprise contextual influences for mechanisms[96]. As it is likely that more than one blocking mechanism may occur in a TIS, other structural and functional conditions may enable and constrain certain activities that are not necessarily caused by them. For instance, it is not difficult to see a lack of technical capability of actors influencing infrastructural problems of lack of technological services. Put differently, structural or functional conditions that are not causes of a specific blocking mechanism may influence its operation.

After considering all these aspects, we can propose an improved conceptual framework for TIS hindering factors. Our proposition is based on a mechanism-based understanding and causally explains the poor system functioning. To summarize, ***systemic problems are the negative attributes of structural elements, being these attributes originated from endogenous or exogenous conditions.*** These negative attributes are the causes (light grey boxes) of poor system functioning, which is given by the patterns of system functions (outcomes – dark grey box). ***Blocking mechanisms are the 'pathways' caused by one or multiple systemic problems that yield an inadequate fulfilment of system processes under specific contextual conditions***. Blocking mechanisms (dashed box) represent how systemic problems manifest themselves to convey the causal forces. As a causal pathway, blocking mechanisms comprise a sequence of activities performed by engaged actors[97]. Finally, TIS endogenous and exogenous conditions represent the contextual influences (light grey box with orange text) and may influence the operation of the blocking mechanism. The figure below depicts our proposition.

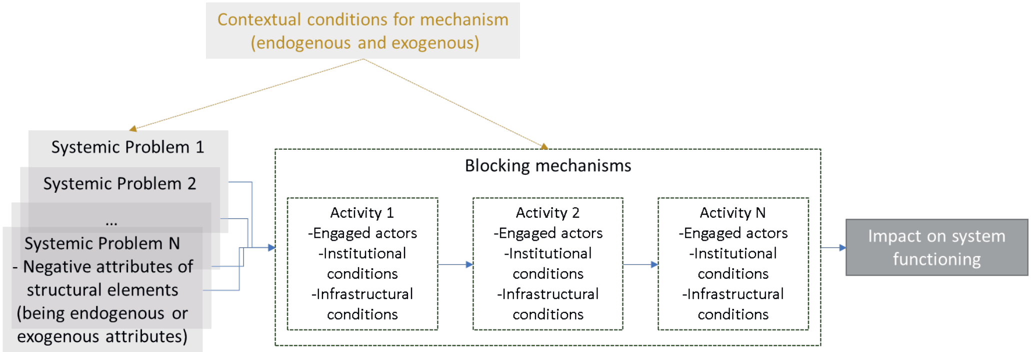


Figure 12 – Mechanism-based explanation for TIS hindering factors

[96] What represents or not contextual conditions depends on the boundary of analysis. Contextual conditions for Bergek et al. (2015) presents TIS as the boundary of analysis. Then, it focused on exogenous conditions (external to the TIS boundaries). However, analysing blocking mechanism represents another boundary of analysis, which is embedded into TIS. Therefore, TIS endogenous conditions (internal to the TIS boundaries) may also act as contextual conditions for blocking mechanisms.

[97] Activities here are actions (verbs) and not states (nouns).

3.4.2 Implications of a mechanism-based conceptual framework for TIS hindering factors and system functioning

Our mechanism-based conceptualisation deals with the limitations discussed before in Section 3.2. First, the clear and explicit definition of concepts, as well as their relationships, enables a more uniform analysis of empirical cases enhancing comparability which is key for the advance of this theoretical field. Second, it better explains the role of TIS exogenous influences, which can comprise the causes or contextual influences. Third, it allows the explanation of the interdependence of TIS hindering factors, so far, an issue that TIS frameworks fall short to explain. From the conceptual framework, as in Figure 12, it is possible to draw distinct types of interdependencies. These interdependencies would cover the direct and indirect interactions of systemic problems and blocking mechanisms. The table below summarises the interdependencies that the framework explains.

Table 4 – Interdependence of TIS hindering factors

Conceptual explanation	Direct interdependence of systemic problems	Direct interdependence of blocking mechanisms	Indirect interdependence of systemic problems
Systemic problems as contextual condition of other systemic problem	✓	X	X
Different systemic problems cause the same activity	✓	X	X
Different activities in one blocking mechanism are caused by different systemic problems	X	X	✓
Systemic problems as contextual conditions for activities in a blocking mechanism	X	X	✓
The same activities across different blocking mechanisms	X	✓	✓
Interaction of activities of different blocking mechanisms	X	✓	✓

These possibilities go much farther than only interaction of systemic problems as suggested by Kieft et al. (2016). With the mechanism-based framework and empirically exploring the activities and entities involved, TIS analysts will be able to explain 6 distinct types of interactions between systemic problems and blocking mechanisms (interdependencies) according to their role in the causal process. It means that interdependent effects can be interactions of causes, interactions of the causal pathways or contextual influences. Therefore, analysts have a more complete conceptual explanation to interpret the empirical phenomena of TIS poor functioning[98].

What is more, the mechanism-based framework also improves the understanding of how system-level and actor-level phenomena interact. Because of its focus on examining activities and actors, analysts can study what, how and why certain activities and actors hinders the fulfilment of system processes. One example of this improvement is the study of the types of interdependencies together with role and strategies of actors, such as in system building activities and strategies (Kukk et al., 2015; Musiolik et al., 2012, 2018; Planko et al., 2015). In other words, our framework enables more explicitly the comprehension of macro/meso-micro explanations. This is a timely advance as previous research has shown the need to better address system dynamics across actors and analytical levels (e.g. Hansen and Coenen, 2017; Liang and Liu, 2018).

Thus, policy recommendations also profit from these more detailed analyses. The more detailed level of analysis the more it provides valuable information with regard to which actors are involved in different moments and activities. It also provides more information on which contextual conditions of these activities are more likely to cause this malfunctioning. For example, we see possibilities for defining policy goals or issues for mitigating systemic problems (initial causes), contextual conditions or even specific activities in blocking mechanisms.

Policy design can be proposed at a higher precision level thereby fostering the achievement of specific goals. It is also possible to draw a portfolio of policy recommendations at different levels, in contrast with single recommendations. However, this fact does not mean that all contradictions of recommending policy instruments will be solved. Next to the analysis of system functioning, it is crucial to examine the policymaking processes, the characteristics of established policy mixes and how information is used in policymaking (Michael Howlett & Rayner, 2013; Rogge et al., 2017; Weible & Sabatier, 2017).

Finally, it is necessary to adapt the methods to study TIS hindering factors. Initially, it is possible to perform the usual TIS analyses to identify the causes and outcomes, i.e., to identify the systemic problems and hindered system functions (or system functioning patterns). Only then blocking mechanisms can be described. Here, analyses require methods that aim to describe causal mechanisms, such as process-tracing methods (D. Beach & Pedersen, 2016a; D Beach & Pedersen, 2019). As analyses may lead to the identification of several different mechanisms, they can be more

[98] Indirect interdependence of blocking mechanisms is not cited in the table because it goes beyond the scope of this framework. It is possible to suggest that once a blocking mechanism hinders a system process, this hindrance would produce an effect on systemic problems, or activities in blocking mechanisms.

comprehensive in terms of interdisciplinary knowledge – for the conceptualisation of activities – and of data collection – for supporting the conceptual claims. Section 3.5 below illustrates part of these implications.

3.5 EXPLORING PREVIOUS BLOCKING MECHANISM LITERATURE WITH MECHANISM-BASED EXPLANATION

This section explores the previous literature to illustrate how the application of MBE improves the explanation of TIS hindering factors. We analyse the works of Staffan Jacobsson, Anna Bergek and colleagues because they are the most prominent in discussing blocking mechanisms. Their conceptual and empirical works have been highly influential in studies seeking to understand development and diffusion of innovations. To this end, we go back and investigate how these authors have applied the blocking mechanism concept in their work regarding renewable energy technologies (Bergek & Jacobsson, 2003; Jacobsson & Bergek, 2004; Jacobsson & Johnson, 2000; Johnson & Jacobsson, 2001)[99]. These studies investigate the development of renewable energy technologies mostly in Germany, Netherlands and Sweden. Used as an illustrative case here, we do not intend to present a complete picture of these cases. The main aim is only to illustrate the usefulness of the MBE in identifying and understanding explanatory gaps that otherwise remain hidden.

The study of mechanisms calls for new research methods whereas the process-tracing methods are among the most prominent (D. Beach & Pedersen, 2016a; D Beach & Pedersen, 2019; Derek Beach & Pedersen, 2013; Bennett & Checkel, 2014). Process-tracing methods have four distinct variants which result from prior knowledge of the causes and outcomes, and from the goal of the study – empirical or theoretical (D. Beach & Pedersen, 2016a). In its most applied fashion, the theory-testing variant, the causes and outcomes are known, and the mechanisms are conceptualised before the empirical validation.

This conceptualisation is made by theory-guided description of the activities, by the verification the causal linkages between activities and by the empirical validation of these descriptions. This empirical validation is performed by applying the Bayesian updating logic where theoretical claims are updated by new empirical information[100].

Finally, process-tracing methods are case-based methods as is the explanation proposed by this new conceptualisation of blocking mechanisms. They seek to dive into the causal explanation of a case study. However, it is possible to generalise the conceptualised mechanisms for a particular population of cases by comparative research strategies (D. Beach & Pedersen, 2016a)

[99] These studies have more than 2500 citations on Google Scholar as in15/11/2018.
[100] For more details, see Bennett (2014) and Beach and Pedersen (2016a).

Thus, we conduct the illustrative case by following the guidelines of the process-tracing methodology (D. Beach & Pedersen, 2016a; Derek Beach & Pedersen, 2013). This implies the discussion of initial causes, the logical connection of causes and activities, between activities and between activities and outcomes, the conceptual description of activities, and the empirical information provided to support this description. However, we do not formally test the empirical data following the Bayesian updating logics due to lack of access to the raw data collected in the research analysed. To draw the figures below we use the same layout as described for Figure 12.

To start with, Jacobsson and Bergek (2004:825) summarised five main blocking mechanisms as main blockages for system functioning found in their empirical studies: high uncertainty, lack of legitimacy, weak connectivity, ambiguous behaviour of established firms and government policy. Below we explore the problem of ambiguous behaviour because it represents a very common category of problems for renewable energy technologies (Negro et al., 2012). For this problem, the authors (Jacobsson and Bergek, 2004: 826-827) state:

> "the ambiguous and/or opposing behaviour of some established energy suppliers and capital goods suppliers has reduced the legitimacy of renewable energy technology and has, thus, blocked the supply of resources and guided the direction of search away from these technologies […]. It has also added to customer uncertainty and vulnerability, which has blocked market formation."

From this quote, we can grasp that ambiguous behaviour may block three key processes: legitimation, resource allocation and market creation. However, the link between the initial problematic factor and what is blocked remains unexplored (see Figure 13). One can understand that ambiguous behaviour adds uncertainty and then hinders market creation, but one cannot know how uncertainty is added, how increasing uncertainty hinders market creation and who is involved. Besides, it is not sufficiently clear for readers how ambiguous behaviour by established firms is an initial cause and causes uncertainty. A MBE would require the complete description of activities from problematic factors to the blockage of the system process(es).

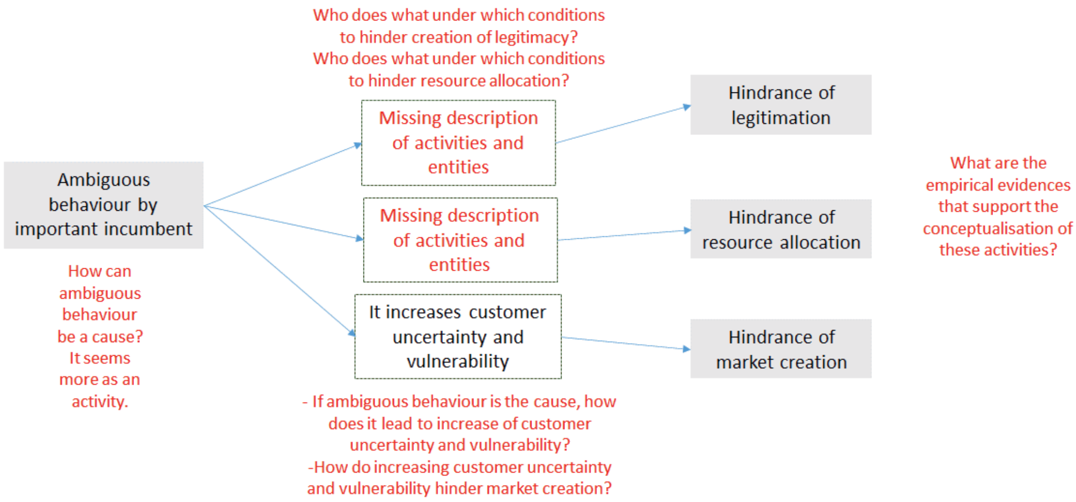


Figure 13 – Example of ambiguous behaviour blocking mechanism and gaps in explanation

The red questions aim to indicate the explanatory gaps. First, ambiguous behaviour indicates more an activity than a cause. Second, there is a missing explanation for the activities that would connect the initial cause and hindrance of legitimation and resource allocation (two dashed boxes with red text). Third, the explanation of how ambiguous behaviour causes uncertainty is not completely clear. Lastly, there are very few empirical evidences presented

Earlier works of the same authors – cited in the study by Jacobsson and Bergek (2004) – e.g. Bergek and Jacobsson (2003); Johnson and Jacobsson (2001), present a clearer picture with respect to causal processes. According to Johnson and Jacobsson (2001:19):

> "The ambiguous acting of some of the established customers (especially the large power companies) blocks market formation. For example, although Vattenfall has made investment in RD&D and states its commitment to renewable energy sources, it had only bought 4 commercial wind turbines by 1990 and 38 by 1998 […]. This type of ambiguous behaviour adds to the uncertainty perceived by other customers, firms and investors. Thus, the power companies influence the demand not only directly (by not buying the equipment), but also indirectly (by blocking the creation of legitimacy and the recognition of potential for growth)."

In this quote, it is possible to grasp more details of how ambiguous behaviour blocks market creation. First, market creation is directly blocked due to the low level of purchases by a main incumbent. Second, market creation is indirectly blocked due to the lack of legitimacy creation. For this latter however, the exact activities are not explained. It is implicitly assumed that there is a causal connection between the two system processes, but this is not demonstrated theoretically. Hence, ambiguous behaviour has two pathways of activities to block market creation, and only one is specifically demonstrated (see Figure 14). Additionally, the initial cause of ambiguous behaviour is still not clear; we cannot identify which of the problematic factor leads to the ambiguous behaviour. This information allows detailing the previous Figure 13.

Then, this distinct manifestation of systemic problems supports the explanation of the role of exogenous conditions (external to TIS). This explanation becomes clearer when it focuses on the identification of entities and activities. Using the same example, we have identified problems for particular types of actors. For instance, the power utility, an important sectoral incumbent, plays different roles in different settings[101], bringing external influences into the focal innovation system. Johnson and Jacobsson (2001:19) explained:

> "The interest in large-scale technologies clearly follows the pattern at Vattenfall, which is dominated by hydro and nuclear power. These technologies have been the measures by which all new technologies have been assessed. Since only such large-scale technologies can have a significant influence on the power balance in the short and medium run, other technologies have been deemed to be of little interest."

Given the high relevance of large-scale power plants for utilities, the business models' conditions of large-scale power plants are used as scale for assessing new business models with renewable energy technologies. In other words, these actors apply the 'large-scale project measurement scale' used in other settings (see footnote 101) to renewable energy innovations (light grey box with yellow text in Figure 14). As these renewable energy innovations present smaller scales, it may lead to less interest in these innovations. Therefore, this sectoral decision-making reasoning[102] represents an important exogenous influence on the ambiguous behaviour of these actors.

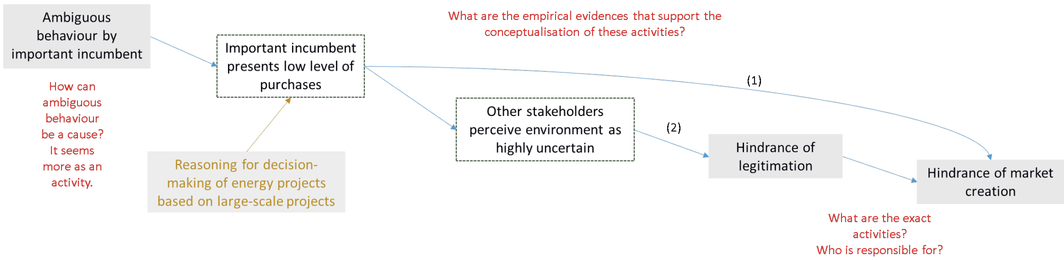


Figure 14 – Two pathways possibly caused by ambiguous behaviour influenced by an exogenous condition [103]

[101] The innovation system of renewable energy technology (the specific case analyzed) is one of them. However, it plays in power and nuclear sectors, which comprise other types of technologies and activities.
[102] It can also be understood as common practices or routines (Nelson & Winter, 1982)
[103] Here, although the explanation is improved, it is still missing the clear indication of empirical evidences and the explanation of why hindrance of legitimation is a cause and which activities hinder market creation.

By now it is easy to see that describing the exact mechanism helps to explore the gaps in the argumentation and in empirical data[104]. Nonetheless, although this short exercise has demonstrated some of the possibilities of MBE, it is still necessary to illustrate how it supports the explanation of the limitations discussed: the interdependence of TIS hindering factors and role of exogenous conditions. First, it is necessary to illustrate how a systemic problem may manifest itself differently. Following with the same example, it becomes clear how ambiguous behaviour varies according to distinct types of actors and how this fact entails different blocking pathways to system functioning. For instance, Johnson and Jacobsson (2001:20) also discussed this behaviour for government:

> …the lack of a governmental vision results in inconsistent policy measures, which have led to an erratic demand, biases in the technology choice away from new technology and undue uncertainties.

This passage evidences the difference between the ambiguous behaviour of governmental actors and power utilities (distinct entities) in hampering the system functioning. Differently from power utilities, government creates barriers to market formation via inconsistent policy measures, which led to increasing perceived uncertainty with consequent problems in demand of new technologies and conservative behaviour towards technological decisions. Moreover, in contrast to previous example, the initial cause is explicitly presented. Whereas for utilities ambiguous behaviour sounds more as a set of activities and not an attribute of actors, for government bodies the lack of long-term vision is clearly a lack of capability (see Figure 15)[105].

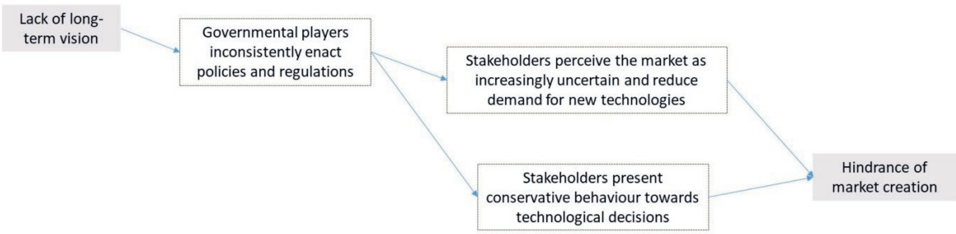


Figure 15 – Example of ambiguous behaviour by government as blocking mechanism[106]

Lastly, the interdependence of TIS hindering factors can be demonstrated if we take the

[104] The more detailed explanation of Figure 6 compared to Figure 5 indicates that this explanation was not presented in a clear manner, although analyses provided this understanding in different publications.
[105] Johnson and Jacobsson (2001) see the lack of governmental vision as a prior problem, but Jacobsson and Bergek (2004) understand it as a different blocking mechanism. Also, Johnson and Jacobsson (2001) do not classify the blocking mechanisms as ambiguous behavior. The two blocking mechanisms are the lock-in to established technologies (which include the ambiguous behavior) and lack of long-term governmental vision.
[106] The explanation for the blocking mechanisms of ambiguous behavior of governmental actors is much clearer and is very suitable to MBE of TIS hindering factors. This fact corroborates that previous TIS studies had an implicit mechanism-based perspective.

example of ambiguous behaviour and open up the *hindrance of the legitimation* box[107]. This exploration indicates that the lack of legitimacy of renewable energy technologies (RET) was not only consequence of the ambiguous behaviour of actors, but also it was broadly recognised as a consequence of the Swedish 'nuclear trauma' (Bergek and Jacobsson (2003; Jacobsson and Bergek, 2004; Johnson and Jacobsson, 2001). This trauma had two main consequences: first, it reduced all debates about RET to a discussion about the replacement of nuclear plants; second, it led to the perception of RET as a threat to the availability of cheap power (as in Figure 16).

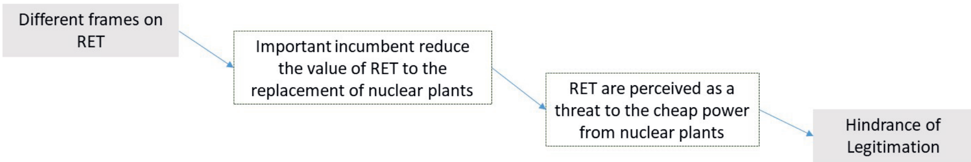


Figure 16 – Nuclear trauma blocking mechanism hindering legitimation

Therefore, for this example, applying the MBE led us from the simple understanding of mechanism (Figure 13) to three pathways for ambiguous behaviour (1 and 2 for power utility and 3 for government) and one pathway of the 'nuclear trauma' (4), which represented the interdependence of problems (see Figure 17 which combines all these pathways). From this, it becomes easy to observe the differences between the activities in each pathway and to verify where there are explanatory gaps. This verification is not only conceptual (search for theoretical gaps) but also empirical (validity of empirical observations).

[107] This represents the red question of how and which activities blocked legitimation in Figure 13.

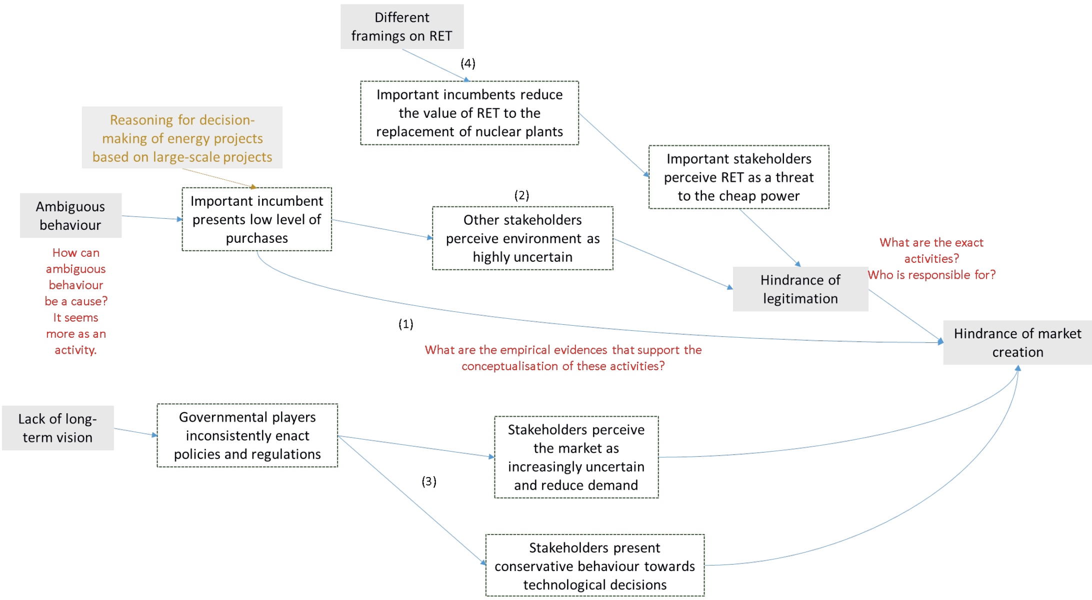


Figure 17 – Example of pathways of blocking mechanism hindering market creation

3.6 DISCUSSION AND CONCLUSIONS

In this paper we have investigated the conceptual limitations of systemic problems and blocking mechanisms analyses to improve conceptual and empirical explanations of TIS hindering factors, i.e. factors at system level that hinder system functioning. With this aim, we have for the first time used the Mechanism-Based Explanation (MBE) (D. Beach & Pedersen, 2016a; Machamer et al., 2000; Mahoney, 2001) to critically review the TIS conceptual frameworks. We discussed that addressing TIS limitations on explaining hindering factors with a MBE better explains the occurrence of poor system functioning.

As a result, our study proposes a new conceptual framework for TIS hindering factors. As a mechanism-based framework, it focuses on the causal explanation by describing mechanisms that connect causes and outcomes under specific contexts. In this framework, the outcome is the poor system functioning, given by the patterns of fulfilment of system functions. The causes are systemic problems, which can originate from TIS endogenous or exogenous conditions. Blocking mechanism are the pathways of activities caused by one or multiple systemic problems under contextual conditions that hinder one or more system functions. In other words, blocking mechanisms are the causal mechanisms that connect causes and outcomes. The contextual conditions which influence the operation of these mechanisms can comprise both TIS endogenous or exogenous conditions.

This new mechanism-based conceptualisation also leads to exploring causal pathways as a sequence of activities with specific actors. This understanding requires analysts to examine how systemic problems manifest themselves to cause the system malfunctioning. Therefore, two implications are relevant. First, blocking mechanisms represent how a specific negative attribute of a structural element unfolds under certain contextual conditions. Second, the focus on activities and actors allows the connection between actor and system level explanations.

These features enabled us to discuss how this conceptual framework addresses current limitations in TIS framework for explaining hindering factors. First, we resolved the distinct empirical interpretations of blocking mechanism concept and explained the ontological difference between systemic problems and blocking mechanisms. The definition proposed makes a clear distinction between structural conditions as causes and the activities that are caused by these structural conditions. Also, our conceptual framework harmonises the explanation of TIS hindering factors for the two most popular frameworks (Bergek, Jacobsson, Carlsson, et al., 2008; Wieczorek & Hekkert, 2012).

Second, our proposition clarifies the possible influences of TIS exogenous conditions on systemic problems, blocking mechanisms and poor system functioning. The influence of exogenous conditions in our conceptual framework is captured by the exogenous systemic problems (as causes) or by contextual conditions of blocking mechanisms (see Figure 12**Erro! Fonte de referência não encontrada.**). Exogenous systemic problems bring into the focal TIS contextual conditions through negative attributes of structural elements. This fact seems to have occurred in the illustrative exercise in Section 5, in which the 'large-scale measure for projects' (an important exogenous influence) is applied in TIS activities by an incumbent.

For exogenous conditions as contextual conditions of blocking mechanisms, our framework understands these conditions as enabling or constraining conditions (D. Beach & Pedersen, 2016a; Falleti & Lynch, 2009). Enabling or constraining conditions do not have direct causal effect but influence the causal process. Although our illustrative example has not covered this influence, an example might be an economic crisis. Such crises occur independently of TIS activities, but that may negatively influence blocking mechanisms of financial resource allocation. Lastly, we see opportunities to apply our conceptualisation in combination with structural couplings and external links concepts (Bergek et al., 2015).

Third, our study has shed new light on how to identify and explain interdependencies among TIS hindering factors. Exploring how causes, activities and entities in the causal pathway and contextual conditions interact, we deduced possible interdependencies. Table 4 described six possible interdependencies derived from the new conceptual framework. These interdependencies are classified into direct or indirect interdependencies of systemic problems and direct interdependence of blocking mechanisms. What defines direct and indirect interdependence is the presence or absence of direct interactions among causes or activities of blocking mechanisms.

Other possibilities of interdependence may also be explored in the future. This is the case of indirect interdependencies of blocking mechanisms. It is expected that mechanisms have some level of interdependency as their outcomes are the poor functioning of system processes. The TIS literature has already demonstrated the interdependence of system processes (Bergek, Jacobsson, & Sandén, 2008; Suurs & Hekkert, 2009b). However, this interdependence goes beyond the scope of this paper since it represents interactions between system processes. Furthermore, feedbacks are also expected. For instance, according to TIS literature (Bergek, Jacobsson, & Sandén, 2008), the legitimation may affect visions and expectations, which in our illustrative example would represent a feedback between hindrance of legitimation and lack of long-term vision (see Figure 17).

These expected interdependencies open up a spectrum of possibilities for TIS analysts to examine why, how and what are the exact factors of poor system functioning. It also underpins conceptual explanation for connecting meso and micro explanations. The illustrative exercise in Section 5 showed an example of a common activity caused by distinct systemic problems that occurs in different blocking mechanisms. Stakeholders' perception of uncertain environment is caused by the low level of purchases from an important incumbent firm and by the inconsistent policies from governmental agencies, which are caused by the ambiguous behaviour and lack of long-term vision respectively (see Figure 17).

Accordingly, depending on the type of interdependence, it will be possible to discuss where coordination is crucial. Another important conclusion may be about the leading actors of proposed interventions. Interventions may be conducted not only by governments, as in the case of policy recommendations. Depending on the case, analysis may lead to activities in which only private actors are relevant. By describing blocking mechanisms comprised of activities and actors and relevant conditions, analysts will have a portfolio of problematic conditions. Therefore, the discussion of policy recommendations may focus on symptoms (activities or blocking mechanisms), on causes (systemic problems) or on contextual conditions of blocking mechanisms.

This fact indicates also significant implications for recommending policy. The first implication refers to an improvement in TIS policy rationales. Being more explicit in describing mechanisms, its parts and their relationship with system concepts produces other policy goals or issues to guide policy instruments. The mitigation of systemic problems or blocking mechanisms continue as important policy goals. However, for blocking mechanisms, mitigating specific activities broadens the space of policy goals. Mitigating or supporting specific contextual conditions of blocking mechanisms are also added to this space.

Hence, the broadening of space for policy goals also indicates more clearly a bigger variety of instruments to stimulate system functioning other than systemic instruments. However, it also suggests that coordination among systemic and actor level goals can be informed. For instance, for the illustrative case presented in Figure 17, it is possible to derive that policy instruments that promote market formation may not achieve the expected results if they do not tackle the perceived uncertainty of stakeholders or the perceived threat of cheap electricity.

A last implication of our conceptual framework refers to the explanation of mechanisms in TIS. On the same vein as the claim for a critical realist perspective in transition studies (Sorrell, 2018; Svensson & Nikoleris, 2018), we posit that applying the MBE to Innovation Systems as a promising avenue for future research. First, we believe that although there may be case-specific mechanisms, there may also be general mechanisms that operate in a broader spectrum of contexts. This is widely accepted by the innovation studies literature (e.g. Binz et al., 2016b; Fuenfschilling and Truffer, 2014; Garud et al., 2010; Onufrey and Bergek, 2015).

Second, this reasoning may be applied also for understanding system dynamics, i.e. one can apply this understanding for inducement, blocking mechanisms and list more general mechanisms that influence system functioning. This task is already done for specific system functions in an implicit manner (Binz, Harris-Lovett, et al., 2016; Dewald & Truffer, 2011; Karltorp, 2016; Konrad et al., 2012; Yap & Truffer, 2018). It may also support the research of mature TISs, which are not necessarily dependent on structuration. Mapping and describing mechanisms may indicate which mechanisms operate for structuring TIS and which mechanisms operate to maintain system functioning.

Finally, although we understand our conceptual analysis as an important step, it is not free from limitations. We acknowledge the need of empirical validation. We expect with this study to open an important empirical avenue for TIS studies. As tracing-mechanisms is a case-based research, a fruitful future research avenue could be to conduct case studies so that different types of blocking mechanisms can be understood, testing the expected interdependencies. It also seems relevant to compare case studies in order to identify more general blocking mechanisms.

However, these future studies must be aware of the need for adapting research designs and methodologies. Mechanism-based causal explanation leads to different assumptions for case selection, which is based on singular causation and causal homogeneity of cases (D. Beach & Pedersen, 2016a, 2016b). It also requires different methods. As discussed, process-tracing is the most prominent family of methods applied to study mechanisms (D. Beach & Pedersen, 2016a; Derek Beach & Pedersen, 2013; Bennett & Checkel, 2014). Following this, we expect to see similar mechanisms across cases, particularly for technologies with comparable characteristics[108]. It is also important to mention that mechanism-based case studies are very intensive in data and time, as analysts must validate the conceptual mechanisms with empirical data. This task may lead to different rounds of data collection and analyses.

Another important limitation that must be explicitly discussed refers to how this framework

[108] These characteristics can be defined as Binz and Truffer (2017) proposed in innovation mode and valuation, which for biogas technologies means to be dependent on local conditions. For our case, it is also important the fact (complete please)

informs policy. Our framework enables analysts to explain how hindering factors manifest themselves and, consequently, it allows to inform the debate on how to mitigate these factors through different policy goals, instruments and coordination of actions. However, our framework does not explicitly account for studying policy mix and politics, which are important factors to inform policy goals and instruments to policy makers. These studies can be done in combination with TIS analyses and may comprise other research avenues.

CHAPTER 4 - SYSTEMIC PROBLEMS AND BLOCKING MECHANISMS OF BIOGAS TECHNOLOGIES IN BRAZIL[109]

- Applies the mechanism-based framework of systemic problems and blocking mechanisms to BBIS
- Develops an innovative method combining event history analysis, interviews and process-tracing
- Demonstrates how the low level of knowledge, divergent frames, financial conditions, and limited spectrum of interactions are the main causes of system hindrance

ABSTRACT

Despite their great production potential and a long history, recent studies suggest that biogas technologies in Brazil experience problems on various dimensions to reach higher levels of diffusion. However, previous studies have not addressed these problems in an integrated and systemic manner. Understanding the development of biogas in Brazil as emerging sociotechnical configurations, this research applies the Technological Innovation system (TIS) framework to explore these hurdles. More specifically, this research aims to explain how systemic problems and blocking mechanisms hinder the development of the Brazilian biogas innovation system. To this end, the TIS framework is adapted to encompass the interaction of systemic problems and their causal link with blocking mechanisms. An innovative methodology was developed combining event history analysis and 24 in-depth interviews to describe systemic problems with a theory-building process-tracing to unpack the blocking mechanisms. Our findings indicate that the low level of knowledge of biogas among players in Brazilian Biogas Innovation System, the divergent frames and financial conditions and the limited spectrum of interactions are the primary causes of system hindrance. These causes manifested themselves in five blocking mechanisms, which elucidates the interdependence of systemic problems. The chapter concludes by discussing how these interdependencies contribute to the conceptualisation of hindering factors in TIS studies and how they lead to an increasing relevance of coordination.

KEYWORDS

Systemic problems, Blocking mechanisms, mechanism-based explanation, process-tracing, biogas, Brazil

---

[109] An earlier version of this chapter was published as de Oliveira (2020) as a book chapter of the book 'The Regulation and Policy of Latin American Energy Transitions'. https://doi.org/10.1016/B978-0-12-819521-5.00014-0

4.1 INTRODUCTION

Brazil is known for its success in promoting bioenergy (IEA, 2013), of which bioethanol and biodiesel represent the most prominent examples (Rico & Sauer, 2015; S. Silveira & Johnson, 2016). However, other bioenergy sources are still struggling to achieve high diffusion rates. Biogas has great potential but has not yet gained momentum (EPE, 2016). The development of biogas technologies in Brazil has a long history dating back to the 1980s (De Oliveira & Negro, 2019). Similarly to bioethanol, biogas received governmental support during this period in response to the oil crisis. Although some critical projects were undertaken, biogas did not diffuse rapidly enough to establish a market before oil prices fell and became more competitive in the late 1980s. In 1998, the Kyoto Protocol renewed interest in Brazilian biogas projects; however, this revival resulted in little impact on the formalisation of the biogas field; limited technological development occurred and—once again— contextual changes negatively pressured these experiments from 2008 onwards. Since 2012, a new wave of support has emerged in state-level policies and the creation of intermediary players such as industry associations, R&D networks and research centres. More recently, a new biofuel law that creates a carbon market for biofuels is expected to boost biogas projects.

This long and bumpy history suggests that the development of the biogas field has faced different problems over time. Biogas technologies in Brazil have several different routes. This variety is a consequence of several possible substrates—e.g. manure, wastewaters, sludge and organic fraction of municipal solid waste—and other uses—e.g. power generation, automotive fuel and thermal fuel injection into natural gas grids. They also distinctly span over Brazilian territory, subject to different actors, regulations and infrastructures. Focusing on the project level, Jende et. al (2016) discussed four main barriers: uncertainty about costs and returns, few reference projects, difficult access to biogas projects' information, and few biogas-specific policies. However, it is not clear how these problems—and likely others that were not discussed—hinder the development of the biogas field.

To address this limitation, I investigate the causes and manifestations of factors hindering the biogas field as this research's primary goal. Applying the Technological Innovation System (TIS) framework (Bergek, Jacobsson, Carlsson, et al., 2008; Wieczorek & Hekkert, 2012) is very insightful for examining the systemic problems and blocking mechanisms of the Brazilian Biogas Innovation System. TIS is well-known for its ability to analyse how configurations of system elements and process patterns enable the development of emerging sociotechnical configurations (Bergek, Jacobsson, Carlsson, et al., 2008; Markard & Truffer, 2008; Sandén & Hillman, 2011). However, systemic problems may reinforce or interact with each other in different ways, thereby creating more intricate problems. Recent

TIS studies have indicated a conceptual limitation on its capacity to evaluate such interdependence (Kieft et al., 2016; Kriechbaum et al., 2018).

This chapter takes up this challenge by applying the mechanism-based explanation (MBE; Beach and Pedersen, 2016a; Bunge, 1997; Mahoney, 2001) developed in the previous chapter to answer the question: *What are the systemic problems, blocking mechanisms and their respective interdependencies impacting the Brazilian biogas innovation system?* The following section introduces the main concepts used to conduct this analysis and the adaptations made to the TIS framework. First, section 4.3 presents the methodology, whereas Section4.4 and Section 4.5 present the findings concerning systemic problems and blocking mechanisms. Next, the discussion of problems' interdependencies and their implications is presented in Section 4.6. Lastly, the conclusions are presented in Section 4.7.

4.2 APPLYING A MECHANISM-BASED EXPLANATION ON SYSTEMIC PROBLEMS, BLOCKING MECHANISMS

The analysis of systemic problems derives from innovation system studies (see Edquist, 1997; Woolthuis et al., 2005) and aims to identify how problems at the system level lead to poor system dynamics so that possible interventions can be proposed (Jacobsson & Bergek, 2011). Among systems approaches, the Technological Innovation System (TIS) framework is the most suitable for analysing technologies or technological fields (Bergek, Jacobsson, Carlsson, et al., 2008; M. P. Hekkert et al., 2007). The TIS framework focuses on analysing the development of an emerging sociotechnical configuration by examining structural and functional conditions (Bergek, Jacobsson, Carlsson, et al., 2008; M. P. Hekkert et al., 2007). Structural analysis refers to the investigation of system elements and their configurations—i.e. actors (organizations, universities, governmental agencies, etc.) and their interactions, institutions (e.g. Scott 1995) and infrastructures (e.g. physical, financial). The functional analysis considers how critical processes at the system level—namely entrepreneurial activity, knowledge production and exchange, the guidance of search, market creation, resource allocation and legitimation—occur and interact to enable or constrain the development of the technological field.

Within the TIS framework, the two main concepts applied to investigate system-level problems are systemic problems and blocking mechanisms. Identifying systemic problems explains negative impacts on system functioning based on the presence or absence and the adequacy or inadequacy of structural components (Wieczorek and Hekkert, 2012). Blocking mechanisms is a similar concept but do not attribute negative characteristics that only hinder system functioning to structural elements. Blocking mechanisms can comprise structural components and aspects external to a TIS (Bergek, Jacobsson, Carlsson, et al., 2008). The empirical analysis of both systemic problems and blocking mechanisms has thus far demonstrated relevance for improving the understanding of TIS and providing insights for policy design, such as how to ensure adequate infrastructure and institutions (Wieczorek & Hekkert, 2012) and how to support advocacy coalition to increase legitimacy (Bergek, Jacobsson, Carlsson, et al., 2008). Such studies have also pointed to the need for a deeper understanding of interdependencies within and between these phenomena (e.g. Patana et al., 2013; Sixt et al., 2018; Turner et al., 2016).

Kieft et al. (2016) proposed a categorisation for systemic problems to understand their interdependencies whereby systemic problems can be independent or interacting problems, thereby accounting for their relationship (or not) to other problems, and can be endogenous or exogenous, referring to innovation system-specific or context-related problems. They argue that blocking mechanisms result from interacting systemic problems. Hence, systemic problems and blocking mechanisms are not synonymous but complementary, the former being the r problematic factors of structural elements and the latter the activities that hinder system functioning. In other words, '[i]nstead of using the term blocking mechanism to indicate a problematic "factor", we use it to indicate a real "mechanism"' (Kieft et al., 2016:34).

Kieft et al. (2016) provide an abstract definition of 'real mechanisms'; however, an MBE can be applied to explore the interdependence of systemic problems further. MBE states that 'causation resides not solely in the variables or attributes of the units of analysis but in mechanisms' (Falleti and Lynch, 2009:1144). This means that MBE focuses on tracing mechanisms that connect causes and outcomes (D. Beach & Pedersen, 2016a; Biesbroek et al., 2017). This connection is a conceptual construction comprised of entities (actors) engaged in activities under certain conditions (D. Beach & Pedersen, 2016a; Derek Beach & Pedersen, 2013). These (sequences of) activities are responsible for transmitting the causal forces from causes to outcomes (Derek Beach & Pedersen, 2013; Mahoney, 2001). Therefore, MBE demands the conceptual explanation of the causal pathway between causes and outcomes by describing activities and entities.

We translate this understanding into TIS analysis due to the need to scrutinise problematic factors of structural elements (systemic problems) and the exact activities that are consequences of these problematic factors and lead to poor system functioning. In short, our analysis aims at investigating how systemic problems are expressed across structural elements, which remains an area for improvement in TIS studies. For instance, analysts can describe actors' lack of capabilities (structural element) as a different type of capability (e.g. technological and organizational capabilities) that is manifested across different types of actors (e.g. governmental agencies and technology suppliers—different subtypes of structural elements).

Moreover, analysts must explain how systemic problems manifest themselves into different (sequences) of activities that hinder system functioning. To do so, it is necessary to understand possible causes, outcomes and contexts, as well as conceptualise the activities between causes and outcomes. Consequently, analysts may also need different theoretical backgrounds (to conceptualise the activities) and must constantly assess the quality of the empirical observations (D. Beach & Pedersen, 2016a; Bennett & Checkel, 2014).

Thus, applying an MBE understanding to TIS, hindering factors or blocking mechanisms can be understood as a consequence of systemic problems, representing the causal pathways between causes and outcomes. The causes are systemic problems, which are negative attributes of structural elements—as in Wieczorek and Hekkert (2012)—and can be endogenous or exogenous, as suggested by Kieft et al. (2016). The outcomes are poor system functioning, which is indicated by the low level of fulfilment of system processes. The causal pathways, i.e. blocking mechanisms, are composed of entities (actors) and activities. Lastly, these mechanisms operate in a given context, which can be conditions external or internal to a focal TIS. Figure 18 below illustrates this explanation.

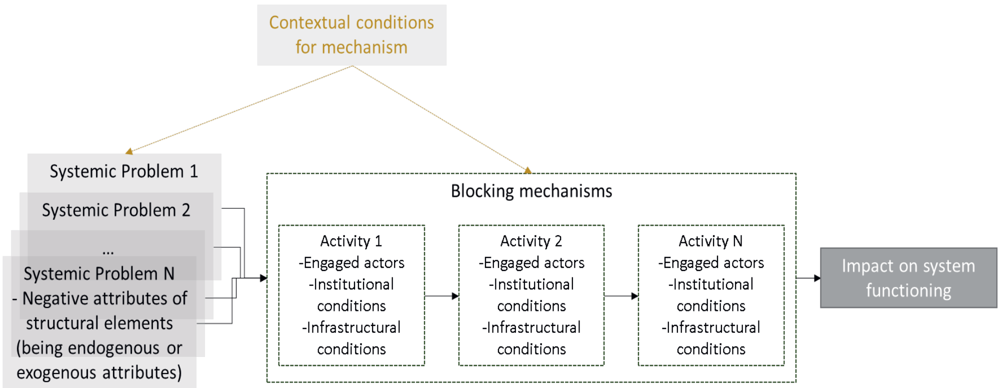


Figure 18 – Mechanism-based understanding of systemic problems and blocking mechanisms

Lastly, this proposition addresses important TIS limitations (De Oliveira et al., 2020). First, this proposition resolves the issue that blocking mechanisms have different empirical interpretations by indicating the ontological distinctions between structural causes (systemic problems) and activities caused by structural conditions (blocking mechanisms).

Second, this conceptualisation explicitly explains exogenous/contextual influences—i.e. influences external to a focal TIS—in two fashions: possible causes of (exogenous systemic problems) and contextual influences for blocking mechanisms. Here, it is important to explain that contextual influences are not causes but affect how activities are performed. An interesting analogy refers to the mechanism of an internal combustion engine. The fuel is the cause, the explosion and movement of gears are the activities, and mechanical power is the outcome. Here, contextual conditions can be temperature, pressure, and the presence of oxygen. These conditions do not modify the primary mechanism but rather influence its operation.

Third, by exploring the entities, activities and conditions set up by systemic problems, it is possible to examine the interdependence of systemic problems, which are expected to be common activities between blocking mechanisms and systemic problems being contextual influences for activities (De Oliveira et al., 2020)[110].

4.3 METHODOLOGY

To apply the above-elaborated new conceptualisation of systemic problems and blocking mechanisms to an analysis of the case of biogas in Brazil, we combined event history analysis and process-tracing methods in two analytical steps, the first of which entailed the examination of systemic problems and the second of which describes the blocking mechanisms. To identify systemic problems, I built upon the framework of TIS developed by Wieczorek and Hekkert (2012) and adapted it to scrutinise both endogenous and exogenous features that affect the structuration and dynamics of the system. We present the last phase, which covers the period from 2012 to 2016[111].

The method adopted for this task is event history analysis (Negro et al., 2007; Suurs & Hekkert, 2009b). Event history analysis conceives an understanding of the innovation journey as a process (Poole et al., 2000; Van de Ven et al., 1999), and it concentrates on mapping events and their sequences to build up a narrative for the evolution of TIS (Negro et al., 2007; Suurs & Hekkert, 2009b). For the empirical data of events, we first conducted desk research of scientific literature (Web of Knowledge, Periódicos Capes, and selected Brazilian universities[112]), media documents (Lexis-Nexis® database, selected newspapers[113] and websites of sectoral media), and documents of relevant organisations (reports of activities, public consultations, research reports, technical reports, and official government documents).

[110] Chapter 3 presents a deeper discussion for this conceptualisation.
[111] Providing a detailed description of this framework is not the aim of this research and can be found in our previous study (De Oliveira & Negro, 2019). The main idea was to include a systematic mapping of contexts, which were identified by the description of biogas value chains (see Sandén and Hillman, 2011) by specifying the information in the event history analysis (Negro et al., 2007; Suurs & Hekkert, 2009b). Only the last phase is presented because it represents the current problems of biogas in Brazil.
[112] The selection of universities was based on an iterative process, i.e. performing the collection of events we identified the most relevant universities.
[113] Digital archives of *O Globo* and *Folha de São Paulo*.

Hence, I constructed a large database of events and their specifications (date, local, sector, main actors, exchange resources, and main activities). After coding them into system functions, we designed the first narrative for the Brazilian Biogas Innovation System (BBIS). Then, between September and December of 2016, I conducted 24 in-depth interviews to obtain more profound insight into the specificities of different dimensions and characteristics of biogas problems. These interviews were held with stakeholders of varying levels of governmental bodies, private and state-owned companies, universities, research institutes, industry associations and farmers. The interviews were transcribed and analysed to refine the narrative and the description of systemic problems. It is essential to highlight that the findings concerning system structure, dynamics and contextual influences are presented by De Oliveira and Negro (2019)[114].

To identify the blocking mechanisms of BBIS, we adopted the theory-building variant of the process-tracing method as presented in Beach and Pedersen (2013). This approach is suitable when one is aware of a correlation between cause and outcome but is not sure about the mechanisms connecting them (p. 16 and 60). This is exactly what the first analytical step will produce: a list of systemic problems and their impacts on system processes. Then, by identifying systemic problems and their impacts on system functioning (section 4.4), we can discuss initial causes and outcomes.

Then, we started by drawing the causal pathways of the blocking mechanisms and describing activities and entities, as recommended by Waldner (2014). Here, the analysis of systemic problems supported the conceptualisation of possible causes, outcomes and activities to draw the blocking mechanisms. Next, we revisited our empirical observations to assess the validity of the mechanisms and quality of empirical observations[115]. Here, the reasoning was to verify whether the conceptualisation of the blocking mechanism is supported by previously collected empirical data and determine the parameters of a new round of data collection. Finally, with the knowledge gained from examining mechanisms, we went back to the description of systemic problems. This was an iterative process that resulted in the description of the blocking mechanisms as presented in section 4.5.

The final step comprised another round of in-depth interviews (n = 10) in the second trimester of 2019, which aimed to check the current applicability of the analyses of systemic problems and blocking mechanisms and identify any relevant changes in the biogas field from the end of 2016 and the time these interviews were conducted. Figure 19 presents these methodological steps.

[114] For more details, please see Chapter 2.
[115] We tested the robustness of our empirical observations following Bayesian updating logic. We strongly recommend to check the annexes; the first briefly introduces the Bayesian updating logic, whereas the table presents our analyses conducted in adherence with Beach and Pedersen (2016) guidelines (Chapter 6).

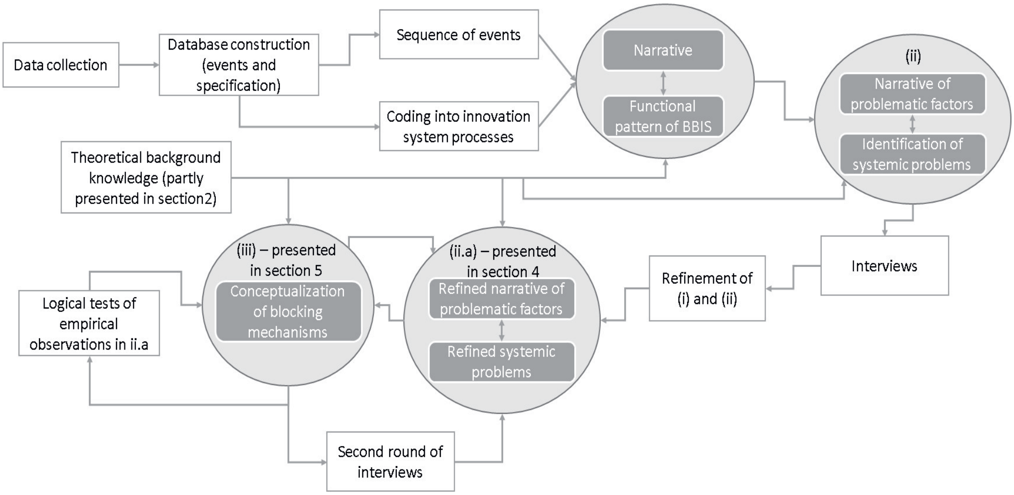


Figure 19 – Methodological steps

4.4 SYSTEMIC PROBLEMS EXPERIENCED IN BBIS

4.4.1 Actors' problems – Lack of capable players

Firstly, there are very few national players developing or adapting biogas technologies with regard to supply. This situation is particularly important for substrate treatment and biogas production technologies due to the specificities of Brazilian biomasses and climate. As interviewee R1 explained, there is still the need to' scaling down biodigestion, biogas treatment and use technologies' for efficient small-scale biogas projects. As interviewee P1 mentioned, 'the upscaling of biodigesters and procedures for controlling the reaction are the main attention points' for large-scale biogas projects. Furthermore, international players stumble in supplying technological solutions to biogas due to their limited knowledge of the Brazilian context. The Brazilian context can be challenging for foreign players due to the diverse technical aspects (substrates, climate and uses) and the highly complex regulations governing operations in the country. These problems often lead to high costs and the unfeasibility of projects.

Secondly, the demand for biogas technologies is inconstant and incipient (De Oliveira & Negro, 2019). As a result, farmers, industries and sanitation companies, which have available substrates, lack the necessary knowledge to estimate their biogas potential, operate biogas projects or even search for suitable firms to evaluate opportunities. In addition, several intermediary players, such as engineering and consultancy companies, also lack adequate knowledge to identify opportunities or develop biogas projects, thereby undermining the intermediary demand for biogas services. Moreover, the lack of basic skills, such as designing and operating biogas projects, represents an extra cost—i.e. trial and error or the cost of hiring external knowledge. These problems seem to have improved in the last couple of years yet remain an important hurdle for project development.

Public bodies also lack adequate knowledge of biogas technologies. The problems are deficient coordination and regulation of biogas activities due to a limited understanding of biogas activities across governmental bodies. For example, there is the limited (or superficial) awareness of biogas issues by governmental organisations at the national level, which leads to difficult policy coordination across ministries and a heterogeneous institutionalisation of biogas issues in the agenda of technical bodies. Once more, the new intermediary players (biogas associations) have successfully acted to mitigate this problem, as can be observed by the inclusion of biogas and biomethane in the Renovabio policy. However, this problem is far from being resolved; knowledge gains are isolated to specific cases.

Lastly, it is necessary to understand these problems within the Brazilian innovation system. The low innovative character of Brazilian firms as represented by insufficient investment in R&D and innovation (see Cassiolato, 2015; Mazzucato and Penna, 2016) and the rigid organisational structures of governmental bodies (as reported by interviewee G6), which are classified by pre-defined sectors and topics, are important background conditions. The former indicates how an organisation tends to behave toward innovation; as interviewee P1 commented, *'there are many people who want to invest, but also many that see R&D investments as expenses.'* The latter makes the absorption and even the discussion of knowledge development on biogas solutions challenging.

4.4.2 Interactional problems—Low-quality interactions

The BBIS has experienced an increasing number of interactions in recent years, which have addressed systemic features (e.g. biomethane regulation, replicable business models, reference projects, new institutional arrangements, and specific support to cost reductions and market creation)[116]. However, the motivation for most of these interactions remains project problems 0028micro-level) rather than system-level issues. This situation results in a project-based focus for interactions, which leads to the engagement of few actors and limits that of distinct types of actors (e.g. little engagement of high-level political actors and universities). Therefore, important system-level processes are hindered, namely the diffusion of knowledge and information (e.g. best practices and successful experiences), the combination of capabilities to address important problems (e.g. technological gaps) and the alignment

[116] Only more recently (2012 onwards) have the two biogas associations (Abiogás and ABBM), CIBiogás, PROBIOGÁS and BiogasFerti network complemented local existent platforms such as the Itaipu Technological Park. These new interactional structures have yielded more interaction between players and entail more knowledge production (e.g. PROBIOGÁS studies in 2015) and diffusion (e.g., rounds for laboratory standardisation of CIBiogás and Embrapa). However, new interactional structures and players still struggle to reach players outside of biogas field.

of expectations and visions about biogas technologies (e.g. to organise demand and coordinate policy and regulations).

Some exogenous factors were also observed. The relatively low level of cooperation of Brazilian firms compared to developed countries (see Mazzucato and Penna, 2016) has engendered a culture of low engagement, as confirmed by both the interviewees and the goals of some programs (e.g. PROBIOGÁS). For instance, the culture of not sharing (as discussed by Jende et al. (2016) was mentioned as apparent even within the biogas associations. Furthermore, the lack of coordination of interactions and activities between sectors and federative levels—or, as stated in Mazzucato and Penna (2016:63), the 'fragmentation of the innovation agenda amongst public institutions', is another important problematic factor. Because the biogas chain overspreads several institutional settings and territories, and—more importantly, it is not the first solution for any of them, coordination becomes crucial. This uncoordinated behaviour and myopia caused by the lack of strategy are exemplified in the presence of varying national-level programs to promote biogas (low carbon swine production, the Ministry of Agriculture and Livestock; PROBIOGÁS, the Ministry of the Cities; the strategic biogas R&D project, Ministry of Mines and Energy through the regulatory agency) represented. Interviewee F1 described, 'there is no boss for biogas at the national government.'

4.4.3 Formal institutional problems

The lack of standards and regulations for designing, operating and trading biogas projects and products was identified as a constant problem across different phases of the development of the biogas field in Brazil (De Oliveira & Negro, 2019). This problem has led to the reproduction of low-efficiency projects that undermines the trust in biogas technological solutions. As interviewee I3 lamented, 'the lack of […] regulations left the biogas in a loose environment, subject to the initiative of pioneers who understood biogas as a trivial business.' A series of regulations and standards recently published mitigated this problem[117].

However, these regulations are primarily focused on the downstream side of the biogas value chain and the biomethane case. Power generation and connection to the grid have not experienced significant problems because these rules were already established in the power sector institutional framework. In contrast, about the treatment of substrates and biogas production, projects still experience very different levels of quality in the control of process and quality of biogas and by-products. This situation is also a consequence of Brazil's distinct conditions in which biogas projects are developed

[117] The main regulations refer to the specification of biogas and biomethane by ANP resolutions nº 8/2015 and 685/2017 and the ABNT standard 16560/2017, which defines the method for measuring the siloxanes content.

and the varying possibilities for technological routes. Therefore, nowadays, it is still possible to observe projects with a limited lifespan and uncertain biogas production due to the low levels of quality in project design and operation.

Other issues derive from the new biomethane regulations. First, although these regulations represent an important advance in formal institutional development, they also create specific problems for small-scale projects. Small-scale biogas projects require the same type of equipment used in large-scale natural gas projects to measure biomethane quality. The result is a significant increase in investment costs, which sometimes makes the project unfeasible. Second, these regulations were enacted in a temporal mismatch with other policies. The biomethane specification published by ANP in 2015 excluded urban substrates and counteracted the promotion policy of Rio de Janeiro State[118]. This incongruence has hindered the development of biogas projects in the state.

Moreover, the lack of a national biogas agenda or policy creates an environment of uncertainty (mainly political uncertainties; Meijer and Hekkert, 2010), thereby leading to divergent strategies, particularly because biogas technologies cut across various regulatory and market structures. Although many interviewees confirmed the relevance of PROBIOGÁS[119], they understood that it was not enough to create a shared vision among high-level bodies[120]. No clear agenda for the biogas field has emerged since the end of the PROBIOGÁS in 2017. The unclear agenda also hampers the ability of players interested in biogas technologies to see future pathways for biogas in the country.

Lastly, macro-level policies and programs have acted as indirect influences that affect the development of innovations[121] (Cassiolato, 2015; Mazzucato & Penna, 2016). In particular, these macro conditions have influenced the availability of resources and the strategies of key actors. For example, many interviewees clearly stated that the current crisis and consequent austerity measures have negatively impacted the development of activities due to the limited availability of resources. Additionally, the current situation has also affected sectoral conditions contributing to the slowing down of biogas activities. For example, interviewees from power and natural gas utilities agreed that the

[118] The policy Rio de Janeiro enacted in 2012 was to create a market quota for biomethane in the state natural gas market. By that time, there was no specific regulation for biomethane, and urban residues were the main source of biogas in the state. Therefore, with the exclusion of urban substrates, the regulation of 2015 hampered the development of projects in the state. This conflict was resolved with the new resolution adopted in 2017; however, the market was already hampered.
[119] Interviewees stated that the program was able to 'keep biogas in high-level government bodies', 'promote the interaction of different types of players' and 'produce and disclose necessary practical information'.
[120] As several interviewees mentioned, this issue is particularly significant because Brazil already has a high share of renewable energy in the energy matrix and an abundance of natural resources, which entail several possible pathways for increasing renewable energy share.
[121] Scholars (e.g. Coutinho, 2005, 2003; Herrera, 2011; Lastres et al., 2014) have conceptualised and demonstrated this situation in the case of macroeconomic policies counteracting industrial and innovation policies, in what they called implicit policy.

current crisis had reduced overall energy demand, which has decreased the need for a new energy supply. Companies had already made contracts with energy suppliers, but the demand did not happen.

4.4.4 Informal institutional problems

The most important concerning informal institutions is how different sectoral (and even some biogas) players frame biogas technologies. Although some biogas players have a positive perspective about the transverse feature of biogas technologies[122], sectoral incumbents tend to differ in their framing of opportunities and solutions. For instance, the perceived value of biogas technologies varies in importance across the position of players in the biogas value chain. Whereas environmental bodies try to explore the environmental treatment value of anaerobic biodigestion, utility companies use energy prices as the main criterion for defining the value of biogas[123]. As interviewee Ut3 explained, environmental bodies must comprehend how anaerobic biodigestion functions to reduce pollution levels, whereas energy utilities are interested in 'the after-power generation systems and their costs'[124].The result is different motivations and expectations toward biogas technologies.

Another example relates to the decentralised and small-scale character of biogas. Biogas projects are highly small-scale to energy sector players, which compare biogas to regular power plants or natural gas fields[125]. The paradigm of centralised energy production makes most energy incumbents (from companies to public bodies) envision biogas solutions as marginal to their portfolios. However, these different framings become more relevant for governmental bodies. As explained by interviewee G6, 'energy governmental/regulatory bodies have to come up with specific solutions for biogas technologies that are not necessarily simple and may require innovative procedures, while the absolute and relative numbers for the energy sector are negligible.' This point is negatively aligned with the problem of rigid organisational structures (section 4.4.1). Similarly, biogas projects require innovative business models, additional capabilities, and knowledge for sectoral incumbents.

Furthermore, previous negative experiences and a shortage of successful cases with biogas technologies negatively impact new biogas projects. The lack of trust in biogas technologies derives from very small-scale production and the 'promise to reduce costs for farmers' to 'the few numbers of large commercial biodigestion plants', as expressed by interviewees R1 and R2, respectively. For most interviewees, this is a minor problem that can be overcome without much difficulty. However, the long

[122] Some interviewees mentioned biogas technologies as a possible common solution for energy, environmental and economic problems in many situations.
[123] This situation is mostly a consequence of the competition with renewable energy resources (e.g. wind and solar power and bioethanol for biofuels).
[124] Some energy actors are guided by local contexts or inner motivations to not engage in biogas activities.
[125] As interviewee P1 observed, even large biogas projects—such as in the sugarcane industry—that have potential for units much bigger than the biggest European plants' are considered small-scale.

durability of this issue has been reproducing technological uncertainties (see Meijer and Hekkert, 2010) through the perception of inefficient technology among decision-makers (Jende & et. al, 2016).

Finally, the main exogenous factors identified were the short-termism and rent-seeking character of investors in Brazil—i.e. companies are averse to taking risks and do not have long-term plans. As interviewee R3 explained, 'Brazilians [firms] are risk-averse because they live where rent-seeking is favoured'. Interviewee G1 similarly elaborated that 'the capital cost in peripheral countries is a crucial variable; here [in Brazil], there is a stimulus for investors being rent-seekers instead of entrepreneurs.

4.4.5 Infrastructural problems

The misalignment of funding structures, the weak structure of biogas services and the underdeveloped infrastructure for technical and professional training represent important problems and encompass both BBIS-specific and context-related influences. The misalignment of financial conditions for biogas projects and the requirements of funding players was a common complaint of many interviewees and biogas players. This misalignment has its main expression in the incapacity of many biogas projects to fulfil the required financial guarantees. Part of this problem derives from supply-side issues, such as a lack of specific lines, which should have more adequate conditions or innovative business models—e.g. new 'project finance' forms (as cited by interviewee I1). Another aspect relates to the biogas players, such as their weak financial capacity, particularly for large-scale and intensive-capital biogas projects, and the small-scale conditions of the biogas projects. Biogas companies are mostly young firms still in the investment phase of projects (as cited by interviewee P3). Additionally, many interviewees acknowledge that the absence of biogas policies contributes to this problem. For instance, some interviewees (G1, R3, P3 and Fin2) compared the current policy support for biogas to biodiesel, which has been tied to specific financial conditions since the launching of the national policy.

Second, the infrastructures of biogas services are incipient. Essential services such as laboratory tests or supplies of ancillary equipment and consultancy services are concentrated in only a few places. As said by interviewee R3, 'we tried to build a project in the mid-west region with a company from the south region because they are one of the best national services' suppliers. However, they could not participate due to the distance and related costs.' Although there has recently been an increase in the number of industrial players offering biogas services, this infrastructure is still hugely concentrated in a limited number of places.

The final major infrastructural problem is the inadequate technical and professional training on biogas services. Several interviewees (e.g. R1, R2, G4 and P3) pointed to the lack of skilled labour as a crucial point inhibiting project development. The underdevelopment of biogas-specific infrastructure for training labour can be understood as a consequence of limited biogas market expansion and the weak professional training system of the Brazilian NIS (Cassiolato, 2015; Mazzucato & Penna, 2016).

4.5 BLOCKING MECHANISMS AND INTERDEPENDENCE OF PROBLEMS FOR BIOGAS TECHNOLOGIES IN BRAZIL

The previous section indicated the interdependent nature of problems experienced in BBIS (see Table 5 for an overview of the problems), as demonstrated through heterogeneous manifestations of problematic factors across actors supported by sectoral and regional conditions and exogenous problems. To better comprehend this interdependence of problems, I explored the blocking mechanisms that hinder the system process of BBIS (as presented in Figure 23). Table 5 describes five blocking mechanisms.

Table 5—Systemic Problems and main layers for BBIS

Problem category	Problem origin		Specific problem	Impacts
Actors	Endogenous	1-	Few national suppliers of biogas technologies and services	High costs for project development
		2-	International companies struggle to do business in Brazil	High costs for project development
		3-	Substrate holders lack the necessary knowledge to identify opportunities and operate projects	Restricted demand for biogas technologies, high operational costs
		4-	Technical intermediary players lack knowledge in developing biogas projects	Restricted demand for biogas technologies and high costs for project development
		5-	Public bodies have little knowledge of biogas technologies	Deficient coordination and conflicting regulations and policies
	Exogenous	6-	The low innovative character of Brazilian firms	Conservative behaviour towards innovation
		7-	Public bodies have rigid organisational structures	Impediments to the absorption of new knowledge
Interactions	Endogenous	8-	Project-based interactions	Little engagement of different players and low development of learning mechanisms.
	Exogenous	9-	Low cooperation among Brazilian firms	Reinforces the little engagement of BBIS players
		10-	Lack of political coordination	Engenders divergent behaviour in BBIS, in particular among public sector players
Formal institutions	Endogenous	11-	Lack of regulations and norms	Permits low-efficiency projects -> undermines the trust in biogas technological solutions and hampers market development
		12-	Incompatible regulations	Hamper project development
		13-	Lack of national biogas agenda/policy	Political uncertainties and divergent behaviour
		14-	Implicit policy effects due to macroeconomic policies	Reduces resource availability and produces conservative behaviour towards innovation
Informal Institutions	Endogenous	15-	Different framing of biogas technologies by sectoral players	Divergent behaviours towards biogas technologies
		16-	Lack of trust in biogas technologies due to past project failures and few commercial units	Reproduces technological behaviour and culture of inefficient technology among decision-makers
	Exogenous	17-	Short-termism and rent-seeking behaviour of Brazilian investors	Conservative behaviour towards innovation
Infrastructures	Endogenous	18-	Misalignment of financial conditions between biogas investors and funding lines	Difficulties accessing funding
		19-	Weak infrastructures for biogas services	High costs for project operation
	Exogenous	20-	Weak infrastructure for professional and technical training	Lack of skilled labour -> high operational costs

The first mechanism presents only one primary activity (bm1 in Figure 20); it is caused by the lack of a national biogas agenda and blocks the necessary orientation of biogas activities, as manifested in the guidance of the search process. Players' visions and expectations play crucial roles in the development of an emerging technological field through the shaping of guidance of search processes (Bergek, Jacobsson, Carlsson, et al., 2008; M. P. Hekkert et al., 2007; van Lente & Rip, 1998; Yap & Truffer, 2018). This blockage is caused by players' limited ability to foresee future pathways for biogas technologies in Brazil (e.g. technology trajectories and future markets).

The difficulty mentioned above is accentuated for players who are not exclusively dedicated to biogas activities—i.e. potential technology users (e.g. players in agricultural and sanitation sectors) and policymakers of respective sectors. This issue was mentioned by entrepreneurs and intermediary players who described the complications of convincing players to invest in biogas projects. Another strong indication of this situation is the limited number of future studies and targets. Only a small group of studies (EPE studies) provide projections for the biogas market. Very few companies and public bodies have defined mostly modest targets (such as the ABC's targets for biogas in swine manure treatment).

The second blocking mechanism (bm2 in Figure 20) mainly derives from the misalignment of financial structures and the financial needs of biogas projects, which yields harsh conditions for biogas investors to access funding. The nonexistence of specific financial conditions for most project types—although there is a particular funding line of the ABC program[126]—is a good illustration of this issue. This mechanism presents two important contextual conditions[127]. One is the nonexistence of a national biogas agenda as a supporting condition of this misalignment. Another is the implicit macroeconomic effects that exacerbate the difficulty of accessing financial resources.

Put simply, without a clear national goal for biogas technologies; it is unlikely that we will see specific funding conditions for biogas projects. For instance, several specific funding conditions are attached to bioethanol and biodiesel, which have institutionalised policies. Likewise, unfavourable macroeconomic conditions and policies will likely restrict the availability of or worsen conditions for the allocation of financial resources, in particular for innovative activities. This issue is observable in the cut-offs in the national and state-level budgets, the revision of investment plans by several companies, the increase of interest rates, and the reduction of debt quotas for some funding lines of BNDES. Lastly, the theoretical assumption here is that adverse conditions for accessing financial resources block the resource allocation process, a consensus point in TIS studies (Karltorp, 2016; Karltorp et al., 2017).

The third blocking mechanism (bm2 in Figure 20) is grounded in the limited engagement of players for interactions. Due to the bias against biogas projects, actors interact in restricted circles,

[126] Low Carbon Agriculture plan.
[127] It is important to highlight that these contextual conditions refer to the blocking mechanism and not to the BBIS.

thereby leading to challenges in developing ties with other players and fugacious bonds that obstruct network structuration. Confirmatory evidence of this mechanism was found in both interviewees' responses and the existence of specific programs addressing this problem[128]. Moreover, this obstruction occurs in an environment of low cooperation among Brazilian firms; thus, private actors have insufficient incentive to interact and share resources. The lack of a biogas agenda also does not provide any incentive for other types of interactions. Evidence for these contextual influences was obtained from interviewees' comments on the challenges hindering information-sharing even within biogas associations and their reports on the difficulty of convincing actors outside the biogas field in the absence of clear future perspectives.

Consequently, few spaces for exchange are created, and actors struggle to find relevant information and resources. Here, the most pertinent information identified in the research were knowledge gaps (e.g., supply of equipment and adaptation of biogas production technologies) and the difficulty of defining business models and institutional arrangements (such as public procurement schemes). This finding supports the recent creation of initiatives to mitigate this problem (e.g. ANEEL's strategic R&D and BiogásFerti). This sequence of activities blocks resource allocation, knowledge production and diffusion processes. At this point, the conceptual assumptions are the need for knowledge recombination (see Arthur, 2009; Boschma et al., 2017) and the need for diverse networks for knowledge and resource allocation processes (Binz, Truffer, et al., 2016; Binz & Truffer, 2017).

[128] Examples include the increasing number of forum and congresses, the activities of Probiogás and biogas associations, and the creation of BiogasFerti.

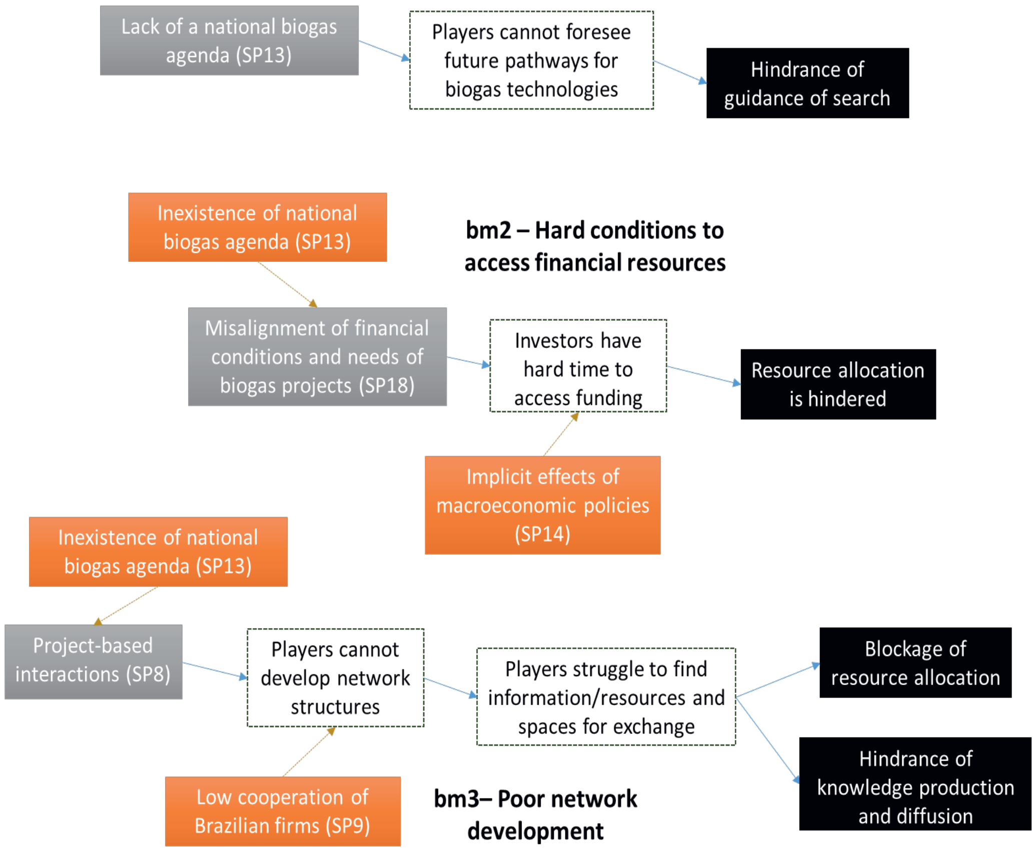


Figure 20 – The first three blocking mechanisms

The following three blocking mechanisms are highly interdependent in that they present common activities. First, the contradictory behaviour of actors (bm4 in Figure 21) is caused by variations in sectoral players' visions and expectations of biogas technologies. In turn, it directly hinders market creation and the creation of legitimacy and indirectly constrains entrepreneurial activities. Firstly, these distinct visions and expectations occur in an environment where players do not fully know biogas technologies and projects[129]. Then, the actors engaged in biogas experimentation are embedded in different sectors and have predetermined criteria for analysing biogas technologies. These diffuse criteria result in distinct framings of problems and solutions regarding biogas technologies. For instance, agricultural and sanitation players view biogas projects as important technologies to improve environmental treatment, whereas energy actors consider them just another renewable energy project. In addition, actors in an environment with no national agenda for biogas are not stimulated to align their distinct criteria and framings.

[129] Exposure to knowledge is an important factor for expectations (Brown & Michael, 2003; Budde et al., 2012).

These distinct framings are manifested in the contradictory behaviour of public bodies. Given the great number of bodies (national, state and municipal levels across different sectors), the design and implementation of policies and regulations are often divergent, which can engender contradictory stimuli among actors. The most emblematic contradictory action was the temporal mismatch between ANP's biomethane regulation[130], which counteracted Rio de Janeiro's biomethane policy. Moreover, the incongruent actions of public agencies are exacerbated by their rigid organisational structures and the lack of coordination between them. Most public bodies have legal obligations in terms of their scope and activities, which reinforces rigid organisational structures. Without clear coordination, compartmentalised actions derived from rigid structures are supported. Initiatives to improve knowledge absorption and interactions across public bodies (e.g., creating committees in states and the Probiogás within the ministry) represent essential evidence of these influences.

Such contradictory behaviour yields essential consequences. First, as exemplified by the case of Rio de Janeiro, state-level policies have been promoting the main market creation mechanisms[131]. This situation is aligned with literature on strategic niche management that highlights the relevance of policies in defining protected spaces for new technologies (Schot & Geels, 2008; Smith & Raven, 2012). Second, this behaviour leads actors in BBIS to perceive the environment of the biogas field as highly unsettled or complex, which is mainly apprehended through the increase in technological and political uncertainties (Meijer & Hekkert, 2010). Stakeholders expressed the possibility that biogas projects may not deliver what is promised during several events and the interviews. Such misalignment with fundamental incumbent values hinders the legitimacy of biogas technologies (Bergek, Jacobsson, & Sandén, 2008; Garud et al., 2014; Markard et al., 2016).

The fifth blocking mechanism demonstrates how entrepreneurs struggle from the beginning of project design, hindering their legitimation and entrepreneurial activities (bm5 in Figure 21). This mechanism is caused by the lack of knowledge of biogas projects and technologies among substrate holders and intermediary players such as engineering and consultancy companies. During the research, several events evinced the inability of these players to estimate biogas potential, select the most appropriate technologies, recognise the effective demand for biogas and design business models. This struggle, particularly the definition of business models, is intensified when players are in an environment populated by distinct sectoral framings of biogas technologies.

Moreover, the difficulties hindering the selection of project designs and business models first lead investors to decide not to invest in biogas projects, thereby hampering the fulfilment of entrepreneurial activities. This issue is displayed by the few projects developed each year and the few

[130] See section 1.4.3.
[131] This situation is also observed in other states, e.g. São Paulo, Ceará, and Rio Grande do Sul. For other biofuels such as bioethanol and biodiesel, policies are also responsible for the most important market creation mechanisms.

players who responded to important requests for proposals such as those associated with the national power project and the Sulgás' calls for biomethane projects. Second, it leads to the development of low-quality biogas projects, as observed in the small-scale projects in rural areas. The environment's lack of standards and regulations for the treatment of biomasses and biogas production continues to foster the reproduction of such projects. As discussed, these projects fail to deliver what was promised and feed into the perception of uncertain, complex, and uncompetitive technologies of biogas projects, which hinders the creation of legitimacy of biogas technologies.

For the last blocking mechanism, i.e. the costly search for knowledge (bm6 in Figure 21), the outcomes are also a hindrance to legitimation and entrepreneurial activities; however, the activities that foster the perception of the lack of competitiveness and high complexity of biogas projects are distinct in this case. This mechanism is caused by the small number of national biogas technologies and services suppliers. The low supply level is reinforced by important contextual forces, namely the environment of conservative behaviour towards innovations imposed by the low innovative character of firms, the short-termism and rent-seeking behaviour of Brazilian firms and investors and the nonexistence of a national biogas agenda that indicates future perspectives for these technologies. For service suppliers, this situation manifests in the low supply of biogas services (project O&M services) across Brazil. For instance, there are still important limitations to biogas services (e.g. valves and gas cleaners, which are simple equipment utilised in other industries but are hardly found in the adequate specification for biogas projects). Nevertheless, some actions led by important players have aimed to tackle this problem (e.g. the laboratory rounds of CIBiogás and Embrapa).

The main consequence of the low supply of services, technologies and equipment is the higher costs of biogas projects, which impact both initial investment and operation and maintenance. Extra costs arise from either the necessity of importing knowledge (biogas technologies or ancillary services and equipment) or the development of case-by-case solutions. Interviewees repeatedly highlighted the challenges of operating biogas projects and the low availability of skilled labour. The latter was also identified in the research of the biogas field (e.g. Probiogás studies) and is intensified by the weak infrastructure of professional training. Regarding importation, the high-cost environment is supported by negative macroeconomic conditions (e.g. exchange rates) and international companies' limited familiarity with Brazilian conditions for biogas projects/technologies and doing business. From this point onwards, this mechanism performs the same manner as the bm3. These two activities become more severe when incompatible regulations (e.g. the quality measurement requirements for biomethane.) are in place. Actors refrain from investing because of the difficulties and extra costs of hiring international expertise or developing basic capabilities. The issue of high costs was pointed out by almost every interviewee and the biogas surveys and studies.

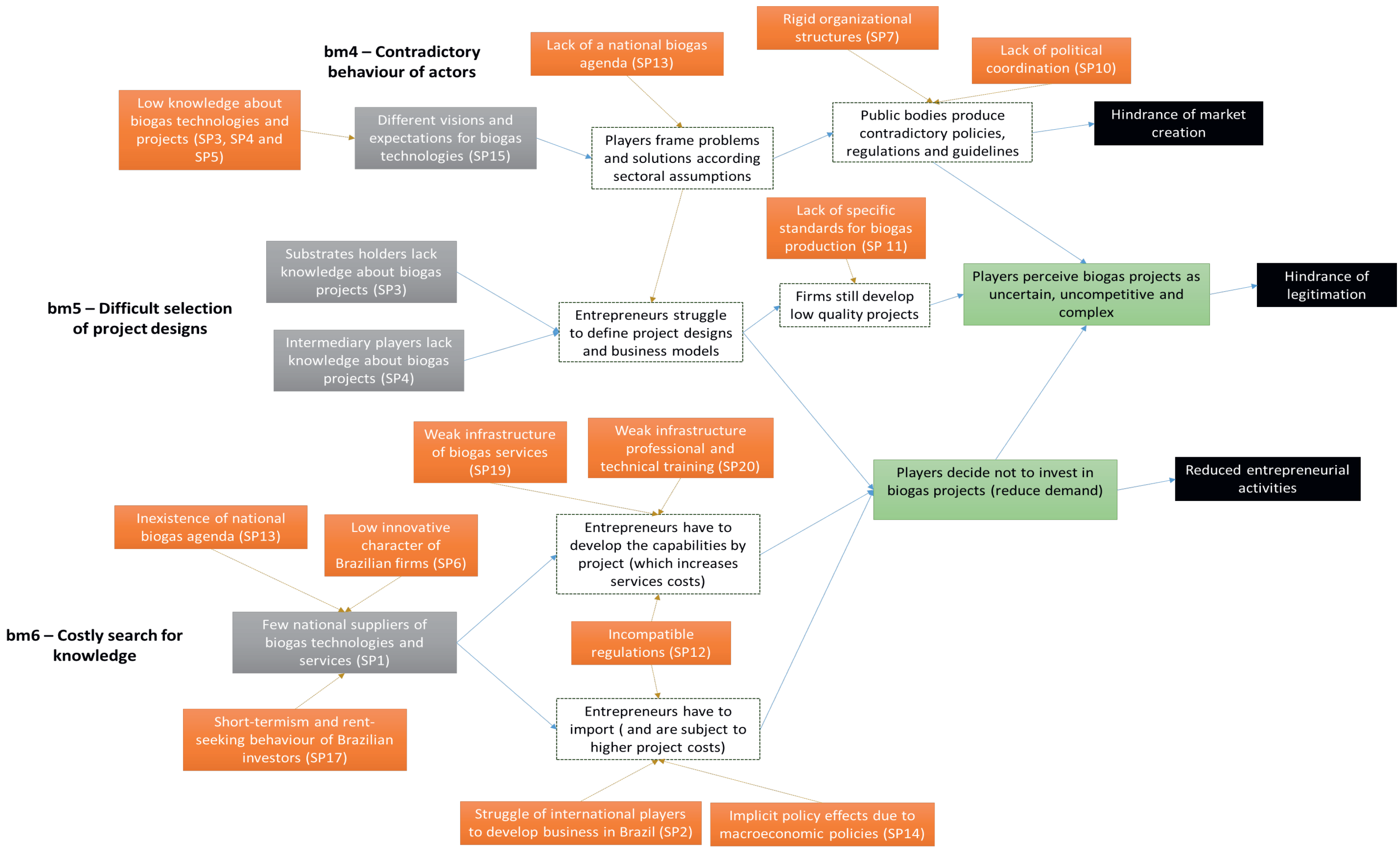


Figure 21 – The second three blocking mechanisms and their interrelationships

4.6 INTERDEPENDENCE OF PROBLEM AND IMPLICATIONS FOR INTERVENTIONS

Considering that blocking mechanisms represent how systemic problems manifest themselves to block system functioning, exploring them helps explain the interdependencies between systemic problems, which were manifested in multiple ways. For example, some problems are causes of blocking mechanisms, whereas others only exert contextual influences for these initial causes and/or for activities in blocking mechanisms. In other words, although some problems are not causes of activities, they influence the manifestation of other problems.

In the context of this research, the situation mentioned above was observed for both exogenous and endogenous systemic problems. Exogenous systemic problems engendered the negative environment for activities in different blocking mechanisms, which demonstrates how exogenous influences affect BBIS dynamics. For example, the problem of limited access to funding is intensified by the implicit effects of macroeconomic conditions (bm1)—i.e. if macroeconomic conditions worsen, as occurred in Brazil, the hindrance of resource allocation becomes more critical. The same happens in the case of high importation costs (bm5), which similarly exacerbated the initial causes, such as short-termism and rent-seeking behaviour due to the low availability of national players.

Similar exacerbating effects were also associated with endogenous systemic problems, although two problems did not cause any blocking mechanism. International players' lack of knowledge of Brazilian conditions intensified the activity of higher costs due to importation (bm6), and incompatible regulations engendered an environment of higher costs for biogas projects (bm6).

A second type of interdependence was evinced in common activities between three blocking mechanisms (bm3, bm4 and bm5). Through different pathways of activities, various actors' lack of knowledge, the limited number of national players and the distinct visions and expectations stimulated the perception of biogas projects as uncompetitive and complex, thereby hindering the legitimation and the entrepreneurial activities of biogas technologies in Brazil. In addition, activities in these blocking mechanisms provided the contextual conditions for activities in other blocking mechanisms, as observed in the divergent ways that distinct framings influenced the selection of business models and the decision not to invest, thereby intensifying the environment of uncertainty and lack of competitiveness in BBIS. In other words, these systemic problems are highly interdependent.

These findings provided a portfolio of problematic situations along with detailed descriptions of activities and interdependencies that open up possibilities for interventions. Actions may range from addressing specific biogas problems to interventions that target the contextual factors that intensify these problems and propositions for interventions extending beyond public policies. Different actors may lead these interventions depending on the activities or mechanisms. For instance, public bodies can devise interventions to mitigate divergent behaviours deriving from rigid organisational structures. To address stakeholders' inability to perceive future technological pathways, private actors could lead actions to create common visions.

4.7 CONCLUSIONS

This chapter aimed to conduct an in-depth investigation of systemic problems constraining biogas technologies in Brazil and interdependencies between these problems. Applying an adapted TIS framework, the analyses identified nineteen problems (Table 5), yielding six blocking mechanisms (Figure 20 and Figure 21). In general, the nonexistence of a national biogas agenda, the misalignment of funding conditions and financial requirements of biogas projects, the low level of knowledge about biogas among players in BBIS, the divergent frames on biogas technologies and the limited spectrum of interactions were the most relevant problematic factors. These problems respectively manifested themselves by hampering the envisioning of future pathways, creating an adverse environment for entrepreneurs to access financial resources, raising the cost of biogas projects and affecting the proper selection of projects' designs, producing divergent behaviours among actors impeding access to information and resources.

Although this study has enhanced the understanding of the problems of BBIS, the data also suggest other possible problems, namely the poor interaction between universities and industries, the role of informality, particularly for interactions, the complex governance of political systems and the need for aligning sectoral institutional frameworks. However, these problems were not included because they are somewhat covered by the problems that were discussed.

Additionally, a decrease in the relevance of some problems was observed over time. For instance, the lack of trust in biogas technologies, which was a strong legitimation problem in earlier decades, has now faded and acts as an intermediary activity in bm3, bm4 and bm5. This shift highlights the dynamic feature of the evolution of technological fields and the need to monitor the systemic problems and blocking mechanisms continually.

Finally, the identification of blocking mechanisms required an adaptation of methodology. The combination of event history analysis (see Negro et al., 2007; Suurs and Hekkert, 2009a) to investigate the dynamics of TIS and the theory-building variant of process-tracing (Derek Beach & Pedersen, 2013) to identify causal mechanisms was demonstrated to be a beneficial methodological strategy for our research problem. The former allowed us to build a thorough narrative around the main theoretical concepts, which was an important input for describing mechanisms (Derek Beach & Pedersen, 2013; Falleti, 2016). The latter enabled us to provide a detailed description of the specific activities that formed mechanisms.

CHAPTER 5 - INFORMING SYSTEMIC POLICY GOALS

- Discusses how TIS informs policy debates
- Expands the current TIS policy recommendations to include systemic, activity and contextual goals
- Understands systemic instruments as policy mixes
- Provides the structure to connect innovation analyses and policy debates

ABSTRACT

Current societal challenges pose different problems, such as the need to change energy systems, and new and emerging technologies or technological fields are often seen as having important roles in solutions. Stimulating and accelerating the development and diffusion of new technologies are common agendas for public policy debates, which are informed by various analytical frameworks. In the case of emerging technological fields, many scholars have applied the Technological System Innovation (TIS) framework. However, conceptual and analytical limitations of this approach have led to constraints in informing policy debates. This chapter advances this debate by demonstrating how a new TIS conceptualisation for hindering factors improves policy recommendations. I propose a conceptual framework that enables the identification and analysis of good policy mixes for the diffusion of emerging technologies and apply it to the case of biogas technologies in Brazil. This chapter demonstrates that TIS can inform systemic goals to mitigate systemic problems, activity goals to mitigate specific activities in blocking mechanisms and contextual goals to support or ameliorate the contextual influences of activities in blocking mechanisms. In the case of biogas in Brazil, the results reveal the need for a national agenda composed of five systemic goals, the necessity of coordinating these systemic goals, and how macro or external factors may counteract goals

KEYWORDS

TIS, policy recommendations, mechanism-based explanation, blocking mechanisms, policy mixes

5.1 INTRODUCTION

Current societal challenges (such as those addressed by the Sustainable Development Goals) pose various problems, such as the need to change energy systems. Emerging technologies or technological fields are often seen as having essential roles in solutions. For instance, new renewable energy technologies are regarded as crucial factors for improving the energy system and climate change issues (IPCC, 2014; IRENA, 2018). However, studies have pointed out that the current development speed of new technological fields and the direction of energy system changes are far from ideal (Victor et al., 2019). This situation suggests that market spaces are not enough and that public policies have a crucial role in governing these changes (Mazzucato, 2016).

Multiple disciplines have studied stimulating technological development and diffusion, and the results have yielded various policy rationales (Frenken, 2017; Laranja et al., 2008; Schot & Steinmueller, 2018). Among these rationales, the systemic failure rationale (Chaminade & Edquist, 2010) states that institutional settings, actors, and their relationships and interactions, as well as material conditions, beget problems other than the allocation issues commonly indicated by studies applying the market failure rationale and its policy recommendations (Arrow, 1962; Rosenbloom et al., 2020). Although the popularity of the systemic rationale is mainly based on the national innovation system framework (Frenken, 2017; Schot & Steinmueller, 2018; Sharif, 2006), other frameworks have also aimed to inform policymaking.

Specifically, in the case of emerging technological fields, scholars have applied the Technological System Innovation (TIS) framework, which focuses on explaining how configurations of system elements support or hamper the fulfilment of critical system-level processes (Bergek, Jacobsson, Carlsson, et al., 2008; M. P. Hekkert et al., 2007). Therefore, TIS studies can identify and analyse the systemic problems and blocking mechanisms that are considered to hinder the fulfilment of system processes. TIS studies aim to inform policy design (Bergek, Jacobsson, Carlsson, et al., 2008; Wieczorek & Hekkert, 2012). However, as demonstrated in Chapter 3, the hindering factor analysis has significant limitations. First, these limitations derive from the analytical limitations of TIS in examining contextual influences (external to the focal TIS). Second, they arise from conceptual limitations of systemic problems and blocking mechanisms in explaining the interdependence of these hindering factors.

Consequently, in Chapter 3, this thesis proposed a new conceptualisation and analytical framework for studying hindering factors in TIS. This new framework states that systemic problems are negative attributes of system elements and cause the blocking mechanisms that impede the fulfilment of one or more system processes. Hence, blocking mechanisms are the way that systemic problems manifest themselves. Moreover, blocking mechanisms are composed of one or more activities in which actors are engaged and are subjected to contextual influences, which can be internal or external to TIS, including other systemic problems and blocking mechanisms. The mechanism-based explanation of hindering factors discussed in previous chapters addresses these limitations and improves explanation in TIS.

Taking this proposition and acknowledging the analysis of hindering factors as the primary analytical step to inform policy, it is necessary to explore the impact of this proposition on recommending policy from TIS studies. That is the primary goal of this chapter, which seeks to answer the question *How do TIS studies inform policymaking based on a mechanism-based explanation of blocking mechanisms for biogas technologies in Brazil?* Understanding that policy issues and goals are the main outcomes of TIS analysis when informing policymaking, in this chapter, we propose a conceptual framework based on technological innovation systems that allow for the identification and analysis of good policy mixes for the diffusion of emerging technologies. This chapter borrows from policy mix literature and expounds that policy goals are part of policy mixes and interact among themselves (Michael Howlett & Rayner, 2013; Rogge et al., 2017).

This chapter explores policy issues and goals that a mechanism-based analysis can inform of hindering factors. The Brazilian Biogas Innovation System (BBIS) case is used to illustrate this proposition. Bringing insights from the literature on policy design and policy mixes into TIS studies sheds light on the relevant policy issues and goals and their primary interactions. Therefore, TIS scholars can draw a space of policy goals from their analyses and explore how these goals interact with the current policyscape in which they are informed.

5.2 INFORMING POLICY WITH TIS ANALYSIS

This section presents the conceptual background and development of the potential to use TIS to inform policy. Hence, it begins with the discussion of how TIS literature, which covers two main analytical frameworks (Bergek, Jacobsson, Carlsson, et al., 2008; Wieczorek & Hekkert, 2012), proposes policy recommendations based on analyses of systemic problems or blocking/inducement mechanisms. Next, it expands the TIS policy rationale, borrowing from the conceptual development in this thesis, particularly Chapter 3, and discusses how a mechanism-based understanding of hindering factors affects the propositions of policy recommendations using the TIS framework. Then, based on the mechanism-based policy rationale of TIS, the third sub-section explains how systemic instruments must be understood as policy mixes rather than single policy instruments. These discussions form the basis for the proposition of a framework to inform policy recommendations using TIS in the final part of this section.

5.2.1 Technological Innovation Systems – Main concepts, policy recommendations and policy rationale

The TIS framework was conceptualised among the development of other systemic theories (e.g. Markard and Truffer, 2008; Weber and Truffer, 2017) with a focus on particular technologies or technological fields (Bergek, Jacobsson, Carlsson, et al., 2008; Sandén & Hillman, 2011). TIS studies examine how specific configurations of system elements (actors, interactions, institutions and infrastructures) fulfil system-level processes (entrepreneurial activities, knowledge production and exchange, the guidance of search, market creation, resource allocation and creation of legitimacy; Bergek et al., 2008a; Hekkert et al., 2007).

This structural-functional analysis indicates which types of system configurations and patterns of system processes are more likely to induce the development and diffusion of a particular technology or technological field—i.e. emerging sociotechnical configuration. In addition, by systemically examining structural and functional conditions, TIS analysts can identify hindering factors to the system structuration, which refers to developing the different configurations of TIS elements. TIS identifies two main concepts for these hindering factors: systemic problems and blocking mechanisms (Bergek, Jacobsson, Carlsson, et al., 2008; Wieczorek & Hekkert, 2012). In addition, the absence of inducement mechanisms is also taken into consideration as an essential element (Bergek, Jacobsson, Carlsson, et al., 2008). These hindering factors are also the main concepts to inform policy recommendations (Bergek, Jacobsson, Carlsson, et al., 2008; Wieczorek & Hekkert, 2012).

- **Policy rationale based on systemic problems**

Systemic problems are understood as negative attributes of system elements that hinder the adequate fulfilment of system processes. Hence, the rationale is that interventions must tackle these problems. In this framework, proposing interventions is to inform the goals of systemic instruments (Wieczorek & Hekkert, 2012). These goals are prescriptive, i.e. they represent 'what the instruments should do to create the circumstances under which the innovation system functions have the highest chances of occurring' (Wieczorek and Hekkert, 2012:83). These goals are also attributed to system elements (Table 6), and they try to influence policy discussions informing the determination of the desired (structural) solutions to mitigate systemic problems. Therefore, it is expected that matching the goals of systemic instruments to the identified systemic problems guides the selection of policy instruments (Wieczorek & Hekkert, 2012).

Table 6 – TIS framework to inform policymaking in Wieczorek and Hekkert (2012)[132]

System function	Structural element	Systemic problem	(Type of) systemic problem	Systemic instrument goals
F1: entrepreneurial activities	Actors	Actors problems	Presence?	Stimulate and organise the participation of relevant actors (1)
			Capabilities?	Create space for actors capability development (2)
	Interactions	Interaction problems	Presence?	Stimulate occurrence of interactions (3)
			Capacity?	Prevent too strong and too weak ties (4)
	Institutions	Institutional problems	Presence?	Secure presence of hard and soft institutions (5)
			Intensity?	Prevent too weak and too stringent institutions (6)
	Infrastructure	Infrastructural problems	Presence?	Stimulate physical, financial and knowledge infrastructure (7)
			Quality?	Ensure adequate quality of infrastructure (8)
F2: knowledge development etc.	Actors	Actors problems	Presence?	Stimulate and organise participation of relevant actors (1)
			Capabilities?	Create space for actors capability development (2)
	Interactions	Interaction problems	Presence?	Stimulate occurrence of interactions (3)
			Intensity?	Prevent too strong and too weak ties (4)
	Institutions	Institutional problems	Presence?	Secure presence of hard and soft institutions (5)
			Capacity?	Prevent too weak and too stringent institutions (6)
	Infrastructure	Infrastructural problems	Presence?	Stimulate physical, financial and knowledge infrastructure (7)
			Quality?	Ensure adequate quality of infrastructure (8)

The reasoning here is that structural elements make system processes 'meaningful' by situating the processes to specific elements (Wieczorek and Hekkert, 2012:78). Distinct interactions and configurations of system elements fulfil system-level processes in different fashions. Put differently, it is the configuration of system elements that leads to the fulfilment of system processes.

- **Policy rationale based on blocking mechanisms**

The above-described comprehension is also present in the inducement and blocking mechanisms framework[133] of Bergek et al. (2008a). Nevertheless, the authors still state that 'it is difficult, if not impossible, to evaluate the "goodness" or "badness" of a particular structural element or combination of elements without referring to its effects on the innovation process' (Bergek et al., 2008a:409). However, (2008a) go beyond defining goals for system elements and emphasise that it is necessary to evaluate the 'goodness' of system elements and their configurations and the 'goodness' of functional patterns.

This perspective slightly alters the rationale based on blocking mechanisms. For this framework, blocking (and inducement) mechanisms are identified following the definition of the so-called process goals, which represent desired/targeted functional patterns (Bergek, Jacobsson, Carlsson, et al., 2008). The reasoning is that structural-functional analysis only elucidates configurations of system structures

[132] An earlier list of goals was proposed by Smits and Kuhlmann (2004).
[133] The framework discusses blocking and inducement mechanisms; however, this thesis only focused on blocking mechanisms. Hence, the ongoing discussion will only refer to blocking mechanisms.

and functional patterns without stating 'how good' they are. After defining these process goals, analysts can identify and describe blocking (and inducement) mechanisms[134]. This description is expected to explain how mechanisms hinder (or support) the existing functional pattern to achieve a desired/targeted functional pattern. Thus, mitigating blocking or stimulating inducement mechanisms of a focal TIS become the main policy issues (Bergek, Jacobsson, Carlsson, et al., 2008). In other words, in this framework, policy issues aim to influence policy discussions by identifying the problems that public agendas must address.

Although these two frameworks have differences, they also share common assumptions to inform policymaking. First, both frameworks consider that emerging sociotechnical configurations require system structuration[135], achieved through distinct configurations of system elements that fulfil system processes under specific contexts. A second implicit assumption is a desired/targeted direction for these system configurations and functional patterns. Third, hindering factors impede the system's structuration towards the targeted direction. Wieczorek and Hekkert (2012) discuss these factors in terms of systemic problems. In contrast, Bergek et al. (2008a) refer to system weaknesses, denoting the presence of blocking mechanisms or the absence of inducement mechanisms.

These concepts, analytical processes and assumptions lead to a rationale for informing interventions: the systemic failure policy rationale, which claims that mitigating hindering factors improves the likelihood of creating better conditions for system structuration and, consequently, the emergence of new socio-technical configurations.

5.2.2 Policy rationale from a mechanism-based explanation of hindering factors

Although TIS studies have provided important insights for understanding the dynamics of emerging socio-technical configurations, important criticisms highlight the conceptual and analytical limitations of TIS frameworks. First, although TIS conceptual frameworks consider the influence of contextual (external to TIS) influences (Bergek, Jacobsson, Carlsson, et al., 2008; M. P. Hekkert et al., 2007; Markard & Truffer, 2008), analytical frameworks do not explain how to analyse them, thereby resulting in case-by-case empirical analyses of contextual influences. TIS scholars have acknowledged this limitation and proposed four main contextual structures to investigate, namely geographical, sectoral,

[134] Process goals are supposed to be specific according to the phase of development and context in which the focal TIS is embedded, being their definition not trivial. The authors suggest (Bergek et al., 2008a:420) to draw "tentative conclusions" from comparisons of similar TISs across different regions. Authors are not clear about what types of similarities, but it seems that similarity refers to technological aspects. However, they are clear on the fact that it has to be at the same phase of development.

[135] Here, it is important to say that this assumption derives from different studies that demonstrated the relevance of both actors and system conditions for technological development (e.g. Arthur, 1989; Dosi, 1982; Garud et al., 1997; Garud and Karnøe, 2003; Leydesdorff, 2000; Perez and Soete, 1988; Pinch and Bijker, 1984; Poole et al., 2000; Rip and Kemp, 1998; Unruh, 2000).

other TIS and political structures (Bergek et al., 2015). However, there are no straightforward suggestions on incorporating these structures in analytical frameworks.

Second, TIS studies lack explanations of interdependent hindering factors. Empirical studies emphasise the role of interdependencies of systemic problems and blocking mechanisms (Kieft et al., 2016; Kriechbaum et al., 2018; Negro et al., 2012; Patana et al., 2013). However, the conceptualisation of systemic problems and blocking mechanisms by the two main analytical frameworks developed by Bergek et al. (2008a) and Wieczorek and Hekkert (2012) do not elucidate possible interdependencies. Instead, interactions and interdependencies are merely regarded as system processes (Bergek, Jacobsson, Carlsson, et al., 2008; M. P. Hekkert et al., 2007; Suurs & Hekkert, 2009b). Due to this lack of conceptual development, some empirical studies have used blocking mechanisms and systemic problems as interchangeable concepts.

These analytical and conceptual weaknesses[136] are carried through in analyses and reflected in how policy issues or goals of systemic instruments are discussed. For example, the goals of systemic instruments proposed by Wieczorek and Hekkert (2012) are generic goals aiming at specific system structures. In contrast, the policy issues elaborated by Bergek et al. (2008a) are essentially the promotion or mitigation of inducement or blocking mechanisms. Moreover, these goals and issues do not consistently discuss the role of contextual influences and neglect the interdependence of hindering factors.

This thesis takes a mechanism-based approach to mitigate the above-mentioned limitations and proposes a new way to discuss interventions' goals and issues. Mechanism-based explanations (MBE) assert that mechanisms connect initial causes and outcomes, a sequence of activities performed by actors in specific contexts (D. Beach & Pedersen, 2016a; Biesbroek et al., 2017). Hence, it is understood that actors fulfil systems-level processes by activities performed by actors under specific contexts.

Actors are part of the innovation systems and the activities they perform, and contexts are enabled and constrained by the other system elements (institutions, interactions, and infrastructures) and contexts external to the TIS. Thus, understanding technologies as a bundle of value chains (see Sandén and Hillman, 2011) enables the systematic examination of contextual influences (De Oliveira & Negro, 2019)[137].

The mechanism-based explanation has led to a new conceptualisation of hindering factors in TIS[138] that enables the examination of their interdependence and contextual influences. In this framework, systemic problems are negative attributes of system elements, similar to the understanding

[136] These can also be understood as consequences of these frameworks being developed by academics in close contact with policy arenas.
[137] Also see Chapter 2.
[138] See Chapter 3 for a detailed discussion.

of Wieczorek and Hekkert (2012); however, elements can be structural couplings (Bergek et al., 2015; Sandén & Hillman, 2011), thereby accounting for exogenous influences as suggested by Kieft et al. (2016). Furthermore, one or more systemic problems are responsible for engendering the blocking mechanisms that hinder the fulfilment of system processes. Hence, blocking mechanisms are comprehended as mechanisms in MBE, thereby representing a causal pathway between systemic problems and the hindrance of system processes.

Another important aspect of this conceptualisation is that blocking mechanisms are composed of actors engaged in a sequence of activities under contextual influences. It is precisely this sequence of activities that conveys the causal force between systemic problems and hindrance of system processes. Moreover, the contexts wherein blocking mechanisms operate influence these activities by enabling or constraining them (Falleti & Lynch, 2009)[139]. As blocking mechanisms operate within a TIS, their contextual conditions can comprise influences external or internal to the focal TIS. For instance, a macro event such as an international crisis may affect an activity in a blocking mechanism; however, other systemic problems that are not the initial cause can also affect different blocking mechanisms. Figure 22 illustrates this new conceptualisation of TIS hindering factors (De Oliveira et al., 2020).

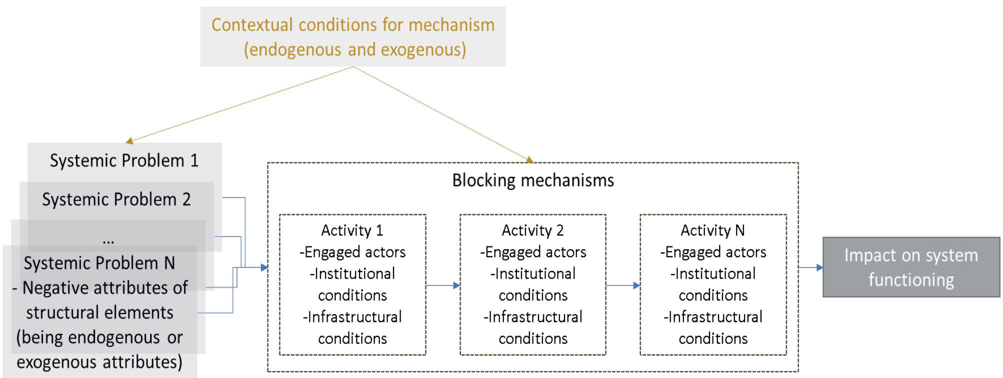


Figure 22 – explanation for system-level problematic factor by applying MBE

This new conceptualisation addresses the limitations mentioned above. First, it provides conceptual clarity and harmonises the two main TIS analytical frameworks, thereby untangling the empirical confusion of these concepts, as discussed in Chapter 3. Second, the role of external influences on the focal TIS on hindering factors can be investigated as systemic problems or as contexts of blocking mechanisms. Third, interdependencies of hindering factors may result from systemic problems

[139] Contexts do not convey causal forces but rather establish the conditions in which they operate. A common example is the combustion engine, in which the fuel is the cause, the engine is the mechanism and the mechanical power the outcome. The context is the presence of oxygen.

performing the contexts of blocking mechanisms, both from common activities among distinct blocking mechanisms and interactions between activities.

The mechanism-based approach also leads to another type of information produced and used for discussing policy issues and goals due to a more explicit explanation of how micro and meso (actors and systems) levels interact. By investigating how actors' activities fulfil system processes, TIS analysts can expand beyond the discussion of how system elements or system processes are adequate (or not) to a particular phase of development or prescriptive goals. TIS analysts can explain how a portfolio of actors' activities—under contextual influences—hinder system-level processes and consequent system structuration. This ability broadens the possibilities for informing interventions, which are not only supposed to mitigate systemic problems or blocking mechanisms but also can promote inducement mechanisms. Interventions may also target contextual conditions or specific activities in blocking mechanisms.

Thus, TIS analysts have a broader space of problems to inform interventions. However, these interventions still aim to promote system structuration—i.e. to promote conditions in which the set of system elements and the system processes are more likely to lead to higher development and diffusion of technological innovation. In other words, this mechanism-based approach also comprehends the systemic failure policy rationale. However, because it explains how actors' activities fulfil system processes, it makes explicit the connections between systemic conditions with other policy rationales which are often merely suggested (Schot & Steinmueller, 2018; Woolthuis et al., 2005).

Put simply, policy recommendations need not always target systemic goals but can also target more 'limited' goals as part of a systemic strategy or as a consequence of the policymaking environment (Michael Howlett & Rayner, 2017). For instance, a common market failure policy recommendation is to stimulate R&D investments through distinct instruments. The mechanism-based framework provides a means to elucidate how these stimuli are aligned with and inserted into broader systemic goals.

5.2.3 Understanding systemic instruments as policy mixes

Problematic factors in traditional TIS analysis are understood as systemic problems or blocking mechanisms. In the mechanism-based approach of TIS developed in this thesis, these problematic elements are called *hindering factors*, which comprise a causal relationship between systemic problems, blocking mechanisms (with all activities) and contextual influences. Hindering factors entail a more diverse portfolio of problems that may lead to conflicting policy goals or issues. As TIS analyses have to explain how different policy goals and issues can guide the selection of policy instruments, the mechanism-based approach reinforces the focus on understanding systemic instruments as 'an integrated coherent set of tools designed for a specific innovation system' (Wieczorek and Hekkert, 2012:86). Moreover, once it is possible to understand systemic instruments as a coherent set of policies to stimulate an innovation system we can also explore systemic instruments as policy mixes (Borrás & Edquist, 2013; Rogge et al., 2017).

Policy mixes are complex governance arrangements composed of policy goals and instruments (Howlett and Rayner, 2007; Kern and Howlett, 2009). Following this definition, policy mixes have two main elements: policy goals and policy instruments[140]. Hence, the combination of policy goals and instruments defines the type of a policy mix (Michael Howlett & Del Rio, 2015). According to Howlett and Del Rio (2015), systemic instruments that aim at a single policy can be understood as instruments mixes. In contrast, policy mixes comprise multiple policies.

When a mechanism-based TIS analysis yields a portfolio of hindering factors, it is more likely that these factors can be tackled by different sets of policy goals and instruments. Moreover, suppose the focal technology or technological field cuts across or is influenced by several policy fields or sectors. In that case, policy interventions can likely occur across these fields and sectors. Technological Innovation Systems are specific types of socio-technical systems which are necessarily influenced by several policy fields (Frank W Geels et al., 2017). Thus, if systemic instruments represent a coherent set of tools, then these tools relate to several policy goals. This understanding facilitates a broader understanding of systemic instruments as policy mixes whereby systemic instruments comprise several goals to guide the selection of instruments that are oriented according to the structural-functional characteristics.

Another critical point is that policy mixes' goals, and instruments can extend across different levels, ranging from more abstract (strategic) to more concrete (operational) levels (Michael Howlett & Rayner, 2013). About goals, there are overall goals, which are ideas that govern policy development (e.g. energy security), objectives, which aim at solving specific problems (e.g. reducing oil importation), and settings, which specify the operationalisation of policies (e.g. reducing diesel oil importation for five years). About instruments, instrument logics state the preferences for certain types of instruments (e.g. economic or coercive), mechanisms represent the specific types of instruments (e.g. taxes or subsides), and calibrations refer to the way instruments are applied (e.g. increasing tax in 1% for imported diesel oil).

Finally, the characteristics of policy mixes result from the interactions between their elements, which can occur across distinct dimensions (Rogge & Reichardt, 2016). The first dimension refers to interactions within the same level, e.g., between goals and instruments' logic. The second dimension refers to interactions across distinct levels, e.g., between goals and objectives or mechanisms and

[140] Instruments can be defined as the means and techniques by which goals are achieved (M Howlett, 2011).

calibrations. Although there are distinct accounts of defining these characteristics (Rogge et al., 2017), it is possible to identify consistency, coherence and congruence as primary characteristics (Howlett and Rayner, 2013:174). Consistency refers to 'the ability of multiple policy tools to reinforce rather than undermine each other in pursuing policy goals'. Coherence refers to 'the ability of multiple policy goals to co-exist and with instrument norms in a logical fashion was developed'. Finally, congruence refers to 'the ability of goals and instruments to work together in a uni-directional or mutually supportive fashion' (idem). Table 7 summarises these elements and interactions.

Table 7 – Policy mix elements and possible interactions (adapted from Howlett and Rayner (2013))

	High/strategic level	Programme / operational level	On-the-ground level	Possible interactions
Policy goals	Goals	Objectives	Settings	Same-level interactions (e.g. interactions between different goals and interactions between objectives and instruments)
Policy Instruments	Instrument logic	Instruments*	Calibrations	Interactions across distinct levels (e.g. interactions between goals and objectives and interactions between instruments and calibrations)

*Howlett and Rayner (2013) use the term 'mechanism'. I have retained the word 'instrument' to avoid confusion with the MBE.

What does this discussion on policy mix elements and characteristics say about systemic instruments? It indicates that if TIS analysis wants to inform a coherent set of instruments (i.e. systemic instruments), then the analysis of hindering factors should be explicit in terms of what types of goals can be informed, how the goals relate to each other and to what level they relate. These aspects enable analysts to explore how multiple proposed goals may or may not be conflicting, as well as inform possible conflicting points between the proposed goals and the established policy mixes. These capabilities are particularly salient for mechanism-based analyses of hindering factors, which discuss problems and can provide a portfolio of goals at distinct levels (system and actor).

5.2.4 Informing policy from a mechanism-based explanation of TIS hindering factors

Considering that the mechanism-based explanation of TIS hindering factors leads to a broader space of problems and to understanding systemic instruments as policy mixes, it is necessary to discuss the levels and characteristics of these goals and instruments. This section initiates the discussion by providing the rationale and focusing on the possibilities and limitations of informing goals based on the MBE of hindering factors.

5.2.4.1 Systemic, activity and contextual policy issues and goals

Using the TIS framework to inform policymaking enables an understanding of the framework's policy design perspective. According to Peters (2015:17–18), a policy design perspective comprises causation between problems and solutions, requires a strategic model for implementation and is the consequence of interactions of several policies and players. This is exactly what is developed by a structural-functional analysis, a mechanism-based analysis of hindering factors and their consequent policy recommendations.

Moreover, it is critical to comprehend the space of problems addressed by TIS studies. As Peters (2005:351) stated, '[t]he intention of producing desired programmatic results through well-chosen instruments might be unfulfilled if there is no appropriate linkage with the problems being addressed'. However, these problems are not analytical problems but rather policy problems. Analytical problems result from particular analytical frameworks to comprehend a specific social phenomenon—such as the TIS framework's attempt to explain the emergence of new socio-technical configurations. In contrast, a policy problem is 'a perceived deviation of an existing state ("is") from a desirable one ("ought")' (Hoppe, 2017:5) by policymakers or proximate to policymakers[141].

For TIS studies, the difference between analytical and policy problems can be understood by what Bergek et al. (2008a) call policy issues. Policy issues attempt to influence the definition of the problem spaces considered by policymakers and proximate to them. As the mechanism-based analysis of hindering factors broadens the space of analytical problems, it is necessary to understand how it affects the possible policy issues. Additionally, policy goals are strictly interrelated to policy issues. Whereas policy issues represent the space of problems, policy goals represent the space of desired/targeted states for system structuration. Therefore, it is also necessary to discuss the types of goals related to these issues.

The main policy issues in TIS studies derive from the mitigation of systemic problems or the promotion of inducement mechanisms and the mitigation of blocking mechanisms (Bergek, Jacobsson, Carlsson, et al., 2008; Wieczorek & Hekkert, 2012). The TIS literature presents goals as pre-defined and attributed to structural elements (see Wieczorek and Hekkert, 2012) or as being defined case-by-case and attributed to system processes (Bergek, Jacobsson, Carlsson, et al., 2008). However, empirical studies do not always clearly present these issues and goals due to the lack of conceptualisation of systemic problems and blocking mechanisms and their dubiously empirical use.

[141] Several societal situations are perceived as problematic; however, only some of them gain the attention of policymakers and are addressed in policy agendas (Herweg et al., 2015; Kingdon, 2014). Analytical problems attract the attention of policymakers due to different aspects such as changes in specific indicators, important events or feedback effects of policies (Herweg et al., 2017). This state of affairs can also be explained by the engagement of specific actors—i.e. problem brokers—in framing problems according to particular conditions of the policymaking process (Knaggård, 2015).

The harmonisation of concepts and the broadening of the portfolio of interventions provided by the mechanism-based analysis of hindering factors enables the identification of more specific policy issues and goals.

- *The first and foremost policy issue still derives from mitigating systemic problems*.

Policy issues can be understood as analytical problems at the system level. In other words, they represent the need for adequate structural conditions of TIS that are the initial causes of distinct activities of system hindrance. This perspective is similar to that of Wieczorek and Hekkert (2012). This first policy issue leads to the first type of goals: ***systemic goals that aim at improving the conditions for system structuration, which are a consequence of both structural conditions and functional patterns***.

As systemic problems are the initial causes of a sequence of activities that hinder system functioning, systemic goals have to address the entire causal relationship. Therefore, goals cannot only address targeted structural conditions, as proposed by Wieczorek and Hekkert (2012); instead, they have to indicate the relationship between those conditions and the functional pattern. In other words, it does not suffice to establish goals for structures if it is not discussed how they impact system functioning, and it is not sufficient to establish goals for patterns of system processes without stating the conditions that system structures fulfil.

An illustration can be derived from the goals presented in Table 6 in Section 5.2.1. If the goal is to stimulate the occurrence of interactions, then it is possible to understand that the problem being addressed is the inexistence or the low occurrence of interactions. However, nothing is said about why more interactions are needed for a particular TIS; it could be to stimulate knowledge exchange, the guidance of search or legitimacy. Another example is drawn from the process goal of 'widen[ing] the range of experiments' (Bergek et al., 2008a:420). It is possible to see the connection with the lack of fulfilment of the entrepreneurial activity process; however, nothing is conveyed about the necessary types of actors, institutions or infrastructures.

- *The second policy issue refers to the mitigation of blocking mechanisms, specifically the mitigation of the specific activities comprising blocking mechanisms.*

In this case, policy issues represent analytical problems at the actor level that support problems at the system level. In other words, they indicate which specific actors' activities influence structural conditions. Therefore, these policy issues must inform specific activities and the respective actors engaged in them. The consequences of these policy issues are ***activity goals, which aim at creating conditions at the actor level to support the systemic goal***.

The difference between systemic and activity goals lies in the level of the issue and the detail of its description. This understanding equates to that of goals and objectives in policy mixes (Michael Howlett & Cashore, 2009; Michael Howlett & Rayner, 2013). For instance, several activities and actors can be engaged to achieve the systemic goal of stimulating interactions to promote knowledge exchange. For example, universities, research centres, companies and public bodies may engage in activities such as research or commercial projects or leverage industry associations to share information on technologies, equipment or business models.

- *The third policy issue refers to the mitigation or promotion of contextual conditions that reinforce or hamper systemic problems or activities in blocking mechanisms.*

Here, policy issues represent how contexts influence systemic conditions or actors' activities. This policy issue yields ***contextual goals, which aim to provide the contextual conditions to support the achievement of systemic and activity goals.*** For instance, systemic goals may concentrate on stimulating interactions to promote knowledge exchange. On the other hand, activity goals may focus on improving university-industry interactions through applied research projects. In this scenario, contextual goals might aim at improving funding conditions or access to necessary equipment.

By engaging with the three types mentioned above of policy issues and goals (see Table 8), TIS analysts can inform and support the framing of policy problems that aim at system structuration and the development of an emerging sociotechnical configuration. Moreover, discussions of systemic and activity goals may guide the selection of instrument logic and specific types of instruments—mechanisms in Howlett and Rayner (2013).

Table 8 – Types of policy issues and goals for a mechanism-based analysis of TIS hindering factors

Policy issues	Goals	Description of the goals
Mitigate systemic problems	Systemic goals	Aim at system structuration by elucidating the relationship between targeted structural conditions and functional fulfilment
Mitigate blocking mechanisms (all or specific activities)	Activity goals	Aim at creating the conditions to support system structuration at the actor level by identifying the targeted activities and respective actors engaged in them
Mitigate or promote contextual influences	Contextual goals	Aim at providing the contextual conditions to support the achievement of systemic and activity goals

5.2.4.2 Coherence of systemic, activity and contextual goals

Informing policy goals at different levels highlights the need to understand how coherent these goals are. Coherence can be understood as the mutual reinforcement and/or alignment of goals (Michael Howlett & Rayner, 2013; Kern & Howlett, 2009). Coherence or incoherence can occur among goals at different levels– i.e. among systemic activity and contextual goals. However, coherence is only meaningful if the influence of goals is analysed through concrete activities and actors. Put simply, it is the effects of goals on actors' activities that indicate the criteria to evaluate coherence.

From a mechanism-based perspective of hindering factors, goals are expected to influence particular activities and actors under specific contexts responsible for system structures and processes. In other words, it is the relationship of goals with actors and activities that indicates whether goals are aligned or reinforce each other. To illustrate, if the systemic goals are (i) to secure the quality of financial structures for increasing resource allocation and (ii) to secure the presence of regulations to guarantee new projects access to energy grids, what indicates the alignment of (i) and (ii) is how the actors engage in the activities of accessing financial resources and developing projects. For instance, alignment for this example can be analysed through how these goals facilitate project development.

At this point, a question arises: What are the analytical steps in charge of evaluating coherence? First, systemic goals are intrinsically coherent with each other when hindering factors do not present interdependencies. As they are outcomes of structural-functional analysis, they are proposed based on the assumption that certain structural conditions are more likely to lead to the fulfilment of system processes for a specific context and phase of development. Therefore, the structural-functional analysis is the analytical step to evaluate the coherence of systemic goals.

Similarly, systemic and activity goals derived from the same blocking mechanism are also intrinsically coherent because they are engaged in the same causal relationship. The mechanism-based analysis of hindering factors informs how system structures lead to specific actors' activities that hinder the fulfilment of system processes. Therefore, goals that aim to mitigate activities in blocking mechanisms support the systemic goal of mitigating the systemic problem. The same is valid for the coherence of systemic or activity goals and contextual goals, which comprise the same blocking mechanism.

However, when hindering factors are interdependent, the description of those interdependencies indicates the possibilities for incoherence among goals. From the types of interdependencies of hindering factors presented in Table 4, it is possible to draw possible sources of incoherence. On the one hand, incoherence among systemic goals and among systemic and activity goals may occur when there is direct and indirect interdependence of systemic problems. On the other hand, incoherence among activity goals may occur when blocking mechanisms have direct interdependence. Lastly, incoherence among contextual goals results from the specific external conditions to be investigated. Table 9 summarises these possibilities.

Table 9 – Interdependencies of systemic problems and blocking mechanisms

Conceptual explanation	Direct interdependence of systemic problems	Direct interdependence of blocking mechanisms	Indirect interdependence of systemic problems
Systemic problems as contextual conditions of other systemic problems	Possible incoherence among systemic goals	X	X
Different systemic problems cause the same activity	Possible incoherence among systemic and activity goals	X	X
Different systemic problems cause different activities in one blocking mechanism	X	X	Possible incoherence among systemic goals
Systemic problems as contextual conditions for activities in a blocking mechanism	X	X	Possible incoherence among systemic and activity goals
The same activities across different blocking mechanisms	X	Possible incoherence among activity goals and among systemic and activity goals	
Interaction of activities of different blocking mechanisms	X	Possible incoherence among activity goals	

5.3 POLICY GOALS FOR STRUCTURING THE BRAZILIAN BIOGAS INNOVATION SYSTEM

As demonstrated in Chapter 4, six main blocking mechanisms hinder the development of the biogas field in Brazil. Although the analysis has identified twenty systemic problems, these blocking mechanisms are mainly a result of seven systemic problems (see Figure 23). This is a consequence of the mechanism-based analysis developed herein, in which the interdependence of problems indicates that only seven problems are the leading causes of system malfunctioning. In contrast, the other problems are either consequences of these seven or represent contextual influences for how these seven problems have manifested themselves. Applying the framework for policy goals to the blocking mechanisms described in the previous chapter (Figure 23), it was possible to identify five main systemic goals, eight activity goals and eleven contextual goals for the BBIS (Table).

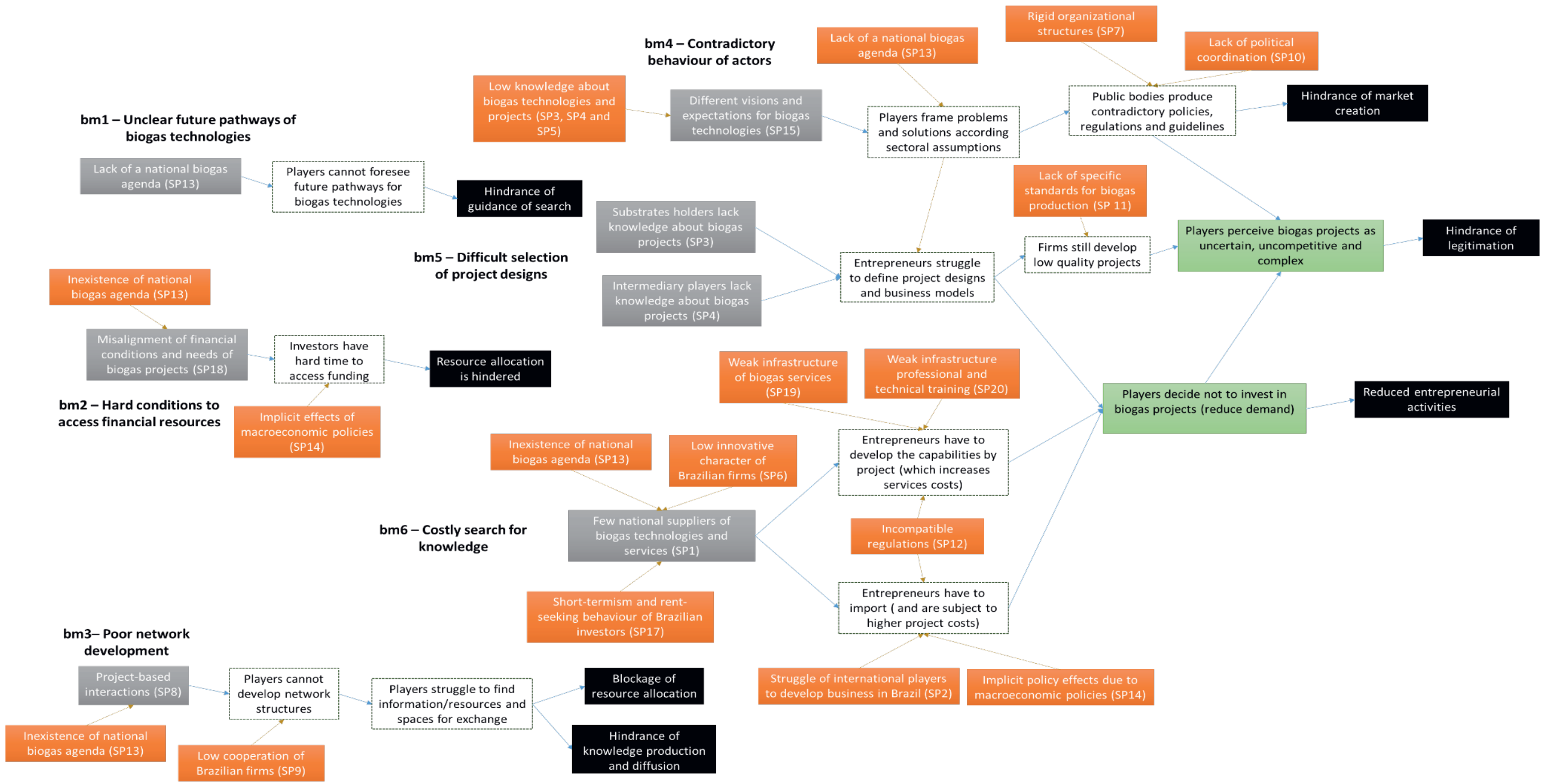


Figure 23 – Blocking Mechanisms of BBIS

(Grey boxes are the initial causes, white boxes denote the activities in blocking mechanisms, black boxes are the outcomes, orange boxes represent the contextual influences, and green boxes are common activities among different blocking mechanisms)

Table 10 – Policy goals for BBIS

Blocking mechanism	Systemic goals	Activity goals	Contextual goals
bm1	Create a national biogas agenda to provide directions for sector development (SG1)	-Develop scenarios, roadmaps or future targets for distinct biogas technological routes (AG1)	-
bm2	Improve funding conditions for biogas projects to increase the allocation of financial resources (SG2)	-Expand the portfolio of funding conditions (AG2)	-Create a national biogas agenda -Provide steady and continuous funding policies / Avoid stop and go programmes
bm3	Promote interactions targeting the development of system resources to facilitate the flow of information and allocation of human and material resources (SG3)	-Stimulate the creation of local and multilevel platforms and networks for information on biogas projects and resources (AG3)	-Create a national biogas agenda -Promote spaces for interactions of companies and public bodies
bm4	Promote inter-sectoral coordination of biogas activities to stimulate market creation (SG4)	-Create or intensify the use of spaces for intersectoral interactions (AG4) -Monitor the coherence and consistency of sectoral policies and regulations (AC5)	-Improve players' biogas capabilities - Create a national biogas agenda -Stimulate innovative organisational structures for public bodies -Promote innovative coordination mechanisms across sectors and governance levels
bm5	Improve the availability of information on business models and project designs to support the development of efficient and feasible projects (SG5)	-Identify and promote typical business models and projects designs (AG6)	-Stimulate common visions on biogas across sectors -Improve quality standards for distinct types of biogas projects
bm6	Support the development of biogas technologies and services to underpin the development of biogas projects (SG6)	-Promote a national industry biogas equipment and services (AG7) -Provide temporary special conditions for importation (AG8)	-Define long-term strategies for biogas -Identify weak points in training and service infrastructures -Create a roadmap of biogas technologies for international interactions

The first set of goals refers to bm1 and aims to create the national biogas agenda to provide direction to the development of the biogas field in Brazil. This is the broadest systemic goal, as it directly or indirectly causes or influences all blocking mechanisms. The main consequence of this problem is the lack of future perspectives for biogas technologies; therefore, the corresponding activity goal asserts the need to develop scenarios/roadmaps with specific targets. These scenarios and targets should account for the specificities of technological routes with all their respective characteristics, such as their regional embeddedness, their sectoral embeddedness and distinct types of involved actors.

The second systemic goal aims at increasing financial resource allocation by improving the funding conditions for biogas projects. As biogas investors experience difficulties accessing existing funding, the activity goal purposes of expanding the portfolio of funding conditions according to the different types of projects. Although there are funding lines and players able to access these lines, this situation represents a minimal spectrum of projects. For instance, the funding lines derived from the ABC programare very restricted in terms of resources volume. Similarly, the existent funding lines of BNDES or commercial banks favour major incumbents, which could provide the required financial guarantees.

In addition, sectoral and regional conditions must be taken into account. For example, in the agriculture sector, players present high levels of debt that hamper access to new loans. Biogas actors struggle to provide guarantees in the energy and sanitation sectors when they are not associated with incumbents. Regional financial players such as regional banks[142] could increase the portfolio of options, and different funds, such as the Climate and Innovation funds, could be used to provide the necessary conditions.

Lastly, the contextual influences in bm2 demonstrate that the expansion of funding conditions may be difficult to implement or ineffective in an environment without clear directions for biogas activities and subject to stop-and-go funding programmes. Therefore, the two contextual goals aim to create a national biogas agenda and promote steady and continuous funding lines. The promotion of predictability for investors is a key factor in these contextual goals.

The third systemic goal aims at improving the availability of system resources[143] *by promoting different types of interactions other than those focused on specific projects.* For this goal, creating spaces, networks or platforms that bring together actors and disclose the information of these resources is a critical activity goal. However, as resources are not evenly distributed across regions, sectors and actors, these aspects have to be considered. In addition, the various technological routes of biogas engage different actors across sectors and regions in Brazil.

As demonstrated by De Oliveira and Negro (2019), four main technological trajectories can be identified and attributed to sectors and regions, thereby realising that system resources can be shared within and across trajectories. Consequently, networks and platforms have to address these gaps in interactions. One example of this situation is the BiogasFerti network led by Embrapa and CIBiogás. The network aims to improve capabilities and standardise laboratory methodologies across Brazil in substrate evaluation and biofertilizer production and use.

[142] E.g. BRDE (Development bank for the South Region) and BNB (Development bank for the Northeast Region).
[143] System resources are non-excludable resources that are created intentionally or not by actors and that have strategic value for actors linked to a particular technology, such as collective expectations, norms, regulations and infrastructures. For more details, see Musiolik (2012:45-46), Musiolik et al. (2018) and Musiolik and Markard (2011).

Lastly, similarly to the previous set of goals, contextual goals indicate the more likely conditions to influence success. First, the national biogas agenda again arises as an important contextual influence. Without clear directions, it is difficult for actors of different sectors and levels to foresee common benefits and engage in these interactions. Second, the situation that Brazilian firms are comparatively less inclined to interact than companies in developing countries might counteract actions for promoting networks and platforms.

The fourth systemic goal aims to unravel market creation mechanisms and increase the legitimacy of biogas technologies by promoting the intersectoral and multilevel coordination of actions across public bodies. For this to happen, it is necessary to identify two activity goals: (i) the creation or intensification of spaces for intersectoral interactions of public bodies and (ii) monitoring the coherence and consistency of sectoral policies and regulations. The former allows public bodies to exchange their main visions, expectations and goals toward biogas technologies. Although each body would continue to have its sectoral demands and requirements, they can attune regulations to encourage biogas projects. This type of action is already developed in western Paraná State, creating a forum for debating regional sustainable development involving distinct types of actors. The monitoring of coherence and consistency of policies and regulations would indicate the main points of contradictions. Hence, public bodies would have specific targets for alignment and learning.

Contextual goals are highly relevant to accomplishing these activities and systemic goals. First, the lack of knowledge about biogas projects and technologies keeps these public bodies apart. If players cannot identify their benefits, it is improbable that they will seek interactions with other players. Hence, improving these players' capabilities for biogas technologies is very important. Second, common expectations and visions and the will to monitor coherence and consistency of policies are unlikely to emerge without clear directions for the biogas field. A national biogas agenda would catalyse these initiatives and is again a relevant contextual goal. Finally, the spaces for interactions and the actions to monitor coherence and consistency will encounter a difficult environment. The lack of political coordination and the rigid organisation structures of public bodies tend to play against these initiatives. Therefore, looking for innovative organisation spaces/structures and mechanisms for political coordination emerge as important contextual goals.

The fifth systemic goal aims at augmenting the legitimacy of biogas technologies and the level of entrepreneurial activities by increasing the availability of information on biogas projects. This systemic goal corresponds to the activity goal of identifying and promoting typical business models and project designs. Necessary information ranges from technical aspects of biogas plants, such as adequate materials, equipment and designs, to business and bureaucratic information, such as supplier lists, related policies and regulations, institutional and commercial arrangements and major risks. This activity goal tends to be more successful when implemented in concert with the activity goal of creating spaces for intersectoral interactions, which creates an environment wherein different information is consolidated. However, disclosing this information does not guarantee that firms will cease to develop low-quality projects. For this to be accomplished, the most feasible action is a contextual action, which relates to the contextual goal of improving standardisation for biogas projects.

The sixth systemic goal aims to increase entrepreneurial activity by stimulating the expansion of national suppliers of biogas equipment and services. A set of activity and contextual goals is necessary to achieve this systemic goal. First, it is necessary to stimulate the national equipment and services industry for biogas projects. This goal entails bringing established industries that can supply biogas equipment and services, such as the chemical and metallurgical industries, and promoting new players for specific biogas technologies. Second, it is necessary to create specific conditions for importation. Initially, these special conditions can be subsidies or tax exemptions—such as those already in place for specific projects via CAMEX[144].

Concerning the contextual goals, creating a biogas agenda with long-term targets could mitigate some of the contextual conditions that support the environment of limited interest in long-term investment in new biogas technologies. In addition, identifying weak points in professional and technical training related to biogas activities could facilitate the definition of actions for this infrastructural problem. Lastly, stimulating international partnerships guided by a technological roadmap could improve international companies' interests and level of information.

A final remark refers to the activities common to bm4, bm5 and bm6, the decision not to invest in biogas projects and the perception of biogas technologies as uncertain, uncompetitive and complex. No specific activity goals correspond with these activity goals because the goals of orienting players' decision-making or perceptions are mostly conditional upon addressing the previous activities.

5.4 SYSTEMIC, ACTIVITY AND CONTEXTUAL GOALS AND POSSIBILITIES FOR INTERVENTIONS TO FOSTER EMERGING SOCIOTECHNICAL CONFIGURATIONS

Defining policy goals reveals essential insights about possible alternative interventions to promote emerging sociotechnical configurations. First, the description of systemic goals can be applied to determine the main directions of system structuration, which can be helpful in connecting TIS analyses to mission-oriented innovation policies. In the case of BBIS, systemic goals help to design the boundaries of a national biogas agenda. Thus, SG1 can be considered an encompassing goal, and the other systemic goals are the main lines of action.

Second, activity goals enable identifying specific regions, sectors, actors, and resources to be targeted in these interventions. In the case of BBIS, these particular activities range from expanding the portfolio of funding conditions to promoting applied R&D in the agriculture sector. Finally, it is essential to mention that although the activity goals stated in Table 10 are more generic,

[144] International Trade Chamber.

the structural-functional analyses and the analyses of hindering factors explain the specificities of sectors, regions and governance levels. Therefore, the goals listed in Table 10 aim to aggregate the main conditions in BBIS.

Third, contextual goals indicate points where influences external to the specific innovation system may counteract goals to promote the emerging technologies. In the case of BBIS, this is evident in the goals of expanding the portfolio of funding alternatives, promoting interactions and supporting national suppliers to reduce the costs of biogas projects. Lastly, both activity and contextual goals indicate where the coordination of systemic goals is necessary. In the case of BBIS, coordination is required to align adequate funding conditions to the main lines of a national biogas agenda, orient the interaction of public bodies towards market creation mechanisms, foster the convergence of expectations on biogas technologies to promote feasible business models and avoid the increase of project costs due to incompatible regulations.

5.5 CONCLUSIONS

This chapter explored how a mechanism-based explanation of hindering factors at the system level (see Chapter 3 for more details) broadens the possibility for informing interventions to promote system structuration. As discussed, informing interventions can extend beyond goals to tackle systemic problems (see Wieczorek and Hekkert, 2012) or issues to address blocking mechanisms (see Bergek et al., 2008a). It is possible to inform interventions that can target systemic problems, contextual conditions or specific activities in blocking mechanisms. Therefore, the space for intervention goals is also expanded.

The analyses presented herein aimed more at informing policy goals than selecting policy instruments. Policies entail many involved actors, and TIS analysts can mainly only indicate possible preferable pathways. The mechanism-based explanation of hindering factors led to three distinct policy issues and goals. Systemic goals aim to mitigate systemic problems, activity goals aim to mitigate specific activities in blocking mechanisms, and contextual goals aim to support or mitigate the contextual influences of activities in blocking mechanisms.

This framework for systemic policy goals aligns with the definition of policy mixes as entailing goals at levels ranging from more abstract to more concrete/operational, enabling analysts to propose varying interventions and stimulate policy debates around a specific technology across different actors and levels. It also allows to understand the hierarchy of goals, points where coordination is necessary and how actor-level goals influence systemic goals. Hence, this framework may be helpful for mission-oriented policies

In the case of the Brazilian Biogas Innovation System, the discussion of these goals reveals important points for promoting biogas technologies. First, it becomes evident that there needs to be a national agenda that promotes future perspectives and scenarios connected to distinct technological routes and regional conditions. The absence of such an agenda has supported an environment in which players see the relevance of biogas technologies. Second, this agenda can be composed of the five systemic goals, which establish the main boundaries for the development of the biogas field. Third, it reveals the points at which coordination of these systemic goals is necessary. Fourth, it discusses where macro or external factors may counteract goals. Thus, this analysis provides insightful information for decision-making in the biogas field in Brazil.

5.5.1 Possibilities and limitations of this framework

Obviously, this analysis is limited in several ways. The main goal of the proposed conceptualisation is to improve how TIS studies inform policymaking. However, the suggested framework is not a panacea to be used as an idealised rational framework (Flanagan & Uyarra, 2016) or to claim complete success in informing policy. The main objective of this framework for policy goals is to raise awareness about the connection of goals at the system and actor levels. Hence, this framework is not free of limitations, and analysts must be aware of these issues when using the TIS framework to inform policymaking.

Firstly, TIS's oft-mentioned implicit normative position towards a specific technology has to be discussed (Markard et al., 2015). TIS studies focus on an already selected technology and do not aim to discuss other technologies or the impacts of a higher diffusion of the chosen technology[145]. This point does not diminish TIS's analytical power or the validity of TIS analyses; however, it indicates that this framework may be more useful when a given technology is already prominent among actors or when it comprises a part of broader goals as mission-oriented innovation policies[146]. TIS informs policy issues and goals that are already more specific, less 'wicked' (Crowley & Head, 2017) or less unstructured (Hoppe, 2010).

Other limitations arise from the fact that policies are not proposed, designed or implemented in blank spaces but rather emerge and are enacted in spaces that comprise several policy goals and instruments (Mettler, 2016; Rogge & Reichardt, 2016). Thus, it is still necessary to understand how emerging policy goals relate to the goals and instruments of established policies—i.e. how they relate to the established policy mix. In addition, actors who participate in policymaking are distinct; therefore, exploring who these actors are and their contextual conditions (e.g. sectoral and geographic embeddedness, their availability of resources and governance systems) becomes crucial for better policy recommendations. Exploring these points raises awareness of possible conflicts regarding incoherence of policy goals, implementation problems and divergent understandings of policy problems.

[145] It is possible to discuss interactions and complementarities with other technologies (Bergek, Jacobsson, & Sandén, 2008; Markard & Hoffmann, 2016); however, there may still be an implicit assumption of the need of greater diffusion of the focal technology.
[146] Comparing TIS analyses of different technologies is an interesting suggestion for mission-oriented innovation policies.

Finally, policy issues and goals have to be discussed with broader audiences of stakeholders in public arenas. Analysts need to communicate limitations by highlighting their uncertainties and ambiguities clearly. As policy issues and problems emerge from different frames on social problems, highlighting limitations raises awareness of possible conflicts in framing policy problems from TIS analysis. By doing so, TIS analysis moves toward strategies of improved evidence-informed policymaking (Alford & Head, 2017; Cairney et al., 2016).

CHAPTER 6 - CONCLUSIONS

This research aimed to explore the possibilities and limitations of informing policies for fostering biogas technologies in Brazil. The main goal was to answer the question *What are the policy recommendations that support the establishment of adequate conditions and the mitigation of problems for fostering the Brazilian Biogas Innovation System?* To this end, it was necessary first to investigate the trajectories undertaken by these technologies in Brazil (Chapter 2, published as De Oliveira and Negro [2019]) and then to explore the specific hindering factors of further development and diffusion (Chapter 3, published as De Oliveira et al. [2020] and Chapter 4[147]). Finally, these two studies enabled the discussion of possible policy goals to mitigate these hindering factors and thereby stimulate activities in the Brazilian biogas field (Chapter 5)[148].

The evolution of the biogas field in Brazil has been dramatically influenced by sectoral and geographic contexts, which have manifested themselves in three forms: the evolution of contextual structures, interactions between these structures, and the structures' translation of external events into BBIS. Contextual structures comprised necessary structural couplings. Sectoral influences were mostly conveyed by policies and regulations, which created the initial conditions for biogas projects and specific actors such as utilities and governmental bodies, the leading actors across several phases of development. This finding does not undermine the role of infrastructures and technologies, which are primarily responsible for constraining biogas projects; however, it emphasises the role of sectoral structures.

Geographic influences occur due to the territorial embeddedness of actors and resources (e.g. infrastructures, skilled labour and substrates) and the regional and local governance structures (e.g. local policies and arenas for decision-making). Interactions among local resources, actors and governance structures create several possibilities and limitations for biogas, thereby constraining the country's perception of common pathways for biogas technologies.

In addition, the interactions of geographic and sectoral structures were the main channel via which macro influences such as the successive economic crises were translated to the biogas field. Regardless of biogas activities or specific conditions, changes in these structural couplings brought important external influences into BBIS.

Sectoral institutional reforms, the expansion of agricultural production and infrastructural systems and the entrance or departure of players have brought different sorts of resources, knowledge, values, interests and frames to BBIS. Additionally, the interaction of other contextual

[147] An earlier version of this chapter was published as de Oliveira (2020).
[148] Part of the research findings has been also applied in a technical publication about problems and pathways of biogas in Brazil to inform the national policy debate (https://mailchi.mp/i17.org/barreiras_recomendacoes_para_biogas_no_brasil).

structures has engendered both positive and negative conditions for biogas activities. An actual positive example is a favourable environment in the Southern Region created by the interactions of regional/local environmental regulations and resourceful local players with national power sector regulations for distributed generation. On the other hand, two unfavourable environments are the initial implementation of net metering regulations developed with significant interactions with solar players and agroenergy policies resulting from the expansion of agricultural production and bioethanol and biodiesel players.

Moreover, sectoral and geographic structural couplings were relevant to translating external events into the biogas field. For example, a positive case was observed in the state of Paraná, where Itaipu created a technological park (a consequence of innovation policies) that has interacted with agricultural players in a clear expansion wave. On the other hand, a negative case occurred with sectoral utilities reducing their interest and investment in biogas projects in response to adverse macroeconomic conditions.

Obviously, biogas-specific factors have acted in combination with these contextual influences. Existent biogas experiments and local knowledge bases were relevant factors in the success of southern experiences. In contrast, the lack of trust and legitimacy of biogas technologies has supported the absence of biogas technologies in agroenergy programmes and their lesser relevance in discussions of the net-metering regulations.

A detailed discussion of the hindering factors of BBIS demonstrated how contextual influences and biogas-specific conditions have created and been manifested into blocking mechanisms. The misalignment of funding conditions and biogas projects, the project-based orientation of interactions and a lack of spaces for exchange, the contradictory behaviour of actors leading to significant regulatory and policy incoherence and the high costs of project development were all to some extent supported by contextual conditions. In addition to causing the blocking mechanisms, biogas-specific systemic problems also presented interdependencies that created conditions for other blocking mechanisms. However, the broadest systemic problem is the inexistence of a national biogas agenda, which has resulted in the overarching blocking mechanism of unclear future perspectives for biogas technologies, which remains a critical issue for activities in all other blocking mechanisms.

The above-described findings highlight an intricate set of relationships among different actors, institutions and technologies across different sectors, regions and governance levels that work to hinder activities in BBIS. The policy issues and goals discussed in Chapter 5 indicate avenues to unravel the intricate situation by providing a clear picture of the why and how actors engage in activities that hamper BBIS functioning. However, the discussion of policy goals also emphasises the limitations of analytical frameworks to inform policy goals, which depend on the availability of decision-makers, resources, and political agendas. These limitations must be further discussed so that informing policy goals for promoting BBIS can identify uncertainties, ambiguities, and possible conflicts.

6.1 EVENTUAL CONFLICTS FOR POLICY RECOMMENDATIONS FROM TIS STUDY TO FOSTER BIOGAS TECHNOLOGIES IN BRAZIL

As discussed in the previous chapters, sociotechnical frameworks—such as the TIS framework—have achieved substantial relevance in producing knowledge to overcome the barriers to technological development and diffusion (e.g. OCDE, 2015). Moreover, such knowledge often intends to inform the design of policy goals and instruments (Bergek, Jacobsson, Carlsson, et al., 2008; Weber & Rohracher, 2012; Wieczorek & Hekkert, 2012). Nevertheless, scholars have highlighted the conceptual and analytical and policy and political limitations of these frameworks to inform policymaking (Borrás & Edquist, 2013; Flanagan et al., 2011; Flanagan & Uyarra, 2016; Laranja et al., 2008; Magro et al., 2014).

More than identifying weaknesses in analytical frameworks, these limitations indicate eventual constraints on the design and implementation of new policies based on the recommendations generated by analytical frameworks. A key limitation refers to the implicit consideration of policymakers as rational and single actors who only borrow or apply policy recommendations (Flanagan et al., 2011; Flanagan & Uyarra, 2016). The policymaking process results from governance and political structures that include several actors across different governance levels and with distinct sets of interests. Additionally, recommendations from such frameworks disregard other policy rationales. Such rationales can define the role of a state's actions (meta rationales) or interpret or translate this role to specific implementation mechanisms (academic rationales, such as the systemic failure rationale) or practices of policymakers (Laranja et al., 2008)

A final analytical limitation concerns the knowledge of the policy context (Mettler, 2016; Rogge & Reichardt, 2016). New policies to foster sociotechnical innovation are not enacted in a blank space. Instead, policies are designed, chosen and implemented among many other policies in a policyscape (Mettler, 2016). They interact with other policy goals and instruments, which may produce unexpected effects (del Río, 2014; Michael Howlett & Rayner, 2007). Therefore, policy recommendations must be aware of possible contentious interactions with existing policies to create supportive effects (Michael Howlett & Rayner, 2013).

These three dimensions, i.e. the roles of policymaking actors, types of policy rationales and policy contexts, support the definition of boundaries for the space of policy design. In other words, analysts can explore possible policymaking conflicts by discussing which types of policy actors and policy rationales relate to each other and possible interactions of established policy mixes with the suggested policy goals. This discussion provides essential insights into how structured policy problems can be (Hoppe, 2010). Moreover, the TIS analyses performed by mapping the activities of actors (as suggested in Chapters 2, 3 and 4) have covered the identification of leading actors, institutional environments and the effects of actors' activities. Hence, analysts have available data on types of actors, policy rationales and policies and regulations.

Specifically, in the case of BBIS, these dimensions reveal the complexity of policy framing to inform proposed policy goals. Although systemic goals can be understood as biogas-specific and national goals, they are not discussed in isolation from sectoral and regional issues. The systemic goal of creating a national biogas agenda is the broadest but is not free from conflicts. Future scenarios and targets for biogas technologies (activity goal) require interactions between several actors. Aggregating varying demands and proposals require substantial effort and time, and reconciling distinct interests with a national agenda in the political arena depends on adequate discourses and narratives.

The same is true of identifying and discussing complementarities and alignments between a policy agenda for biogas and established agendas across different sectors and regions. Centralising the documents enacted by these policies and studying their possible interactions requires training and resources. Moreover, the recognition of the need for a national agenda arises from the idea that markets are not capable of promoting a new technological field. Although this issue is less critical for academics in the field of innovation systems, the Brazilian government's current is more aligned with the rationales of free markets and non-state intervention, which creates obstacles for any new policy goal that contrasts with this rationale.

The second systemic goal, improving funding conditions for biogas projects, also presents potential conflicting points, the first of which relates to the definition of the main types of biogas projects and their respective conditions. This issue has to derive from a national biogas agenda, which must be sufficiently clear and legitimate to engage financial actors. Second, implementing public policies that establish new funding lines in public banks—such as development banks—or creating public funds, such as the idea of a guaranty fund (ABiogas, 2015, 2018)—seems incompatible with the pro-market rationale of the current government agenda. Third, these specific public funding lines or funds may encounter a restrictive environment regarding resource availability due to the current macroeconomic situation. Sectoral and regional characteristics play a minor role; however, biogas projects have a much smaller scale than sanitation and energy projects. This situation shows that financing practices in these sectors are inclined towards large-scale projects.

The following three systemic goals present similar difficulties for entering policy agendas. These three goals mainly aim to engage different sets of actors. The engagements have distinct objectives: the creation of system resources, the unblockage of market mechanisms, and the improvement of information and knowledge exchange and diffusion. The main conflicting points derive from the diversity of the necessary types of actors and interactions. The first difficulty is the alignment of key actors' expectations, visions, and goals around an agenda concerning system resources. As demonstrated in Chapter 2, contextual conditions have historically provided this alignment. As a result, important biogas-specific issues are neglected. Maintaining the alienation of biogas players in alignment processes will very likely hinder the creation of platforms and networks and any effort to intensify the use of existent interaction spaces (e.g. councils, committees and networks), which will depend on how sectoral and regional actors understand biogas technologies.

Second, even with a convergence of visions and expectations based on biogas-specific issues and system resources, these goals have less legitimacy than the already-established goals for other technologies (e.g. hydropower, oil fuels, and even wind and solar). This situation indicates that the dispute over these interaction spaces may be intense. For instance, council and ministry committees, regulatory agencies and state-level bodies have already defined their agendas. These aspects become crucial because new networks, platforms or other interaction spaces demand actors' financial, human and time resources. Moreover, these directed interactions demand resources and capabilities not necessarily available across regions and actors. For instance, identifying business models, designing projects and monitoring the coherence and consistency of policies and regulations may be difficult across sectors and regions due to distinct capabilities and resources. In addition, resourceful actors may restrict access to knowledge and information, favouring their interests, as is often the case with companies seeking competitive advantages.

The last systemic goal of promoting a national industry for biogas technologies and services can be understood as the most contentious one. First, without a national agenda, it is highly unlikely that specific goals to promote the biogas industry will emerge. Second, as discussed in Chapters 2 and 4, although biogas technologies have great potential in terms of production and use, biogas solutions only represent small shares of sectoral markets. This situation has led several actors to see biogas technologies as marginal solutions. Therefore, it will be necessary to reconcile the biogas industry with other industries.

At this point, it is imperative to examine other innovations and industrial policies for renewable energy and biotechnologies. Again, doing so depends on the availability of resources and the specific capabilities of governmental bodies. In addition, without precise market mechanisms, it is unlikely that companies will expand their business models to include biogas-specific services. Along with the weak infrastructure and lack of policies of professional training, this situation could be an essential hurdle for any policies devised to achieve this goal. Third, importing technologies and services is essential but also subject to macroeconomic risks (e.g. exchange rates). A long-term policy for the biogas industry must deal with this issue.

To conclude, this research provides a set of findings that can inform policymaking. The historical dynamics of the biogas field and current systemic problems and blocking mechanisms elucidate how biogas technologies have developed and struggled in Brazil. The discussion of systemic, activity and contextual goals indicates a direction for fostering mechanisms and public policies. Finally, this discussion on possible conflicts influencing these goals sheds light on the practical difficulties of designing supportive policies.

The main suggestion that can be taken from this research is the urgent need to determine a national agenda for biogas technologies in Brazil as a first step. An agenda that is developed in a participatory manner and considers regional and sectoral specificities could steer expectations and visions towards the development of the other systemic goals. Obviously, current fostering initiatives and alignment with important policy agendas (such as the Renovabio) must not be ignored. The debate must align these initiatives to systemic and activity goals. Finally, it is critical to evaluate and monitor the evolution of these goals. It is imperative to understand contextual conditions and their effects on supporting or undermining systemic and activity goals and their coordination.

6.2 ADVANCING THE MECHANISM-BASED UNDERSTANDING OF TECHNOLOGICAL INNOVATION SYSTEMS

The empirical analyses presented in this thesis have also supported the conceptual improvement of the TIS framework. This research proposes to enhance the explanatory power of how system structuration is blocked due to structural and functional features. The TIS literature typically explains such blockages by applying the concepts of systemic problems and blocking mechanisms along with system functions. However, previous research failed to answer important questions about how systemic problems and blocking mechanisms have caused the insufficient fulfilment of system-level processes. By taking a distinct epistemological approach toward exploring systemic problems and blocking mechanisms—the mechanism-based explanation, this research has demonstrated that negative attributes of structural elements (or structural couplings) cause distinct sequences of activities—mechanisms—that impede the fulfilment of system-level processes. Therefore, an improved conceptualisation of systemic problems and blocking mechanisms is possible.

The mechanism-based literature (D. Beach & Pedersen, 2016a; Biesbroek et al., 2017; Bunge, 1997, 2004; Falleti & Lynch, 2009; Hedström & Ylikoski, 2010; Tilly, 2001) focuses on unveiling the causal mechanisms to explain the connection between causes and outcomes in specific contexts. Mechanisms are composed of sequences of activities, which are necessarily performed by actors and transmit causal forces to outcomes through these sequences. Hence, innovation systems studies need to explore how these activities and actors relate to system structures and processes.

Chapters 3 and 4 demonstrated how the aforementioned understanding could be applied to explain the hindrance of a TIS. First, discussing the limitations of current concepts of systemic problems and blocking mechanisms, Chapter 3 conceptualised systemic problems as negative attributes of structural elements, which may be either endogenous to a TIS or structural couplings—i.e. shared structures between a TIS and other exogenous systems. Second, blocking mechanisms were defined as causal mechanisms that link negative attributes to poor system functioning. The weak fulfilment of system functions expresses the latter. Moreover, blocking mechanisms operate under certain contexts, which can be exogenous influences and structures, such as sectors, regions, international crises, etc., or internal influences and structures, such as institutions, infrastructures or activities of other mechanisms.

This new conceptualisation addresses two critical shortcomings of TIS explanations: the interdependence of hindering factors and the influences external to the focal TIS. Thus far, this discussion is at a nascent stage in the TIS literature. Although the TIS literature indicates which types of influences to consider (Bergek et al., 2015), it says nothing about how to consider them. In addition, empirical studies have acknowledged the interdependence of hindering factors; however, the conceptualisation of this phenomenon remains underdeveloped. Therefore, it is possible to say that previous studies have not entirely informed interventions, which are the primary intended outcomes of systemic problems and blocking mechanisms analyses.

The proposed conceptualisation and analytical framework resolve these issues by providing conceptual tools to glean the interrelationships of systemic problems and blocking mechanisms. The three interdependencies elaborated herein—the direct and indirect interdependence of systemic problems and the direct interdependence of blocking mechanisms—represent an initial conceptual approach for TIS studies. In addition, the conceptualisation of exogenous systemic problems and the contextual forces that contribute to blocking mechanisms help to understand influences that extend beyond the TIS focus on hindering factors.

Although this thesis focuses on hindering factors, it also provides new avenues to explain structural couplings and external links in TIS analyses (Bergek et al., 2015). In the context of this thesis, exogenous influences may reinforce or hamper some activities, or they may be part of these activities. In sum, it elaborates how and why actors engage in specific activities and how these activities are influenced by their contexts in a manner that enables the explanation of interdependence between external influences to the traditional TIS focus on hindering factors at the system level.

Chapter 2 also discussed the issue of influences external to the traditional TIS focus. This chapter proposed another essential improvement for the TIS framework related to analytical development. Borrowing the idea of technology as being composed of a 'bundle of value chains' (Sandén & Hillman, 2011), the chapter addressed the limitations of analysing contextual influences.

As technologies and technological fields can be defined as bundles of value chains, clearly defining the boundaries of these chains is the first step toward addressing the challenge of identifying which contextual influences to analyse. The second step is to explore actors and their specific activities at different value chain stages. Hence, analysts can identify actors exclusive to the focal TIS and play in different structures (sectors, regions, etc.), their different roles and how they act (their activities). Elucidating these aspects considers how external influences are brought, translated or converted into the TIS structures and processes.

The analytical proposition in Chapter 2 is closely aligned with the mechanism-based literature. The focus on actors' activities and how they support system structures and processes are precisely the same understanding applied to the conceptualisation of systemic problems and blocking mechanisms. This way, it moves away from a processual approach and connects system- and actor-level explanations.

The TIS framework sustains analyses on recurring patterns of events and descriptive narratives but neglects explanations of causality. Descriptive narratives disclose who, what and when actors did something but do not disclose how and why they did so. Actors may engage in activities for different reasons and are conditioned by contextual conditions. Hence, temporal depictions of events fall short in explaining causality. As Beach and Pedersen (2016:73) proposed, 'to be a part of a causal explanation, events need to be placed into an explicit explanatory framework in the form of a theorized mechanism that links cause with the outcome'.

By focusing on the activities of actors with respective contextual conditions and disclosing causal mechanisms, the TIS framework augments its explanatory power. Analysts can explain the fulfilment of system processes and consequent structuration through the interplay of actors and their activities as subjected to their distinct positions, resources and interests, and particular material and institutional conditions. In this thesis, this understanding was applied only to conceptualise and explain the hindering factors at the system level. Thus, although this thesis advances the mechanism-based understanding of the TIS framework, it is only a first step.

Furthermore, this new epistemological approach required a new methodological approach as well. This thesis combined an adapted event history analysis and process-tracing method, which demonstrated the suitability of a descriptive narrative derived from events to identify initial causes and outcomes and sketch out mechanisms, particularly for the theory-building variant of process tracing applied herein (D. Beach & Pedersen, 2016a). Finally, the position proposed in this thesis is similar to the proposition of taking a critical realist perspective on socio-technical studies[149] (Sorrell, 2018; Svensson & Nikoleris, 2018). This perspective opens different avenues for empirical cases.

As the goal of this thesis was to explore ways to inform policies, Chapter 5 elucidates the main implications of the conceptual development presented in the previous chapters—i.e. how the mechanism-based explanation of hindering factors improves the recommendations derived from TIS studies. Furthermore, the detailed discussion of systemic problems as causes, blocking mechanisms as causal pathways and sequences of activities and the influence of contextual conditions leads to new policy issues and policy goals for innovation system analyses.

TIS analyses inform the policy debate supporting the framing of policy problems (with policy issues) and identifying policy goals. The TIS literature discusses three main policy issues: mitigating systemic problems (Wieczorek & Hekkert, 2012), mitigating blocking mechanisms, and stimulating

[149] Actually, TIS can be understood as a sociotechnical system focused on innovation.

inducement mechanisms (Bergek, Jacobsson, Carlsson, et al., 2008). The mechanism-based framework harmonises the two main TIS frameworks, informing new policy issues and goals.

The first policy problem is derived from the policy issue of mitigating systemic problems. As systemic problems are causes of system malfunctioning, mitigating these causes aims to create the conditions for system structuration. Therefore, policy goals are systemic goals, aligning with the previous TIS literature. However, the goal is to stimulate structural conditions and the structural conditions that have a direct causal link with system processes.

The second policy issue refers to mitigating blocking mechanisms either as a whole or in specific activities. As blocking mechanisms convey causal forces through particular activities, it is possible to understand the policy goals as activity goals. Activity goals aim to clarify the actor-level conditions that support the system structuration. These goals must clearly state the specific activities and target actors.

The final policy issue refers to mitigating or stimulating contextual conditions. As contextual conditions enable or constrain the causal forces and activities in blocking mechanisms, these policy goals are contextual. Contextual goals aim to provide the conditions to support the achievement of systemic and activity goals.

The new policy issues and policy goals derived from the mechanism-based framework of hindering factors broaden the possibilities for TIS to inform the policy debate. In this way, the systemic failure rationale enables new policy problems based on a theoretical explanation that connects actor and system levels within a causal framework. In addition to informing issues and goals, these new goals enable an exploration of policy agendas and mixes' current possibilities. Hence, this mechanism-based framework for TIS can inform policy mixes for promoting the development and diffusion of emerging technologies. Put differently, this framework is a useful analytical tool for assessing the coherence and consistency of policy goals and instruments that aim to foster emerging technologies.

What does this mean? As policy debates and new policies emerge among a multitude of interests, limited resources, and established policies, decision-makers may have more leeway to design new policies. For instance, when public debate does not support a complete repackaging of policies, incremental steps based on activity and contextual goals may be taken to address systemic goals.

6.3 LIMITATIONS AND FUTURE RESEARCH

The empirical findings of this research provide essential findings to inform fostering policies for the biogas field in Brazil. Explaining the mechanisms by which the biogas field has evolved and the blocking mechanisms that currently hinder further development advance the policy debate on biogas technologies in Brazil. However, although the proposed goals result from consultation with various stakeholders, these stakeholders may have other understandings of priorities and problems. Therefore, a necessary next step is to discuss these policy goals with a broader audience of actors involved with biogas activities. Such discussions should account for the TIS normative position of a pre-selected technology and specific sectoral and regional aspects. Although several actors understand the relevance of biogas technologies, the energy transition in Brazil is a competitive field that also includes solar, wind and other biofuel technologies, which currently enjoy greater legitimacy than biogas technologies and already have important interest groups that support related policy actions. Therefore, competition for political agendas and resources must be addressed by comparing technologies and understanding distinct frames of actors, which is beyond the scope of this research.

In addition, regional and sectoral aspects are essential topics for a country as large as Brazil. This research has demonstrated how such aspects have contributed to the hindering factors of biogas development in Brazil, and it has discussed their relevance to policy goals. However, more detailed analyses are necessary to inform regional policies. Such analyses should explore the specific capabilities of actors, infrastructural conditions and policy and political dynamics. Another important aspect not discussed in this thesis is the selection of policy instruments. Although some instruments were mentioned in the discussion of problems and goals, specific impacts, interactions and alignment with policy goals were not discussed. These issues are important elements of policy formulation tasks.

Finally, the conceptual endeavour of this thesis has provided a framework to improve the explanatory power of TIS. Extending the development of the TIS framework based on the processual approaches (Bergek, Jacobsson, Carlsson, et al., 2008; M. P. Hekkert et al., 2007; Negro et al., 2007), the mechanism-based explanation for TIS provides another important avenue for development. This thesis did not explore all of those possibilities; for example, it is still necessary to explore the fulfilment mechanisms of TIS functions. Several studies have already performed this task (e.g. Karltorp et al., 2017; Markard et al., 2016; Yap and Truffer, 2018). A crucial next step is to review the literature and enumerate those mechanisms. This task may lead, for example, to a review of the motors of innovation frameworks by focusing on how mechanisms interact, similarly to what was done in Chapter 3.

Further studies should specify these mechanisms (causes, activities, outcomes and contexts) and test them with other empirical cases. However, biogas technologies in Brazil have supported a mechanism-based proposition, as they present characteristics different from other technologies or industries. Detailing the mechanisms that impact other technologies may lead to other policy issues and policy goals; for instance, stimulating inducement could be an interesting policy issue. For this to happen, it will be necessary to conceptualise these mechanisms causally as this thesis did for blocking mechanisms. Thus, the activity goals discussed herein would also include activities of inducement mechanisms.

SUMMARY

Current societal challenges—such as those translated into the Sustainable Development Goals (SDG)—pose many problems for which solutions will require introducing new practices and technologies. In the energy sector, the transition from systems based on fossil fuels and expanding access to affordable energy requires developing and adopting renewable energy technologies (RET) across different regions and contexts.

However, expanding the use of RET in energy systems is far from being an easy task, as there are distinct technological, economic, institutional and cultural barriers, which manifest themselves differently according to specific contexts. The severity of economic and financial obstacles varies depending on the situation of each country or region. Technological issues can be more manageable depending on a country's knowledge base and engineering capacity. Adaptations or policy changes rely on the institutional framework and its respective political structures and actors.

This situation shows that the debate about actions to mitigate these problems and promote RET is not a trivial one. Activities can be privately or publicly oriented, in turn leading to corporate strategies or public policies; can focus on different stages of the value chain of the technology; can target a single technology or a group of them; can be attached to one or several sectors or policy domains and can reinforce or undermine established measures; or even can impact single or several regions. Thus, deciding which actions to take requires an in-depth understanding of the technologies and their application contexts. In other words, to propose measures to foster RET, analysts must scrutinise the intricate set of conditions in which the RET operates and is implemented.

Studying problems of emerging technologies has been a focus of various disciplines that take distinct perspectives on technological development and change. These different analytical approaches have led to several frameworks to explain technological change and understand its explanation through innovation processes. The innovation studies literature has demonstrated such processes through two main rationales, the linear and the systems model, which also intend to inform strategic decision-making.

Among the several innovation systems frameworks, the approach that most explicitly deals with emerging technologies and system dynamics is the Technological Innovation System (TIS), applied in this research to explore the empirical question of fostering RET. TIS scholars have formulated varying system processes to explain how configurations of elements influence system dynamics. These processes are called 'functions' and comprise entrepreneurial activity, knowledge creation and exchange, the guidance of search, market creation, resource allocation, creation of legitimacy and positive externalities.

These dynamics are explained from the focus on how configurations of actors, institutions, and materials enable or constrain innovations so that systems present problems, failures or mechanisms that hinder system development and must be addressed. Thus, by explaining system structure and functioning, these analytical frameworks extend beyond market structures to inform intervention actions to foster or govern the evolution of emerging technologies and provide evidence of where and how to intervene to promote emerging technologies.

Another perspective of fostering RET understands the relevance of public policies to establish supportive conditions for or mitigate the problems of RET diffusion faces, which is widely acknowledged among scholars and practitioners. A multitude of policies directly or indirectly influences the development and diffusion of emerging technologies due to the participation of several actors, different resources and knowledge flows necessary. In other words, the embeddedness of emerging technology into sectors and production systems, such as energy, transportation, and financial, creates several points and forms of influence of policies and their instruments.

These influences are also multiple because policies comprise several elements and can be understood as policy mixes. Policy design studies evince those policies cannot be analysed as single elements but instead are composed of goals and instruments. Depending on their design features and application contexts, these goals and instruments interact in distinct fashions to influence the problem being addressed. Furthermore, as new policies are designed and implemented amidst pre-existing policies, the process of changing policy mixes also becomes a relevant consideration. Therefore, informing new policies must consider these specificities of policy mixes involved for the technologies.

These aspects of understanding the development and diffusion of RET as innovation systems and several raises a third important point for this thesis, and the role of policies to foster emerging technologies relates: how analytical innovation frameworks can inform policy design. Analytical frameworks commonly try to explain problems in innovation systems and recommend policy instruments. However, this scheme for informing policymaking has been criticised for being idealised and overly rational. Issues such as actors' roles, target populations, varying rationales, policy environments, and the distinct framing of instruments and problems play crucial roles in designing and implementing policies.

The TIS framework also has analytical and explanatory limitations that affect how analysts inform decision-making. As a result, TIS falls short in critical areas, which can be classified into two groups, innovation analysis and informing policy. Regarding innovation analysis, criticisms of TIS commonly cite the limited study of contexts, the delimitation of boundaries and issues of spatiality. Another criticism is the normative departure point on particular technologies (Bening et al., 2015). However, the latter criticism can be understood as an analytical choice, requiring only scholars to be aware of the issue from the outset and make it explicit.

The delimitation of boundaries on specific technologies or technological fields may neglect aspects such as TIS embeddedness in sectors and regions and the macroeconomic and political contexts. However, this is not necessarily a conceptual weakness. First, it can be viewed as an analytical choice. Second, TIS presents analytical tools to account for exogenous influences on the mechanisms that explain system dynamics (Bergek, Jacobsson, Carlsson, et al., 2008). Nonetheless, this limitation is highlighted when empirical studies have not sufficiently been explicit in identifying and analysing these exogenous influences.

The issue mentioned above is closely linked to criticisms concerning boundary definitions and the superficial analysis of spatial aspects. As definitions of technology and technological fields may vary, the TIS boundary is always dependent on the research inquiry, making the comparison of studies and the systematic inclusion of contextual influences difficult. The result is several empirical studies that focus on national cases, which facilitates the boundary definition. To address the above criticisms, TIS scholars have proposed four typical contextual structures, namely sectoral, geographic, technological and political, as analytical tools to organise what TIS studies should consider.

Criticisms about informing policy concentrate on unclear or superficial recommendations, the lack of contextualisation of recommendations and the need for more objective evidence. These criticisms relate to conceptualisations of the role of actors and the low awareness of policy context. However, the TIS conceptual framework does afford an examination of the role of actors; its origins focused on agent networks, institutional settings, and the system-level processes of guidance of search and creation of legitimacy constitute the conceptual foundations for analysis.

Nevertheless, although TIS empirical studies explore configurations of actors and networks and how system processes are fulfilled, they rarely provide a detailed examination of how and why actors engage in activities. In other words, empirical analyses may not explain actors' motivations and power relations. Therefore, subsequent studies of TIS problematic factors from which policy recommendations are derived may not cover the specificities of these problems.

Furthermore, although the context in which policies are proposed, changed and implemented is highly relevant, TIS recommendations barely consider it, excluding some recent studies about TIS and policy mixes. Hence, neglecting the contexts in which policy recommendations are made may lead to innocuous or superficial recommendations.

In this context of the need to promote RET, policies being robust fostering mechanisms and the TIS framework presenting some limitations on how to inform these policies, this thesis explores topical research gaps for TIS research:

- How to include the analysis of broader contexts and their influences on TIS studies.
- How to explain TIS problematic factors considering contexts and actors' motivations.

- And how to design policy recommendations after addressing these gaps and considering the broader policy context.

The selected empirical case is the biogas technologies in Brazil. The reasoning behind the selection of this case follows a group of criteria. First, Brazil is very successful in promoting renewable energies by implementing several policies, particularly in the bioenergy field, but biogas is still struggling to succeed. Second, biogas technologies and projects go across several sectors and differ across regions, which indicates several influences of different contexts. Third, biogas technologies have multiple pathways of development. Fourth, Brazil has already some biogas policies in place. Thus, biogas technologies in Brazil present all necessary features to test the research gaps to advance the TIS debates. Hence, the main research question is: *How can we inform policies that support adequate conditions and the mitigation of problems to foster the Brazilian Biogas Innovation System (BBIS)?*

This research question is explored across the chapters on specific research problems. After the introduction, Chapter 2 addresses the evolution of the Brazilian Biogas Innovation System from 1979 to 2016, proposing an analytical framework for considering all contextual influences. Chapter 3 dives into the TIS framework's analytical and conceptual gaps, offering a mechanism-based framework to explain systemic problems and blocking mechanisms. Chapter 4 applies the new framework developed in the previous chapter to discuss the main systemic problems and blocking mechanisms of the biogas case in Brazil. Finally, Chapter 5 addresses the TIS limitations of informing policies by designing a specific framework of policy recommendations for TIS based on the advancements made in previous chapters. Chapter 5 also brings the conclusions of the biogas case in Brazil.

Chapter 2 provides an important analytical method that focuses on exploring activities and their background conditions to consider contextual influences in TIS. First, by employing the 'bundle of value chains' perspective of technologies, instead of an ad hoc selection and description of contexts, identifying the contexts that really mattered for the case was possible. Then, the specification of events, including the search for agents, sectors, locality, motivations and resources, enabled me to recognise the activities and their background conditions, which explained contextual influences. Consequently, three significant contextual influences for TIS studies are suggested – the evolution of contextual structures, the interaction of contextual structures and the translation of external events by these interactions.

Chapter 3 proposes a mechanism-based conceptual framework that understands blocking mechanisms as causal pathways linking systemic problems (causes) to poor system functioning (outcomes). By detailing the causal pathways in activities and respective actors, it is possible to explain system malfunctioning adequately. Therefore, it was possible to discuss six patterns of direct or indirect interdependencies among systemic problems and blocking mechanisms. These interdependencies indicate where analysts must pay attention when designing recommendations for informing policies. What is more, it also expands the rationale of informing policy by using TIS. Being more explicit in describing mechanisms, their parts, and their relationship with system concepts produces other policy goals or issues to guide policy instruments. The mitigation of systemic problems or blocking mechanisms continues as an essential policy goal. However, for blocking mechanisms, mitigating specific activities broadens the space of policy goals. Mitigating or supporting specific contextual conditions of blocking mechanisms is added to this space.

Chapter 4 indicates that the low level of knowledge of biogas among players in the Brazilian Biogas Innovation System, the divergent frames and financial condition, and the limited spectrum of interactions are the primary causes of system hindrance. These causes manifested themselves in five blocking mechanisms, which elucidate the interdependence of systemic problems. The chapter concludes by discussing how these interdependencies contribute to the conceptualisation of hindering factors in TIS studies and how they lead to the increasing relevance of coordination for developing biogas in Brazil.

Chapter 5 proposes a conceptual framework that enables the identification and analysis of good policy mixes for the diffusion of emerging technologies and applies it to the case of biogas technologies in Brazil. This chapter demonstrates that TIS can inform systemic goals to mitigate systemic problems, activity goals to mitigate specific activities in blocking mechanisms and contextual goals to support or improve the contextual influences of activities in blocking mechanisms. In the case of biogas in Brazil, the results reveal the need for a national agenda composed of five systemic goals, the necessity of coordinating these systemic goals, and how macro or external factors may counteract specific biogas goals.

This thesis advances the research agenda of TIS in two crucial points. First, by proposing a mechanism-based framework for blocking mechanisms, TIS research must focus on the activities of actors with respective contextual conditions and disclosing causal mechanisms. This fact makes the explanatory power of TIS more robust and comprehensive because analysts can explain the fulfilment of system processes and consequent structuration through the interplay of actors and their activities as subjected to their distinct positions, resources and interests, and particular material and institutional conditions. Although this thesis focuses on the hindering factors at the system level, the mechanism-based understanding of the TIS framework can be further studied for system dynamics in future research.

Second, this more comprehensive explanation allowed me to better the how policies would act in innovation processes and led to the description of other policy issues and goals than those commonly indicated by innovation systems frameworks, namely mitigating systemic problems or failures. In this way, it is possible to identify points of interaction of policies and instruments, allowing analysts to explore multiple possibilities of policies strategies given the established policy sets. For instance, when public debate does not support a complete repackaging of policies, incremental steps based on activity and contextual goals may be taken to address systemic goals.

The main policy issue TIS analysis can address is still mitigating systemic problems, but here systemic problems are the cause of activities that hinder system functioning. Hence, the main goal of mitigating systemic problems is to allow system structuration, i.e. a systemic goal. The subsequent policy issue is the mitigation of blocking mechanisms either as a whole or in specific activities. Here the goal is to promote activities that actors can engage in to fulfil particular functions and encourage system structuration, i.e. an activity goal. The last issue refers to adequate contextual conditions for mitigating systemic problems or reducing blocking mechanisms. At this point, the goal is to provide the right environment for systemic and activity goals, i.e. contextual goals.

Empirically, the outcomes reveal a set of few systemic problems as the leading causes of the slow development of Brazil's biogas sector. The misalignment of funding conditions and biogas projects, the project-based orientation of interactions and a lack of spaces for exchange, the contradictory behaviour of actors leading to significant regulatory and policy incoherence and the high costs of project development were all to some extent supported by contextual conditions. In addition to causing the blocking mechanisms, biogas-specific systemic problems also presented interdependencies that created conditions for other blocking mechanisms. However, the broadest systemic problem is the inexistence of a national biogas agenda, which has resulted in the overarching blocking mechanism of unclear future perspectives for biogas technologies, which remains a critical issue for activities in all other blocking mechanisms.

These systemic problems and consequent blocking mechanisms led to the design of six systemic goals: create a national agenda, improve funding conditions, promote interactions for system resources development, promote inter-sectoral coordination, improve the availability of information, and support the development of technologies. These systemic goals are reflected in eight activity goals and eleven contextual goals that can comprise a space of discussion of policy agendas for biogas in Brazil.

However, the outcomes also bring out the complexity of policy framing to inform proposed policy goals. Although systemic goals can be understood as biogas-specific and national goals, they are not discussed in isolation from sectoral and regional issues. This fact indicates new biogas policies in Brazil require substantial effort and time to reconcile distinct interests within a national agenda, considering the different realities of sectors and regions. It also suggests discourses, narratives and policy rationales must be adapted to those preferred by decision-makers.

Thus, this research provides a set of findings that can inform policymaking. Second, the historical dynamics of the biogas field and current systemic problems and blocking mechanisms elucidate how biogas technologies have developed and struggled in Brazil. Third, the discussion of systemic, activity and contextual goals indicates a direction for fostering mechanisms and public policies. Finally, this discussion on possible conflicts influencing these goals sheds light on the practical difficulties of designing supportive policies.

Summing up, this research provides a comprehensive understanding of the dynamics of the Brazilian biogas sector with recommendations to navigate the development of fostering policies. Also, it opens an important avenue for TIS research based on mechanism understanding with important reflections on how TISS explains innovation processes and informs strategic decision making. Finally, practitioners and policymakers can use the policy framework of systemic, activity and contextual goals as guidance for discussing systemic policies.

SAMENVATTING

De huidige maatschappelijke uitdagingen – zoals de *Sustainable Development Goals* (SDGs) – stellen de wereld voor veel problemen, waarvoor nieuwe werkwijzen en technologieën ingevoerd moeten worden. In de energiesector is het de energietransitie, weg van systemen op basis van fossiele brandstoffen, alsmede de toegang tot betaalbare energie die ertoe leiden dat technologieën voor hernieuwbare energie (RET) in verschillende regio's en contexten moeten worden ontwikkeld en toegepast.

Het uitbreiden van het gebruik van RET in energiesystemen is echter zeker niet gemakkelijk, omdat er verschillende technologische, economische, institutionele en culturele belemmeringen zijn die in verschillende contexten op verschillende manieren tot uiting komen. De ernst van zulke economische en financiële belemmeringen varieert, afhankelijk van de situatie in een land of regio. Technologische problemen kunnen beter of minder goed beheersbaar zijn, en dat hangt af van de kennisbasis en technologische capaciteit van een land. Aanpassingen of beleidswijzigingen worden bepaald door het institutionele kader en de politieke structuren en actoren daarbinnen.

Deze situatie laat zien dat het debat over maatregelen om deze problemen te verzachten en de RET te bevorderen belangrijk is. Zulke maatregelen kunnen georiënteerd zijn op het bedrijfsleven of op de publieke zaak, wat leidt tot bedrijfsstrategieën of overheidsbeleid; ze kunnen zich richten op verschillende stadia van de waardeketen van de technologie; ze kunnen zich richten op een enkele technologie of een groep technologieën; ze kunnen worden gekoppeld aan een of meer sectoren of beleidsdomeinen; ze kunnen gevestigde maatregelen versterken of ondermijnen; en ze kunnen zelfs van invloed zijn op enkele of meerdere regio's. Beslissen welke acties moeten worden ondernomen, vereist dus een diepgaand begrip van de technologieën en van de context waarin zij worden toegepast. Met andere woorden, het voorstellen van maatregelen om de RET te bevorderen, vereist dat analisten de ingewikkelde reeks omstandigheden waarin de RET opereert en wordt geïmplementeerd onder de loep nemen.

Verschillende disciplines, met verschillende perspectieven op technologische ontwikkeling en verandering, zijn bezig geweest met het bestuderen van de problemen met betrekking tot opkomende technologieën. Deze verschillende analytische benaderingen hebben geleid tot verschillende kaders om technologische verandering te verklaren en om deze verklaring te begrijpen door te kijken naar innovatieprocessen. De literatuur over innovatiestudies heeft dergelijke processen aangetoond met het lineaire en het systeemmodel, die ook bedoeld zijn om strategische besluitvorming te ondersteunen.

Onder de verschillende kaders voor innovatiesystemen is het *Technological Innovation System* (TIS) de benadering die het meest expliciet betrekking heeft op opkomende technologieën

en systeemdynamiek. Het TIS wordt hier gebruikt om de empirische kwestie van het bevorderen van de RET te onderzoeken. TIS-wetenschappers hebben verschillende systeemprocessen beschreven om uit te leggen hoe configuraties van elementen van invloed zijn op de systeemdynamiek. Deze processen worden 'functies' genoemd en omvatten ondernemersactiviteiten, kenniscreatie en -uitwisseling, *guidance of search*, marktcreatie, het toewijzen van middelen, en het creëren van legitimiteit en positieve externaliteiten.

Deze dynamiek wordt verklaard vanuit de focus op hoe configuraties van actoren, instituties en materialen innovaties mogelijk maken of beperken, zodat systemen de problemen, storingen of mechanismen laten zien die de systeemontwikkeling belemmeren en die moeten worden aangepakt. Door de systeemstructuur en het functioneren te verklaren, kijken deze analytische kaders dus verder dan marktstructuren om informatie te verschaffen ten behoeve van interventies om de evolutie van opkomende technologieën te bevorderen of te sturen en ook aan te tonen waar en hoe kan worden ingegrepen om opkomende technologieën te bevorderen.

Een ander perspectief op het bevorderen van RET richt zich op de relevantie van overheidsbeleid om ondersteunende voorwaarden te scheppen voor RET of voor het verminderen van de problemen met RET, en dit wordt algemeen onderschreven door wetenschappers en andere professionals. Een scala aan beleidsmaatregelen beïnvloedt direct of indirect de ontwikkeling en verspreiding van opkomende technologieën als gevolg van de deelname van verschillende actoren, verschillende middelen en kennisstromen. Met andere woorden, de inbedding van opkomende technologie in sectoren en productiesystemen zoals energie, transport en financiën, creëert verschillende vormen van beleidsinvloed en beleidsinstrumenten.

Deze invloed is meervoudig omdat beleid uit verschillende elementen bestaat en kan worden opgevat als beleidsmix. Uit studies naar het ontwerpen van beleid blijkt dat beleid niet als een op zichzelf staand element kan worden geanalyseerd maar is samengesteld uit doelen en instrumenten. Afhankelijk van hun eigenschappen en toepassingscontext, werken deze doelen en instrumenten op verschillende manieren samen om het probleem dat wordt aangepakt te beïnvloeden. Bovendien wordt het proces van veranderende beleidsmixen ook relevant naarmate nieuw beleid wordt ontworpen en wordt geïmplementeerd te midden van reeds bestaand beleid. Daarom moet bij het ondersteunen van nieuw beleid rekening worden gehouden met de specifieke kenmerken van beleidsmixen die op de technologieën betrekking hebben.

Deze aspecten van het begrijpen van de ontwikkeling en verspreiding van RET als innovatiesystemen werpen een derde belangrijk punt op voor dit proefschrift. De rol van beleid om opkomende technologieën te bevorderen heeft betrekking op de manier waarop analytische innovatiekaders ondersteuning bieden bij het ontwerpen van beleid. Analytische kaders proberen vaak problemen in innovatiesystemen te verklaren en bevelen vaak beleidsinstrumenten aan. Dit schema voor het ondersteunen van beleidsvorming wordt echter bekritiseerd omdat het geïdealiseerd is en te rationeel. Kwesties zoals de rol van actoren, doelgroepen, verschillende beweegredenen, beleidsomgevingen en de verschillende *framing* van instrumenten en problemen spelen een cruciale rol bij het ontwerpen en uitvoeren van beleid.

Het TIS-kader heeft ook analytische en verklarende beperkingen die van invloed zijn op de manier waarop analisten informatie verschaffen omtrent de besluitvorming. Hierdoor schiet het TIS-kader tekort op kritieke gebieden die kunnen worden ingedeeld in twee groepen: innovatieanalyse en beleidsinformatie. Met betrekking tot innovatieanalyse, worden als kritiek op TIS vaak de beperkte studie van contexten, de afbakening van grenzen, en kwesties van ruimtelijkheid genoemd. Een ander punt van kritiek is het normatieve uitgangspunt van bepaalde technologieën (Bening et al., 2015). De laatste kritiek kan echter worden opgevat als een analytische keuze, waarbij wetenschappers vanaf het begin op de hoogte moeten zijn van het probleem en het expliciet moeten maken.

De afbakening van de grenzen van specifieke technologieën of technologische gebieden kan bepaalde aspecten verwaarlozen, zoals de inbedding van TIS in sectoren en regio's en de macro-economische en politieke context. Dit is echter niet noodzakelijkerwijs een conceptuele zwakte. Ten eerste kan het worden gezien als een analytische keuze. Ten tweede presenteert TIS analytische hulpmiddelen om rekening te houden met exogene invloeden op de mechanismen die systeemdynamiek verklaren (Bergek, Jacobsson, Carlsson et al., 2008). Deze beperking komt vooral naar voren wanneer empirische studies niet voldoende expliciet zijn bij het identificeren en analyseren van deze exogene invloeden.

De hierboven genoemde kwestie hangt nauw samen met kritiek op grensdefinities en de oppervlakkige analyse van ruimtelijke aspecten. Omdat de definities van technologie en technologische gebieden kunnen variëren, is de TIS-begrenzing altijd afhankelijk van het onderzoeksdoel, waardoor het vergelijken van studies en het systematisch opnemen van contextuele invloeden moeilijk is. Het resultaat is dat er verschillende empirische studies zijn die zich richten op nationale casussen, wat de grensdefinitie vergemakkelijkt. Om de bovenstaande kritiek aan te pakken, hebben TIS-wetenschappers vier typische contextuele structuren voorgesteld, namelijk sectoraal, geografisch, technologisch en politiek, als analytische hulpmiddelen om te organiseren wat TIS-studies zouden moeten overwegen.

Kritiek op ondersteuning van beleid richt zich op onduidelijke of oppervlakkige aanbevelingen, een gebrek aan contextualisering van aanbevelingen, en een behoefte aan meer objectief bewijs. Deze kritiek heeft betrekking op de conceptualisering van de rol van actoren en het feit dat men zich weinig bewust is van de beleidscontext. Het conceptuele kader van TIS biedt echter wel een onderzoek naar de rol van actoren; van oorsprong richtte dit zich op agentnetwerken en institutionele instellingen. De processen op systeemniveau die *guidance of search* en het creëren van legitimiteit sturen, vormen de conceptuele basis voor analyse.

Empirisch TIS-onderzoek kijkt naar de configuraties van actoren en netwerken en de manier waarop systeemprocessen worden vervuld. Toch wordt zelden gedetailleerd onderzocht hoe en waarom actoren zich bezighouden met activiteiten. Met andere woorden, empirische analyse kan de motivatie van actoren en de machtsverhoudingen tussen hen niet verklaren. Hierdoor worden de specifieke kenmerken van deze problemen mogelijk niet behandeld in toekomstige studies naar problematische TIS-factoren, waaruit beleidsaanbevelingen worden afgeleid.

Hoewel de context waarin beleid voorgesteld, gewijzigd en geïmplementeerd wordt zeer relevant is, houden TIS-aanbevelingen er nauwelijks rekening mee, met uitzondering van enkele recente studies naar TIS en beleidsmixen. Daarom kan het negeren van de context waarin beleidsaanbevelingen worden gedaan, leiden tot weinig verrassende of vooral oppervlakkige aanbevelingen.

Er is een noodzaak om RET te bevorderen. Beleid speelt hierbij een belangrijke rol en het TIS-kader heeft enkele beperkingen voor wat betreft de ondersteuning van dit beleid. In deze context onderzoekt dit proefschrift de volgende actuele onderzoekslacunes in TIS-onderzoek:

- Hoe kan de analyse van bredere contexten en de invloed hiervan worden opgenomen in TIS-onderzoek?
- Hoe kunnen problematische TIS-factoren worden verklaard, terwijl er rekening wordt gehouden met de context en motivaties van actoren?
- Hoe kunnen beleidsaanbevelingen worden opgesteld nadat deze lacunes zijn aangepakt, waarbij rekening wordt gehouden met de ruimere beleidscontext?

De empirische casus betreft biogastechnologieën in Brazilië. Deze casus werd gekozen om verschillende redenen. Ten eerste is Brazilië zeer succesvol in het bevorderen van hernieuwbare energie door middel van verschillende beleidsmaatregelen, met name op het gebied van bio-energie, maar toch is biogas nog steeds niet succesvol. Ten tweede hebben biogastechnologieën en -projecten betrekking op verschillende sectoren en verschillen ze van regio tot regio, wat erop wijst dat de verschillen in context van invloed zijn. Ten derde hebben biogastechnologieën meerdere ontwikkelingspaden. Ten vierde heeft Brazilië nu al beleid met betrekking tot biogas. Biogastechnologieën in Brazilië bieden dus alle noodzakelijke kenmerken om de onderzoekslacunes te testen en zo het TIS-debat verder te brengen. Daarom is de belangrijkste onderzoeksvraag: *hoe kunnen we beleid ondersteunen dat voldoende voorwaarden schept en problemen vermindert, en zo het Braziliaanse biogasinnovatiesysteem (BBIS) bevordert?*

Deze onderzoeksvraag wordt onderzocht in de hoofdstukken over specifieke onderzoeksproblemen. Na de inleiding behandelt hoofdstuk 2 de evolutie van het Braziliaanse biogasinnovatiesysteem van 1979 tot 2016; hierin wordt ook een analytisch kader voorgesteld waarin rekening wordt gehouden met alle contextuele invloeden. Hoofdstuk 3 duikt in de analytische en conceptuele hiaten in het TIS-kader en biedt een op mechanismen gebaseerd kader om systemische problemen en belemmeringsmechanismen te verklaren. Hoofdstuk 4 gebruikt dit nieuwe TIS-kader om de belangrijkste systemische problemen en blokkeringsmechanismen van de biogaszaak in Brazilië te bespreken. Ten slotte behandelt hoofdstuk 5 de beperkingen van TIS bij het ondersteunen van beleid, door een specifiek kader van beleidsaanbevelingen voor TIS te ontwerpen op basis van de vooruitgang die in eerdere hoofdstukken is geboekt. Hoofdstuk 5 bevat ook de conclusies van de biogascasus in Brazilië.

Hoofdstuk 2 beschrijft een belangrijke analytische methode die zich richt op het verkennen van activiteiten en de omstandigheden, om zo de contextuele invloeden in TIS te onderzoeken. Ten eerste, door gebruik te maken van het 'bundel van waardeketens'-perspectief van technologieën – in plaats van een ad-hoc selectie en beschrijving van contexten – was het mogelijk om vast te stellen welke contexten werkelijk van belang waren voor de casus. Vervolgens stelde het specificeren van gebeurtenissen, inclusief de zoektocht naar agenten, sectoren, locaties, motivaties en middelen, me in staat om de activiteiten en hun omstandigheden te herkennen, wat contextuele invloeden verklaarde. Als gevolg hiervan stel ik drie belangrijke contextuele invloeden voor TIS-studies voor: de evolutie van contextuele structuren, de interactie tussen contextuele structuren, en de vertaling van externe gebeurtenissen door deze interacties.

In hoofdstuk 3 wordt een op mechanismen gebaseerd conceptueel kader beschreven dat blokkeringsmechanismen opvat als causale routes die systemische problemen (oorzaken) koppelen aan het slecht functioneren van het systeem (uitkomsten). Door gedetailleerd te kijken naar de causale paden in activiteiten en de betrokken actoren, is het mogelijk om het slecht functioneren van het systeem in voldoende mate te verklaren. Daarom was het mogelijk om zes patronen van directe of indirecte onderlinge afhankelijkheid tussen systemische problemen en blokkeringsmechanismen te bespreken. Deze onderlinge afhankelijkheid geeft aan waar analisten op moeten letten bij het ontwerpen van aanbevelingen voor het ondersteunen van beleid. Bovendien verruimt het ook de argumentatie hiervoor door gebruik te maken van TIS. Als het beschrijven van mechanismen, hun onderdelen en hun relatie met systeemconcepten explicieter wordt, leidt dit tot andere beleidsdoelen en andere kwesties die beleidsinstrumenten sturen. Het verminderen van systemische problemen of blokkeringsmechanismen blijft een essentieel beleidsdoel. Het beperken van specifieke activiteiten verruimt echter de ruimte van beleidsdoelstellingen. Het verminderen of ondersteunen van specifieke contextuele omstandigheden van blokkeringsmechanismen wordt aan deze ruimte toegevoegd.

Hoofdstuk 4 geeft aan dat de belangrijkste oorzaken van systeemverstoring zijn: het lage kennisniveau van biogas bij spelers in het Braziliaanse biogasinnovatiesysteem, de uiteenlopende frames en financiële omstandigheden, en het beperkte scala aan interacties. Deze oorzaken manifesteerden zich in vijf blokkeringsmechanismen, die de onderlinge afhankelijkheid van systemische problemen verduidelijkten. Het hoofdstuk eindigt met een bespreking van hoe deze onderlinge afhankelijkheid bijdraagt aan de conceptualisering van belemmerende factoren in TIS-studies en hoe deze leiden tot een toenemende relevantie van coördinatie bij de ontwikkeling van biogas in Brazilië.

Hoofdstuk 5 presenteert een conceptueel kader dat de identificatie en analyse van een goede beleidsmix voor de verspreiding van opkomende technologieën mogelijk maakt en past dit toe op biogastechnologieën in Brazilië. In dit hoofdstuk wordt aangetoond dat TIS ondersteuning kan bieden ten behoeve van systemische doelen, om zo systemische problemen te verminderen; ten behoeve van activiteitsdoelen, om zo specifieke activiteiten in blokkeringsmechanismen te verminderen; en ten behoeve van contextuele doelen, om zo de contextuele invloeden van activiteiten in blokkeringsmechanismen te ondersteunen of te verbeteren. Bij biogas in Brazilië laten de resultaten de noodzaak zien van (1) een nationale agenda bestaande uit vijf systemische doelen, (2) de noodzaak om deze systemische doelen te coördineren, en (3) de manier waarop macro- of externe factoren specifieke biogasdoelen kunnen tegenwerken.

Dit proefschrift brengt de onderzoeksagenda van TIS op twee cruciale punten verder. Ten eerste, door een op mechanismen gebaseerd kader voor blokkeringsmechanismen te presenteren, moet TIS-onderzoek zich richten op de activiteiten van actoren met hun contextuele omstandigheden en het aantonen van causale mechanismen. Dit maakt de verklarende kracht van TIS robuuster en uitgebreider omdat analisten dan de vervulling van systeemprocessen en de daaruit voortvloeiende structurering kunnen verklaren uit het samenspel van actoren en hun activiteiten, die beïnvloed worden door hun verschillende posities, middelen en belangen, en de specifieke materiële en institutionele omstandigheden. Hoewel dit proefschrift zich richt op de belemmerende factoren op systeemniveau, kan het op mechanismen gebaseerde begrip van het TIS-kader in toekomstig onderzoek verder worden bestudeerd op systeemdynamiek.

Ten tweede heeft deze uitgebreidere uitleg me in staat gesteld om de manier te verbeteren waarop beleid werkt in innovatieprocessen. Ook heeft het geleid tot de beschrijving van andere beleidskwesties en -doelen dan die gewoonlijk worden aangegeven door kaders voor innovatiesystemen, namelijk het verminderen van systemische problemen of mislukkingen. Op deze manier is het mogelijk om te identificeren op welke punten beleid en instrumenten interacteren, waardoor analisten meerdere mogelijkheden van beleidsstrategieën kunnen verkennen, gezien de vastgestelde beleidsset. Wanneer het publieke debat bijvoorbeeld geen volledige verandering van beleid ondersteunt, kunnen incrementele stappen op basis van activiteit en contextuele doelen worden genomen om systemische doelen aan te pakken.

Het belangrijkste beleidsprobleem dat TIS-analyse kan aanpakken, is nog steeds het verminderen van systemische problemen; hier zijn systemische problemen de oorzaak van activiteiten die het functioneren van het systeem belemmeren. Daarom is het belangrijkste doel van het verminderen van systemische problemen dat systeemstructurering mogelijk wordt gemaakt, met andere woorden: een systemisch doel. De daaropvolgende beleidskwestie is het verminderen van blokkeringsmechanismen als geheel of in specifieke activiteiten. Hier is het doel om activiteiten te stimuleren die actoren kunnen ondernemen om bepaalde functies te vervullen en systeemstructurering te bevorderen, met andere woorden: een activiteitsdoel. Het laatste probleem heeft betrekking op de contextuele voorwaarden die nodig zijn voor het verminderen van systemische problemen of het verminderen van blokkeringsmechanismen. Op dit punt is het doel om de juiste omgeving te bieden voor systemische en activiteitsdoelen, met andere woorden: een contextueel doel.

Empirisch gezien laten de resultaten een aantal systemische problemen zien als de belangrijkste oorzaak van de langzame ontwikkeling van de Braziliaanse biogassector. De verkeerde afstemming van financieringsvoorwaarden en biogasprojecten, de projectmatige oriëntatie van interacties, een gebrek aan ruimte voor uitwisseling, het tegenstrijdige gedrag van actoren dat leidde tot aanzienlijke regelgevings- en beleidsincoherentie, en de hoge kosten van projectontwikkeling werden allemaal tot op zekere hoogte versterkt door contextuele omstandigheden. Naast het veroorzaken van de blokkeringsmechanismen, lieten biogasspecifieke systemische problemen ook onderlinge afhankelijkheden zien die de omstandigheden hebben gecreëerd waarin andere blokkeringsmechanismen zich konden ontwikkelen. Het grootste systemische probleem is echter het ontbreken van een nationale biogasagenda, wat heeft geresulteerd in het overkoepelende blokkeringsmechanisme van onduidelijke toekomstperspectieven voor biogastechnologieën, wat een kritieke kwestie blijft voor activiteiten met betrekking tot alle andere blokkeringsmechanismen.

Deze systemische problemen en de daaruit voortvloeiende blokkeringsmechanismen hebben geleid tot het ontwerpen van zes systemische doelstellingen: (1) het opstellen van een nationale agenda, (2) het verbeteren van de financieringsvoorwaarden, (3) het bevorderen van interacties voor de ontwikkeling van systeembronnen, (4) het bevorderen van intersectorale coördinatie, (5) het verbeteren van de beschikbaarheid van informatie, en (6) het ondersteunen van de ontwikkeling van technologieën. Deze systemische doelen worden weerspiegeld in acht activiteitsdoelen en elf contextuele doelen die de discussie over beleidsagenda's voor biogas in Brazilië kunnen ondersteunen.

De resultaten brengen echter ook de complexiteit naar voren van beleidsvorming om voorgestelde beleidsdoelen te ondersteunen. Hoewel systemische doelen kunnen worden opgevat als biogasspecifieke en nationale doelen, worden ze niet los van sectorale en regionale kwesties besproken. Dit feit geeft aan dat het nieuwe biogasbeleid in Brazilië aanzienlijke inspanning en tijd vergt om de verschillende belangen binnen een nationale agenda met elkaar te verzoenen, waarbij rekening moet worden gehouden met de verschillende omstandigheden in sectoren en regio's. Het geeft ook aan ook dat de discussies, verhalen en beleidsredenen moeten worden aangepast aan de voorkeur van besluitvormers.

Dit onderzoek biedt dus een reeks bevindingen die de beleidsvorming kunnen informeren. Daarbij laten de historische dynamiek van het biogasveld en de huidige systemische problemen en blokkeringsmechanismen zien hoe biogastechnologieën zich in Brazilië hebben ontwikkeld en de worsteling die daarmee gepaard is gegaan. Bovendien geeft de discussie over systemische, activiteits- en contextuele doelen een richting aan voor het bevorderen van mechanismen en overheidsbeleid. Ten slotte werpt de discussie over mogelijke conflicten die van invloed zijn op deze doelen licht op de praktische moeilijkheden bij het ontwerpen van ondersteunend beleid.

Samenvattend biedt dit onderzoek een uitgebreid inzicht in de dynamiek van de Braziliaanse biogassector met aanbevelingen om een weg te vinden in de ontwikkeling van het bevorderen van beleid. Het opent ook een belangrijke weg voor TIS-onderzoek op basis van mechanismen, met belangrijke reflecties over hoe TIS innovatieprocessen uitlegt en informatie verschaft ten behoeve van strategische besluitvorming. Ten slotte kunnen beleidsmakers en mensen uit de praktijk het beleidskader van systemische, activiteits- en contextuele doelen gebruiken als leidraad voor het bespreken van systemisch beleid.

REFERENCES

ABiogas. (2015). *Proposta de Programa Nacional do Biogás e do Biometano - PNBB*.

ABiogas. (2018). *Proposta de Programa Nacional do Biogás e do Biometano*.

Alford, J., & Head, B. W. (2017). Wicked and less wicked problems: a typology and a contingency framework. *Policy and Society*, *36*(3), 397–413.

Andersen, A. D. (2015). A functions approach to innovation system building in the South: the pre-Proálcool evolution of the sugarcane and biofuel sector in Brazil. *Innovation and Development*, *5*(1), 1–21. https://doi.org/10.1080/2157930X.2014.996855

Arrow, K. (1962). Economic Welfare and the Allocation of Resources for Invention. In *The Rate and Direction of Inventive Activity: Economic and Social Factors* (pp. 609–626). National Bureau of Economic Research, Inc.

Arthur, W. Brian. (1989). *Competing Technologies, Increasing Returns, and Lock-In by Historical Events*. The Economic Journal. http://www.jstor.org/stable/2234208?seq=1#page_scan_tab_contents

Arthur, W B. (2009). *The Nature of Technology: What It Is and How It Evolves*. Free Press.

Asheim, B. T., & Isaksen, A. (1997). Location, Agglomeration and Innovation: Towards Regional Innovation Systems in Norway? *European Planning Studies*, *5*(3).

Asheim, B. T., & Isaksen, A. (2002). Regional Innovation Systems: The Integration of Local "Sticky" and Global "Ubiquitous" Knowledge. *Journal of Technology Transfer*, *27*, 77–86.

Azar, C., & Sandén, B. A. (2011). The elusive quest for technology-neutral policies. *Environmental Innovation and Societal Transitions*, *1*(1), 135–139. https://doi.org/10.1016/j.eist.2011.03.003

Babb, S. (2013). The Washington Consensus as transnational policy paradigm: Its origins, trajectory and likely successor. *Review of International Political Economy*, *20*(2), 268–297. https://doi.org/10.1080/09692290.2011.640435

Bacchi, C. L. (2009). *Analysing Policy: What's the Problem Represented to Be?* Pearson.

Balat, M., & Balat, H. (2009). Biogas as a Renewable Energy Source—A Review. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, *31*(14), 1280–1293. https://doi.org/10.1080/15567030802089565

Beach, D., & Pedersen, R. B. (2016a). *Causal Case Study Methods: Foundations and Guidelines for Comparing, Matching, and Tracing*. University of Michigan Press.

Beach, D., & Pedersen, R. B. (2016b). Selecting Appropriate Cases When Tracing Causal Mechanisms. *Sociological Methods & Research*, 0049124115622510-. https://doi.org/10.1177/0049124115622510

Beach, D, & Pedersen, R. B. (2019). *Process-tracing Methods: Foundations and Guidelines*. University of Michigan Press.

Beach, Derek, & Pedersen, R. B. (2013). *Process-Tracing Methods: Foundations and Guidelines*. University of Michigan Press.

Bechtel, W., & Abrahamsen, A. (2005). Explanation: a mechanist alternative. *Stud. Hist. Phil. Biol. & Biomed. Sci*, *36*, 421–441. https://doi.org/10.1016/j.shpsc.2005.03.010

Bening, C. R., Blum, N. U., & Schmidt, T. S. (2015). The need to increase the policy relevance of the functional approach to Technological Innovation Systems (TIS). *Environmental Innovation and Societal Transitions*, *16*, 73–75. https://doi.org/10.1016/j.eist.2015.07.007

Bennett, A. (2014). Appendix: Disciplining our conjectures Systematizing process tracing with Bayesian analysis. In A. Bennett & J. T. Checkel (Eds.), *Process Tracing From Metaphor to Analytic Tool* (pp. 276–298). Cambridge University Press.

Bennett, A., & Checkel, J. T. (Eds.). (2014). *Process Tracing From Metaphor to Analytic Tool*. Cambridge University Press. https://doi.org/10.1017/CBO9781139858472

Bento, N., & Fontes, M. (2015). The construction of a new technological innovation system in a follower country: Wind energy in Portugal. *Technological Forecasting and Social Change*, *99*, 197–210. https://doi.org/10.1016/j.techfore.2015.06.037

Bento, N., & Fontes, M. (2019). Emergence of floating offshore wind energy: technology and industry. *Renewable and Sustainable Energy Reviews*, *99*, 66–82. https://doi.org/10.1016/j.rser.2018.09.035

Bergek, A., Hekkert, M., Jacobsson, S., Markard, J., Sandén, B., & Truffer, B. (2015). Technological innovation systems in contexts: conceptualizing contextual structures and interaction dynamics. *Environmental Innovation and Societal Transitions*, *16*, 51–64. https://doi.org/10.1016/j.eist.2015.07.003

Bergek, A., & Jacobsson, S. (2003). The Emergence of a Growth Industry: A Comparative Analysis of the German, Dutch and Swedish Wind Turbine Industries*. In J Stan Metcalfe & Uwe Canter (Eds.), *Change, Transformation and Development* (pp. 197–227). Physica-Verlag.

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., & Rickne, A. (2008). Analyzing the functional dynamics of technological innovation systems: a scheme of analysis. *Research Policy*, *37*(3), 407–429. https://doi.org/10.1016/j.respol.2007.12.003

Bergek, A., Jacobsson, S., Hekkert, M., & Smith, K. (2010). Functionality of Innovation Systems as a Rationale for and Guide to Innovation Policy. In Ruud E. Smits, S. Kuhlmann, & P. Shapira (Eds.), *The Theory and Practice of Innovation Policy* (pp. 115–144). Edward Elgar Publishing. https://doi.org/10.4337/9781849804424.00013

Bergek, A., Jacobsson, S., & Sandén, B. A. (2008). 'Legitimation' and 'development of positive externalities': two key processes in the formation phase of technological innovation systems. *Technology Analysis & Strategic Management*, *20*(5), 575–592.

Berns, B. A., Schnicke, H.-P., & Bombonatti, P. (2015). *Avaliações de opções para o tratamento de efluentes da produção de biogás* (Coletânea de Publicações Do PROBIOGÁS). Ministério das Cidades.

Biesbroek, R., Dupuis, J., Wellstead, A., Kroeze, C., Vranken, H., Caniels, M., & Huitema, D. (2017). Explaining through causal mechanisms: resilience and governance of social–ecological systems. *Current Opinion in Environmental Sustainability*, *28*, 64–70. https://doi.org/10.1016/j.cosust.2017.08.007

Binz, C., Harris-Lovett, S., Kiparsky, M., Sedlak, D. L., & Truffer, B. (2016). The thorny road to technology legitimation — Institutional work for potable water reuse in California. *Technological Forecasting & Social Change*, 249–263. https://doi.org/10.1016/j.techfore.2015.10.005

Binz, C., & Truffer, B. (2017). Global Innovation Systems—A conceptual framework for innovation dynamics in transnational contexts. *Research Policy*, *46*(7), 1284–1298. https://doi.org/https://doi.org/10.1016/j.respol.2017.05.012

Binz, C., Truffer, B., & Coenen, L. (2014). Why space matters in technological innovation systems - Mapping global knowledge dynamics of membrane bioreactor technology. *Research Policy*, *43*(1), 138–155. https://doi.org/10.1016/j.respol.2013.07.002

Binz, C., Truffer, B., & Coenen, L. (2016). Path Creation as a Process of Resource Alignment and Anchoring: Industry Formation for On-Site Water Recycling in Beijing. *Economic Geography*, *92*(2), 172–200. https://doi.org/10.1080/00130095.2015.1103177

Bley Jr., C. (2015). *Biogás - a energia invisível*. Planeta Sustentável.

Bley Jr., C., Libânio, J. C., Galinkin, M., & Oliveira, M. M. (2009). *Agroenergia da biomassa residual* (T. Editora (Ed.)).

Blum, N. U., Bening, C. R., & Schmidt, T. S. (2015). An analysis of remote electric mini-grids in Laos using the Technological Innovation Systems approach. *Technological Forecasting and Social Change*, *95*, 218–233. https://doi.org/10.1016/j.techfore.2015.02.002

Bond, T., & Templeton, M. R. (2011). History and future of domestic biogas plants in the developing world. *Energy for Sustainable Development*, *15*(4), 347–354. https://doi.org/10.1016/j.esd.2011.09.003

Boon, W., & Edler, J. (2018). Demand, challenges, and innovation. Making sense of new trends in innovation policy. *Science and Public Policy*, *45*(4), 435–447. https://doi.org/10.1093/scipol/scy014

Borrás, S., & Edquist, C. (2013). The Choice of Innovation Policy Instruments. *Technological Forecasting & Social Change*, *80*(8), 1–47. https://doi.org/10.1016/j.techfore.2013.03.002

Boschma, R., Coenen, L., Frenken, K., & Truffer, B. (2017). Towards a theory of regional diversification: combining insights from Evolutionary Economic Geography and Transition Studies. *Regional Studies*, *51*(1), 31–45. https://doi.org/10.1080/00343404.2016.1258460

Brown, N., & Michael, M. (2003). A Sociology of Expectations: Retrospecting Prospects and Prospecting Retrospects. *Technology Analysis & Strategic Management*, *15*(1), 3–18. https://doi.org/10.1080/0953732032000046024

Budde, B., Alkemade, F., & Weber, K. M. (2012). Expectations as a key to understanding actor strategies in the field of fuel cell and hydrogen vehicles. *Technological Forecasting and Social Change*, *79*(6), 1072–1083. https://doi.org/10.1016/j.techfore.2011.12.012

Bunge, M. (1997). Mechanism and Explanation. *Philosophy of the Social Sciences*, *27*(4), 410–465.

Bunge, M. (2004). How Does It Work? The Search for Explanatory Mechanisms. *Philosophy of the Social Sciences*, *34*(2), 182–210. https://doi.org/10.1177/0048393103262550

Cabral, C. B. G., Hoffmann, H., Jende, O., Rosenfeldt, S., Colturato, L. F. de D. B., Burkard, T., Linnenberg, C., Daniel, Stinner, W., Zörner, F., & Schröder, E. S. (2015). *Tecnologias de digestão anaeróbia com relevância para o Brasil: substratos, digestores e uso de biogás* (Coletânea de Publicações Do PROBIOGÁS). Ministério das Cidades. https://doi.org/10.1017/CBO9781107415324.004

Cairney, P., Oliver, K., & Wellstead, A. (2016). To Bridge the Divide between Evidence and Policy: Reduce Ambiguity as Much as Uncertainty. *Public Administration Review*, *76*(3), 399–402. https://doi.org/10.1111/puar.12555

Carlsson, B. (2016). Industrial Dynamics: A Review of the Literature 1990–2009. *Industry and Innovation*, *23*(1), 1–61. https://doi.org/10.1080/13662716.2015.1120658

Carlsson, B., Jacobsson, S., Holmén, M., & Rickne, A. (2002). Innovation systems: analytical and methodological issues. *Research Policy*, *31*(2), 233–245. https://doi.org/10.1016/S0048-7333(01)00138-X

Carlsson, B., & Stankiewicz, R. (1991). On the nature, function and composition of technological systems. *Journal of Evolutionary Economics*, *1*(2), 93–118. https://doi.org/10.1007/BF01224915

Cassiolato, J. E. (2015). Evolution and Dynamics of the Brazilian National System of Innovation. In *Emerging Economies* (pp. 265–310). Springer India. https://doi.org/10.1007/978-81-322-2101-2_11

Chaminade, C., & Edquist, C. (2006). *Rationales for public policy intervention from a systems of innovation approach: the case of VINNOVA* (2006/04).

Chaminade, C., & Edquist, C. (2010). Rationales for Public Policy Intervention in the Innovation Process: Systems of Innovation Approach. In R. E. Smits, S. Kuhlmann, & P. Shapira (Eds.), *The Theory and Practice of Innovation Policy An International Research Handbook* (pp. 95–114). Edward Elgar Publishing, Inc.

Chaminade, C., Lundvall, B.-Å., Vang, J., & Joseph, K. J. (2009). No Designing Innovation Policies for Development: Towards a Systemic Experimentation-based Approach. In *Handbook of Innovation Systems and Developing Countries Building Domestic Capabilities in a Global Setting* (p. 20). Edward Elgar Publishing, Inc. https://doi.org/10.4337/9781849803427.00022

Coelho, S. T., Garcilasso, V. P., Ferraz Junior, A. D. N., Santos, M. M. dos, & Joppert, C. L. (2018). *Tecnologias de produção e uso de biogás e biometano* (IEE Intituto de Energia e Meio Ambiente da Universidade de São Paulo; Isabelle Assumpção (Ed.)). Synergia.

Coenen, L., Benneworth, P., & Truffer, B. (2012). Toward a spatial perspective on sustainability transitions. *Research Policy*, *41*(6), 968–979. https://doi.org/10.1016/j.respol.2012.02.014

Coenen, L., Hansen, T., & Rekers, J. V. (2015). Innovation Policy for Grand Challenges. An Economic Geography Perspective. *Geography Compass*, *9*(9), 483–496. https://doi.org/10.1111/gec3.12231

Coimbra-Araújo, C. H., Mariane, L., Bley Jr., C., Frigo, E. P., Frigo, M. S., Araújo, I. R. C., & Alves, H. J. (2014). Brazilian case study for biogas energy: Production of electric power, heat and automotive energy in condominiums of agroenergy. *Renewable and Sustainable Energy Reviews*, *40*, 826–839. https://doi.org/10.1016/j.rser.2014.07.024

Colturato, L. F. de D. B. (2015). *Dessulfuração de biogás da metanização da vinhaça: uma nova abordagem para remoção de altas concentrações de H2S*. UFMG - Universidade Federal de Minas Gerais.

Cooke, P., Gomez Uranga, M., & Etxebarria, G. (1997). Regional innovation systems: Institutional and organisational dimensions. *Research Policy*, *26*(4–5), 475–491. https://doi.org/10.1016/S0048-7333(97)00025-5

Coutinho, L. (2005). Regimes macroeconômicos e estratégias de negócios: uma política industrial alternativa para o Brasil no século XXI. In A. LASTRES, H.M.M., CASSIOLATO, J., ARROIO (Ed.), *Conhecimento, sistemas de inovação e desenvolvimento*. Ed. da UFRJ e Contraponto.

Coutinho, L. G. (2003). *Macroeconomic Regimes and Business Strategies: An Alternative Industrial Policy for Brazil in the Wake of the 21st Century*. "Edward Elgar Publishing, Inc." https://doi.org/http://dx.doi.org/10.4337/9781781009895.00021

Crowley, K., & Head, B. W. (2017). The enduring challenge of "wicked problems": revisiting Rittel and Webber The impact and origins of "wicked problems." *Policy Sci*, *50*, 539–547. https://doi.org/10.1007/s11077-017-9302-4

Da Costa Gomez, C. (2013). 1 – Biogas as an energy option: an overview. In *The Biogas Handbook* (pp. 1–16). https://doi.org/10.1533/9780857097415.1

de Oliveira, L. G. S. (2020). The role and impacts of policies in hampering the biogas transition in Brazi. In L. B. T.-T. R. and P. of L. A. E. T. Noura Guimarães (Ed.), *The Regulation and Policy of Latin American Energy Transitions* (pp. 243–259). Elsevier. https://doi.org/https://doi.org/10.1016/B978-0-12-819521-5.00014-0

De Oliveira, L. G. S., & Negro, S. O. (2019). Contextual structures and interaction dynamics in the Brazilian Biogas Innovation System. *Renewable and Sustainable Energy Reviews*, *107*(February), 462–481. https://doi.org/10.1016/j.rser.2019.02.030

De Oliveira, L. G. S., Subtil Lacerda, J., & Negro, S. O. (2020). A mechanism-based explanation for blocking mechanisms in technological innovation systems. *Environmental Innovation and Societal Transitions*, *37*, 18–38. https://doi.org/https://doi.org/10.1016/j.eist.2020.07.006

Dechezleprere, A., Glachant, M., & Re, Y. (2008). The Clean Development Mechanism and the international diffusion of technologies: An empirical study. *Energy Policy*, *36*, 1273–1283. https://doi.org/10.1016/j.enpol.2007.12.009

Dechezleprêtre, A., Glachant, M., & Mé Niè Re, Y. (2009). Technology transfer by CDM projects: A comparison of Brazil, China, India and Mexico. *Energy Policy*, *37*, 703–711. https://doi.org/10.1016/j.enpol.2008.10.007

del Río, P. (2014). On evaluating success in complex policy mixes: the case of renewable energy support schemes. *Policy Sciences*, *47*(3), 267–287. https://doi.org/10.1007/s11077-013-9189-7

del Río, P., & Mir-Artigues, P. (2014). Combinations of support instruments for renewable electricity in Europe: A review. *Renewable and Sustainable Energy Reviews*, *40*, 287–295. https://doi.org/10.1016/j.rser.2014.07.039

Dewald, U., & Truffer, B. (2011). Market Formation in Technological Innovation Systems—Diffusion of Photovoltaic Applications in Germany. *Industry & Innovation*, *18*(3), 285–300. https://doi.org/10.1080/13662716.2011.561028

DiMaggio, P. J., & Powell, W. W. (1983). *The Iron Cage Revisited: Institutional Isomorphism and Collective Rationality in Organizational Fields*. American Sociological Review. http://www.jstor.org/stable/2095101?seq=1#page_scan_tab_contents

Dosi, G. (1982). Technological paradigms and technological trajectories. *Research Policy*, *11*(3), 147–162. https://doi.org/10.1016/0048-7333(82)90016-6

Dutra, R. M., & Szklo, A. S. (2008). Incentive policies for promoting wind power production in Brazil: Scenarios for the Alternative Energy Sources Incentive Program (PROINFA) under the New Brazilian electric power sector regulation. *Renewable Energy*, *33*(1), 65–76. https://doi.org/10.1016/j.renene.2007.01.013

Edler, J., & Fagerberg, J. (2017). Innovation policy: what, why, and how. *Oxford Review of Economic Policy*, *33*(1), 2–23. https://doi.org/10.1093/oxrep/grx001

Edmondson, D. L., Kern, F., & Rogge, K. S. (2018). The co-evolution of policy mixes and socio-technical systems: Towards a conceptual framework of policy mix feedback in sustainability transitions. *Research Policy*. https://doi.org/10.1016/j.respol.2018.03.010

Edquist, C. (1997). *Systems of Innovation: technologies, institutions, and organizations*.

Edquist, C., & Chaminade, C. (2006). Industrial policy from a systems-of-innovation perspective. *EIB Papers*, *11*(1), 108–132.

Edsand, H.-E. (2017). Identifying barriers to wind energy diffusion in Colombia: A function analysis of the technological innovation system and the wider context. *Technology in Society*, *49*, 1–15. https://doi.org/10.1016/j.techsoc.2017.01.002

Elmer Hansen, U., Nygaard, I., Romijn, H., Wieczorek, A., Kamp, L. M., & Klerkx, L. (2017). *Sustainability transitions in developing countries: Stocktaking, new contributions and a research agenda*. https://doi.org/10.1016/j.envsci.2017.11.009

EPE. (2016). *Demanda de Energia 2050* (No. 13; Estudos Da Demanda de Energia).

Falleti, T. G. (2016). Process tracing of extensive and intensive processes. *New Political Economy*. https://doi.org/10.1080/13563467.2015.1135550

Falleti, T. G., & Lynch, J. (2008). From Process to Mechanism: Varieties of Disaggregation. *Qual Sociol*, *31*, 333–339. https://doi.org/10.1007/s11133-008-9102-4

Falleti, T. G., & Lynch, J. F. (2009). Context and Causal Mechanisms in Political Analysis. *Comparative Political Studies*, *42*(9), 1143–1166. https://doi.org/10.1177/0010414009331724

FEAM, GIZ, & FIEMG. (2015). *Guia técnico ambiental de biogás na agroindústria*. https://doi.org/10.1017/CBO9781107415324.004

Flanagan, K., & Uyarra, E. (2016). Four dangers in innovation policy studies – and how to avoid them. *Industry and Innovation*, *23*(2), 177–188. https://doi.org/10.1080/13662716.2016.1146126

Flanagan, K., Uyarra, E., & Laranja, M. (2011). Reconceptualising the ‘policy mix’ for innovation. *Research Policy*, *40*(5), 702–713. https://doi.org/10.1016/j.respol.2011.02.005

Fouquet, R. (2016). Historical energy transitions: speed, prices and system transformation. *Energy Research & Social Science*, *22*, 7–12. https://doi.org/10.1016/j.erss.2016.08.014

Freeman, C. (1987). *Technology, policy, and economic performance: lessons from Japan*. Pinter Publishers.

Frenken, K. (2017). A Complexity-Theoretic Perspective on Innovation Policy. *Complexity, Governance & Networks*, *0*(1), 35–47.

Fuenfschilling, L., & Truffer, B. (2014). The structuration of socio-technical regimes—Conceptual foundations from institutional theory. *Research Policy*, *43*(4), 772–791. https://doi.org/10.1016/j.respol.2013.10.010

Fuenfschilling, L., & Truffer, B. (2016). The interplay of institutions, actors and technologies in socio-technical systems - An analysis of transformations in the Australian urban water sector. *Technological Forecasting and Social Change*, *103*, 298–312. https://doi.org/10.1016/j.techfore.2015.11.023

Furtado, A. T., Hekkert, M. P., & Negro, S. O. (2020). Of actors, functions, and fuels: Exploring a second generation ethanol transition from a technological innovation systems perspective in Brazil. *Energy Research & Social Science*, *70*, 101706. https://doi.org/https://doi.org/10.1016/j.erss.2020.101706

Furtado, A. T., Scandiffio, M. I. G., & Cortez, L. A. B. (2011). The Brazilian sugarcane innovation system. *Energy Policy*, *39*(1), 156–166. https://doi.org/10.1016/j.enpol.2010.09.023

Gabriel, C.-A. (2016). What is challenging renewable energy entrepreneurs in developing countries? *Renewable and Sustainable Energy Reviews*, *64*, 362–371. https://doi.org/10.1016/j.rser.2016.06.025

Garud, R., & Karnøe, P. (2003). Bricolage versus breakthrough: distributed and embedded agency in technology entrepreneurship. *Research Policy*, *32*(2), 277–300. https://doi.org/10.1016/S0048-7333(02)00100-2

Garud, R., Kumaraswamy, A., & Karnøe, P. (2010). Path Dependence or Path Creation? *Journal of Management Studies*, *47*(4), 760–774. https://doi.org/10.1111/j.1467-6486.2009.00914.x

Garud, R., & Rappa, M. A. (1994). A Socio-Cognitive Model of Technology Evolution: The Case of Cochlear Implants The Case of Cochlear Implants. *Organization Science*, *5*(3), 344–362.

Garud, R., Schildt, H. A., & Lant, T. K. (2014). Entrepreneurial Storytelling, Future Expectations, and the Paradox of Legitimacy. *Organization Science*, *25*(5), 1479–1492. https://doi.org/10.1287/orsc.2014.0915

Garud, R., Stern, L. N., & Jain, S. (1997). *The Embeddedness of Technological Systems* (#IS-97-31).

Geels, F. W. (2005). Processes and patterns in transitions and system innovations: Refining the co-evolutionary multi-level perspective. *Technological Forecasting and Social Change*, *72*(6), 681–696.

https://doi.org/10.1016/j.techfore.2004.08.014

Geels, Frank W. (2002). *Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study*. *31*, 1257–1274. https://doi.org/10.1016/S0048-7333(02)00062-8

Geels, Frank W. (2004). From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. *Research Policy*, *33*(6–7), 897–920. https://doi.org/10.1016/j.respol.2004.01.015

Geels, Frank W. (2010). Ontologies, socio-technical transitions (to sustainability), and the multi-level perspective. *Research Policy*, *39*(4), 495–510. https://doi.org/10.1016/j.respol.2010.01.022

Geels, Frank W., & Schot, J. (2010). The Dynamics of Transitions - A Socio-Technical Perspective. In *Transitions to Sustainable Development: New Directions in the Study of Long Term Transformative Change*. Routledge.

Geels, Frank W. (2017). *Disruption and low-carbon system transformation: Progress and new challenges in socio-technical transitions research and the Multi-Level Perspective*. https://doi.org/10.1016/j.erss.2017.10.010

Geels, Frank W, Sovacool, B. K., Schwanen, T., & Sorrell, S. (2017). The Socio-Technical Dynamics of Low-Carbon Transitions. *Joule*, *1*, 463–479. https://doi.org/10.1016/j.joule.2017.09.018

Gerring, J. (2007). Review Article: The Mechanismic Worldview: Thinking Inside the Box. *B.J.Pol.S*, *38*, 161–179. https://doi.org/10.1017/S0007123408000082

Glennan, S. S. (1996). MECHANISMS AND THE NATURE OF CAUSATION. *Erkenntnis*, *44*, 49–71.

Godin, B., & Lane, J. P. (2013). Pushes and Pulls: Hi(S)tory of the Demand Pull Model of Innovation. *Science, Technology & Human Values*, *38*(5), 621–654. https://doi.org/10.1177/0162243912473163

Goldemberg, J., Coelho, S. T., & Guardabassi, P. (2008). The sustainability of ethanol production from sugarcane. *Energy Policy*, *36*(6), 2086–2097. https://doi.org/10.1016/j.enpol.2008.02.028

Goldenberg, J., & Prado, L. T. S. (2003). Reforma e crise do setor elétrico no período FHC. *Tempo Social*, *15*(2), 219–235. https://doi.org/10.1590/S0103-20702003000200009

Gosens, J., Lu, Y., & Coenen, L. (2015). The role of transnational dimensions in emerging economy 'Technological Innovation Systems' for clean-tech. *Journal of Cleaner Production*, *86*, 378–388. https://doi.org/10.1016/j.jclepro.2014.08.029

Grubler, A., Wilson, C., & Nemet, G. (2016). Apples, oranges, and consistent comparisons of the temporal dynamics of energy transitions. *Energy Research & Social Science*, *22*, 18–25. https://doi.org/10.1016/j.erss.2016.08.015

Hansen, T., & Coenen, L. (2017). Unpacking resource mobilisation by incumbents for biorefineries: the role of micro-level factors for technological innovation system weaknesses. *Technology Analysis and Strategic Management*, *29*(5), 500–513. https://doi.org/10.1080/09537325.2016.1249838

Hedström, P., & Ylikoski, P. (2010). Causal Mechanisms in the Social Sciences. *Annu. Rev. Sociol*, *36*, 49–67. https://doi.org/10.1146/annurev.soc.012809.102632

Hekkert, M. P., Suurs, R. A. A., Negro, S. O., Kuhlmann, S., & Smits, R. E. H. M. (2007). Functions of innovation systems: a new approach for analysing technological change. *Technological Forecasting and Social Change*, *74*(4), 413–432. https://doi.org/10.1016/j.techfore.2006.03.002

Hekkert, Marko P., & Negro, S. O. (2011). Understanding technological change: explanation of different perspectives on innovation and technological change. In *Utrecht University* (Issue November). Utrecht University.

Hekkert, Marko P., Negro, S. O., Heimeriks, G., & Harmsen, R. (2011). Technological Innovation System Analysis: a manual for analysts. In *Utrecht University* (Issue November). Utrecht University.

Heller, L., & Nascimento, N. de O. (2005). Pesquisa e desenvolvimento na área de saneamento no Brasil: necessidades e tendências. *Engenharia Sanitária e Ambiental*, *10*(1), 24–25.

Hellsmark, H., & Jacobsson, S. (2009). Opportunities for and limits to Academics as System builders—The case of realizing the potential of gasified biomass in Austria. *Energy Policy*, *37*(12), 5597–5611. https://doi.org/10.1016/j.enpol.2009.08.023

Hellsmark, H., Mossberg, J., Oderholm, P. S. €, & Frishammar, J. (2016). Innovation system strengths and weaknesses in progressing sustainable technology: the case of Swedish biorefinery development. *Journal of Cleaner Production*, *131*, 702–715. https://doi.org/10.1016/j.jclepro.2016.04.109

Herrera, A. O. (2011). Los determinantes sociales de la política científica en América Latina. Política científica explícita y política científica implícita. In *El pensamiento latinoamericano en la problemática ciencia-tecnología- desarrollo-dependencia* (pp. 133–150). Ediciones Biblioteca Nacional.

Herweg, N., Huß, C., & Zohlnhöfer, R. (2015). Straightening the three streams: Theorising extensions of the multiple streams framework. *European Journal of Political Research*, *54*(3), 435–449. https://doi.org/10.1111/1475-6765.12089

Herweg, N., Zahariadis, N., & Zohlnhöfer, R. (2017). The Multiple Streams Framework: Foundations, Refinements and Empirical Applications. In C. M. Weible & P. A. Sabatier (Eds.), *Theories of the Policy Process* (Fourth Edi, pp. 17–54). Westview Press.

Hillman, K. M., Suurs, R. A. A., Hekkert, M. P., & Sandén, B. A. (2008). Cumulative causation in biofuels development: a critical comparison of the Netherlands and Sweden. *Technology Analysis & Strategic Management*, *20*(5), 593–612. https://doi.org/10.1080/09537320802292826

Holm-Nielsen, J. B., Al Seadi, T., & Oleskowicz-Popiel, P. (2009). The future of anaerobic digestion and biogas utilization. *Bioresource Technology*, *100*(22), 5478–5484. https://doi.org/10.1016/j.biortech.2008.12.046

Holtz, G., Alkemade, F., de Haan, F., Köhler, J., Trutnevyte, E., Luthe, T., Halbe, J., Papachristos, G., Chappin, E., Kwakkel, J., & Ruutu, S. (2015). Prospects of modelling societal transitions: Position paper of an emerging community. *Environmental Innovation and Societal Transitions*, *17*, 41–58. https://doi.org/10.1016/j.eist.2015.05.006

Hoppe, R. (2010). *The Governance of Problems: Puzzling, Powering and Participation*. Policy Press.

Howlett, M. (2011). *Designing Public Policies: Principles and Instruments*. Routledge.

Howlett, Michael, & Cashore, B. (2009). The Dependent Variable Problem in the Study of Policy Change: Understanding Policy Change as a Methodological Problem. *Journal of Comparative Policy Analysis: Research and Practice*, *11*(1), 33–46. https://doi.org/10.1080/13876980802648144

Howlett, Michael, & Del Rio, P. (2015). The parameters of policy portfolios: verticality and horizontality in design spaces and their consequences for policy mix formulation. *Environment and Planning C: Government and Policy*, *33*, 1233–1245. https://doi.org/10.1177/0263774X15610059

Howlett, Michael, & Rayner, J. (2007). Design Principles for Policy Mixes: Cohesion and Coherence in 'New Governance Arrangements.' *Policy and Society*, *26*(4), 1–18. https://doi.org/10.1016/S1449-4035(07)70118-2

Howlett, Michael, & Rayner, J. (2013). Patching vs Packaging in Policy Formulation: Assessing Policy Portfolio Design. In *Politics and Governance* (Vol. 1, Issue 2). https://doi.org/10.12924/pag2013.01020170

Howlett, Michael, & Rayner, J. (2017). Patching versus packaging in policy formulation: assessing policy portfolio design. In *Handbook of Policy Formulation*. https://doi.org/https://doi.org/10.4337/9781784719326.00013

Huang, P., Negro, S. O., Hekkert, M. P., & Bi, K. (2016). How China became a leader in solar PV: an innovation system analysis. *Renewable and Sustainable Energy Reviews*, *64*, 777–789. https://doi.org/10.1016/j.rser.2016.06.061

IEA. (2013). *World Energy Outlook 2013*. OECD/IEA.

Intarakumnerd, P., Chairatana, P., & Tangchitpiboon, T. (2002). National innovation system in less successful developing countries: the case of Thailand. *Research Policy*, *31*(8–9), 1445–1457. https://doi.org/10.1016/S0048-7333(02)00074-4

IPCC. (2014). Climate Change 2014: Synthesis Report. In *Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*.

IRENA. (2018). *Global Energy Transformation: A Roadmap to 2050, Executive Summary*.

IRENA. (2019). *A new world - The geopolitics of the Energy Transformation*.

Jacobsson, S., & Bergek, A. (2004). Transforming the energy sector: the evolution of technological systems in renewable energy technology. *Industrial and Corporate Change*, *13*(5), 815–849. https://doi.org/10.1093/icc/dth032

Jacobsson, S., & Bergek, A. (2011). Innovation system analyses and sustainability transitions: Contributions and suggestions for research. *Environmental Innovation and Societal Transitions*, *1*(1), 41–57. https://doi.org/10.1016/j.eist.2011.04.006

Jacobsson, S., Bergek, A., Finon, D., Lauber, V., Mitchell, C., Toke, D., & Verbruggen, A. (2009). EU renewable energy support policy: faith or facts? *Energy Policy*, *37*(6), 2143–2146. https://doi.org/10.1016/j.enpol.2009.02.043

Jacobsson, S., & Johnson, A. (2000). The diffusion of renewable energy technology: an analytical framework and key issues for research. *Energy Policy*, *28*(9), 625–640. https://doi.org/10.1016/S0301-4215(00)00041-0

Jacobsson, S., & Karltorp, K. (2013). Mechanisms blocking the dynamics of the European offshore wind energy innovation system – Challenges for policy intervention. *Energy Policy*, *63*, 1182–1195. https://doi.org/10.1016/j.enpol.2013.08.077

Jende, O., & et. al. (2016). *Barreiras e propostas de soluções para o mercado de biogás no Brasil* (H. Cardoso, J. Giersdorf, L. Costa Jr., R. Knopki, & W. Santos (Eds.)). PROBIOGÁS.

Johnson, A. (1998). Functions in Innovation System Approaches. In *Conferencia Nelson-Winter.*

Johnson, A., & Jacobsson, S. (2001). Inducment and blocking mechanisms in the development of a new industry: the case of renewable energy in Sweden. In R. Coombs, K. Green, V. Walsh, & A. Richards (Eds.), *Technology and the Market: Demand, Users and Innovation*. Edward Elgar.

Karltorp, K. (2016). Challenges in mobilising financial resources for renewable energy—The cases of biomass gasification and offshore wind power. *Environmental Innovation and Societal Transitions*, *19*, 96–110. https://doi.org/10.1016/j.eist.2015.10.002

Karltorp, K., Guo, S., & Sandén, B. A. (2017). Handling financial resource mobilisation in technological innovation systems - The case of chinese wind power. *Journal of Cleaner Production*, *142*, 3872–3882. https://doi.org/10.1016/j.jclepro.2016.10.075

Kebede, K. Y., & Mitsufuji, T. (2014). Diffusion of solar innovations in Ethiopia: Exploring systemic problems. *International Journal of Technology Management & Sustainable Development*, *13*(1), 53–72. https://doi.org/10.1386/tmsd.13.1.53_1

Kemp, R., Schot, J., & Hoogma, R. (1998). Regime shifts to sustainability through processes of niche formation: The approach of strategic niche management. *Technology Analysis & Strategic Management*, *10*(2), 175–198. https://doi.org/10.1080/09537329808524310

Kern, F. (2015). Engaging with the politics, agency and structures in the technological innovation systems approach. *Environmental Innovation and Societal Transitions*, *16*, 67–69. https://doi.org/10.1016/j.eist.2015.07.001

Kern, F., & Howlett, M. (2009). Implementing transition management as policy reforms: A case study of the Dutch energy sector. *Policy Sciences*, *42*(4), 391–408. https://doi.org/10.1007/s11077-009-9099-x

Kieft, A., Harmsen, R., & Hekkert, M. P. (2016). Interactions between systemic problems in innovation systems: The case of energy-efficient houses in the Netherlands. *Environmental Innovation and Societal Transitions*, *24*(32–44). https://doi.org/10.1016/j.eist.2016.10.001

Kingdon, J. W. (2014). *Agendas, alternatives, and public policies*. Pearson.

Kivimaa, P., & Kern, F. (2015). Creative Destruction or Mere Niche Creation? Innovation Policy Mixes for Sustainability Transitions. *Research Policy*, *02*(1), 29. https://doi.org/10.1016/j.respol.2015.09.008

Kivimaa, P., & Virkamäki, V. (2014). Policy Mixes, Policy Interplay and Low Carbon Transitions: The Case of Passenger Transport in Finland. *Environmental Policy and Governance*, *24*(1), 28–41. https://doi.org/10.1002/eet.1629

Kline, S. J., & Rosenberg, N. (1986). An Overview of Innovation. In R. Landau & N. Rosenberg (Eds.), *The Positive Sum Strategy: Harnessing Technology for Economic Growth* (pp. 275–305). National Academy Press.

Knaggård, Å. (2015). The Multiple Streams Framework and the problem broker. *European Journal of Political Research*, *54*(3), 450–465. https://doi.org/10.1111/1475-6765.12097

Konrad, K., Markard, J., Ruef, A., & Truffer, B. (2012). Strategic responses to fuel cell hype and disappointment. *Technological Forecasting and Social Change*. https://doi.org/10.1016/j.techfore.2011.09.008

Kriechbaum, M., Brent, A. C., & Posch, A. (2018). Interaction patterns of systemic problems in distributed energy technology diffusion: a case study of photovoltaics in the Western Cape province of South Africa. *Technology*

Analysis & Strategic Management. https://doi.org/10.1080/09537325.2018.1473851

Kuhlmann, S., & Rip, A. (2018). Next-Generation Innovation Policy and Grand Challenges. *Science and Public Policy*, 1–7.

Kukk, P., Moors, E. H. M., & Hekkert, M. P. (2015). The complexities in system building strategies — The case of personalized cancer medicines in England. *Technological Forecasting and Social Change*, *98*, 47–59. https://doi.org/10.1016/j.techfore.2015.05.019

Laranja, M., Uyarra, E., & Flanagan, K. (2008). Policies for science, technology and innovation: Translating rationales into regional policies in a multi-level setting. *Research Policy*, *37*(5), 823–835. https://doi.org/10.1016/j.respol.2008.03.006

Lastres, H. M. M., Garcez, C. M. D., Lemos, C. R., Barbosa, E. K., & de Assis Magalhães, W. (2014). Innovation, Production and Innovation Systems and the BNDES' Contribution. In Gustavo Crespi & Gabriela Dutrénit (Eds.), *Science, Technology and Innovation Policies for Development* (pp. 87–108). Springer International Publishing. https://doi.org/10.1007/978-3-319-04108-7_5

Leoneti, B., Leão Do Prado, E., Valle, S., & Borges De Oliveira, W. (2011). Saneamento básico no Brasil: considerações sobre investimentos e sustentabilidade para o século XXI*. *Revista de Administração Pública*, *45*(2), 331–348.

Leydesdorff, L. (2000). The triple helix: an evolutionary model of innovations. *Research Policy*, *29*(2), 243–255. https://doi.org/10.1016/S0048-7333(99)00063-3

Liang, X., & Liu, A. M. M. (2018). The evolution of government sponsored collaboration network and its impact on innovation: A bibliometric analysis in the Chinese solar PV sector. *Research Policy*, *47*(7), 1295–1308. https://doi.org/10.1016/j.respol.2018.04.012

Lindberg, M. B., Markard, J., & Dahl Andersen, A. (2018). Policies, actors and sustainability transition pathways: A study of the EU's energy policy mix. *Research Policy*, 1–15. https://doi.org/10.1016/j.respol.2018.09.003

Lobato, L. C. S., Chernicharo, C. A. L., Pujatti, F. J. P., Martins, O. M., Melo, G. C. B., & Recio, A. A. R. (2013). Use of biogas for cogeneration of heat and electricity for local application: performance evaluation of an engine power generator and a sludge thermal dryer. *Water Science and Technology*, *67*(1), 159–167. https://doi.org/10.2166/wst.2012.549

Loorbach, D. (2014). *To Transition! Governance panarchy in the new transformation*.

Lundvall, B.-Å. (1992). *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning* (B.-Å. Lundvall (Ed.)). Pinter Publishers.

Lundvall, B.-Å., Johnson, B., Andersen, E. S., & Dalum, B. (2002). National systems of production, innovation and competence building. *Research Policy*, *31*(2), 213–231. https://doi.org/10.1016/S0048-7333(01)00137-8

Lundvall, B.-Å., Joseph, K. J., Chaminade, C., & Vang, J. (2009). *Handbook of Innovation Systems and Developing Countries Building Domestic Capabilities in a Global Setting*. Edward Elgar Publishing, Inc.

Machamer, P., Darden, L., & Craver, C. F. (2000). Thinking about Mechanisms. *Philosophy of Science*, *67*(1), 1–25.

Magro, E., Navarro, M., & Zabala-Iturriagagoitia, J. M. (2014). Coordination-Mix: The Hidden Face of STI Policy. *Review of Policy Research*, *31*(5), 367–389. https://doi.org/10.1111/ropr.12090

Mahoney, J. (2001). Beyond Correlational Analysis: Recent Innovations in Theory and Method Social Mechanisms: An Analytical Approach to Social Theory. *Sociological Forum Fuzzy-Set Social Science. Charles C. Ragin. Chicago*, *16*(3), 575–592.

Mahoney, J. (2016). Mechanisms, Bayesianism, and process tracing Mechanisms, Bayesianism, and process tracing. *New Political Economy*, *21*(5), 493–499. https://doi.org/10.1080/13563467.2016.1201803

Malerba, F. (2002). Sectoral systems of innovation and production. *Research Policy*, *31*(2), 247–264. https://doi.org/10.1016/S0048-7333(01)00139-1

Markard, J. (2018). The life cycle of technological innovation systems. *Technological Forecasting and Social Change*, *July*, 1–16. https://doi.org/10.1016/j.techfore.2018.07.045

Markard, J., Hekkert, M., & Jacobsson, S. (2015). The technological innovation systems framework: response to six criticisms. *Environmental Innovation and Societal Transitions*, *16*, 76–86.

https://doi.org/10.1016/j.eist.2015.07.006

Markard, J., & Hoffmann, V. H. (2016). Analysis of complementarities: Framework and examples from the energy transition. *Technological Forecasting and Social Change*, *111*, 63–75. https://doi.org/10.1016/j.techfore.2016.06.008

Markard, J., Raven, R., & Truffer, B. (2012). Sustainability transitions: An emerging field of research and its prospects. *Research Policy*, *41*(6), 955–967. https://doi.org/10.1016/j.respol.2012.02.013

Markard, J., & Truffer, B. (2008). Technological innovation systems and the multi-level perspective: towards an integrated framework. *Research Policy*, *37*(4), 596–615. https://doi.org/10.1016/j.respol.2008.01.004

Markard, J., Wirth, S., & Truffer, B. (2016). Institutional dynamics and technology legitimacy – A framework and a case study on biogas technology. *Research Policy*, *45*(1), 330–344. https://doi.org/10.1016/j.respol.2015.10.009

Mastroeni, M., Tait, J., & Rosiello, A. (2013). Regional innovation policies in a globally connected environment. *Science and Public Policy*, *40*(1), 8–16. https://doi.org/10.1093/scipol/scs115

Mayntz, R. (2004). Mechanisms in the Analysis of Social Macro-Phenomena. *Philosophy of the Social Sciences*, *34*(2), 237–259. https://doi.org/10.1177/0048393103262552

Mazzucato, M. (2016). From market fixing to market-creating: a new framework for innovation policy. *Industry and Innovation*, *23*(2), 140–156. https://doi.org/10.1080/13662716.2016.1146124

Mazzucato, M., & Penna, C. C. R. (2016). *The Brazilian Innovation System : A Mission-Oriented Policy Proposal* (Temas Estratégicos Parao Desenvolvimento Do Brasil).

Mcadam, D., Tarrow, S., & Tilly, C. (2008). Methods for Measuring Mechanisms of Contention. *Qual Sociol*, *31*, 307–331. https://doi.org/10.1007/s11133-008-9100-6

Meijer, I., & Hekkert, M. P. (2010). Managing Uncertainties in the Transition Towards Sustainability: Cases of Emerging Energy Technologies in the Netherlands. *Journal of Environmental Policy & Planning*, *9*(3–4), 281–298.

Melegari de Souza, S. N., Borsoi, A., Santos, R. F., Secco, D., Frigo, E. P., & da Silva, M. J. (2012). Production potential of biogas in sugar and ethanol plants for use in urban buses in Brazil. *Journal of Food Agriculture & Environment*, *10*(1), 908–910.

Menanteau, P., Finon, D., & Lamy, M. L. (2003). Prices versus quantities: Choosing policies for promoting the development of renewable energy. *Energy Policy*, *31*(8), 799–812. https://doi.org/10.1016/S0301-4215(02)00133-7

Mettler, S. (2016). The Policyscape and the Challenges of Contemporary Politics to Policy Maintenance. *Perspectives on Politics*, *14*(2), 369–390. https://doi.org/10.1017/S1537592716000074

Mignon, I., & Bergek, A. (2016a). Investments in renewable electricity production: The importance of policy revisited. *Renewable Energy*, *88*, 307–316. https://doi.org/10.1016/j.renene.2015.11.045

Mignon, I., & Bergek, A. (2016b). System- and actor-level challenges for diffusion of renewable electricity technologies: an international comparison. *Journal of Cleaner Production*, *128*, 105–115. https://doi.org/10.1016/j.jclepro.2015.09.048

Mir-Artigues, P., & del Río, P. (2014). Combining tariffs, investment subsidies and soft loans in a renewable electricity deployment policy. *Energy Policy*, *69*, 430–442. https://doi.org/10.1016/j.enpol.2014.01.040

MME/EPE. (2019). *Balanço Energético Nacional*.

Moraes, B S, Triolo, J. M., Lecona, V. P., Zaiat, M., & Sommer, S. G. (2015). Biogas production within the bioethanol production chain: Use of co-substrates for anaerobic digestion of sugar beet vinasse. *Bioresource Technology*, *190*, 227–234. https://doi.org/10.1016/j.biortech.2015.04.089

Moraes, Bruna S, Zaiat, M., & Bonomi, A. (2015). Anaerobic digestion of vinasse from sugarcane ethanol production in Brazil: challenges and perspectives. *Renewable & Sustainable Energy Reviews*, *44*, 888–903. https://doi.org/10.1016/j.rser.2015.01.023

Moreira, J. R., & Goldemberg, J. (1999). The alcohol program. *Energy Policy*, *27*, 229–245.

Moreira, J. R., Pacca, S. A., & Parente, V. (2014). The future of oil and bioethanol in Brazil. *Energy Policy*, *65*, 7–15.

https://doi.org/10.1016/j.enpol.2013.09.055

Musiolik, J. (2012). *Innovation system-building: on the role of actors, networks and resources - The case of stationary fuel cells in Germany*.

Musiolik, J., & Markard, J. (2011). Creating and shaping innovation systems: Formal networks in the innovation system for stationary fuel cells in Germany. *Energy Policy*, *39*(4), 1909–1922. https://doi.org/10.1016/j.enpol.2010.12.052

Musiolik, J., Markard, J., & Hekkert, M. (2012). Networks and network resources in technological innovation systems: Towards a conceptual framework for system building. *Technological Forecasting and Social Change*, *79*(6), 1032–1048. https://doi.org/10.1016/j.techfore.2012.01.003

Musiolik, J., Markard, J., Hekkert, M., & Furrer, B. (2018). Creating innovation systems: How resource constellations affect the strategies of system builders. *Technological Forecasting & Social Change*. https://doi.org/10.1016/j.techfore.2018.02.002

Nadaletti, W. C. C., Cremonez, P. A. A., de Souza, S. N. M. N. M., Bariccatti, R. A. A., Belli Filho, P., & Secco, D. (2015). Potential use of landfill biogas in urban bus fleet in the Brazilian states: a review. *Renewable & Sustainable Energy Reviews*, *41*, 277–283. https://doi.org/10.1016/j.rser.2014.08.052

Negro, S. O. (2007). *Dynamics of Technological Innovation Systems*. Utrecht University.

Negro, S. O., Alkemade, F., & Hekkert, M. P. (2012). Why does renewable energy diffuse so slowly? A review of innovation system problems. *Renewable and Sustainable Energy Reviews*, *16*(6), 3836–3846. https://doi.org/10.1016/j.rser.2012.03.043

Negro, S. O., Hekkert, M. P., & Smits, R. E. (2007). Explaining the failure of the Dutch innovation system for biomass digestion-a functional analysis. *Energy Policy*, *35*(2), 925–938. https://doi.org/10.1016/j.enpol.2006.01.027

Negro, S. O., Hekkert, M. P., & Smits, R. E. H. M. (2008). Stimulating renewable energy technologies by innovation policy. *Science and Public Policy*, *35*(6), 403–416. https://doi.org/10.3152/030234208X323334

Nelson, R. R., & Winter, S. G. (1982). *An Evolutionary Theory of Economic Change*. Harvard University Press.

Novak, A. C., Schneider, A. H., Simão, C. A. F., Fröhlich, C. E., Sydney, E. B., Bosch, E., Lofhagen, J. C. P., Bazzo, J., Wildauer, L. D. B. S., Makishi, L. M. M., Souza, M. de, & Stumm, M. G. (2016). *OPORTUNIDADES DA CADEIA PRODUTIVA DE BIOGÁS PARA O ESTADO DO PARANÁ* (Vol. 53, Issue 9). SENAI/PR. https://doi.org/10.1017/CBO9781107415324.004

OCDE. (2015). *SYSTEM INNOVATION : SYNTHESIS REPORT*.

OECD. (2015). The Brazilian Agricultural Innovation System. In *OECD Food and Agricultural Reviews* (pp. 103–133). Organisation for Economic Cooperation and Development (OECD). https://doi.org/10.1787/9789264237056-10-en

Onufrey, K., & Bergek, A. (2015). Self-reinforcing Mechanisms in a Multi-technology Industry: Understanding Sustained Technological Variety in a Context of Path Dependency. *Industry and Innovation*, *22*(6), 523–551. https://doi.org/10.1080/13662716.2015.1100532

Padula, A. D., Santos, M. S., Ferreira, L., & Borenstein, D. (2012). The emergence of the biodiesel industry in Brazil: Current figures and future prospects. *Energy Policy*, *44*, 395–405. https://doi.org/10.1016/j.enpol.2012.02.003

Painuly, J. P. (2001). Barriers to renewable energy penetration: A framework for analysis. *Renewable Energy*, *24*(1), 73–89. https://doi.org/10.1016/S0960-1481(00)00186-5

Palhares, J. C. P. (2008). *Biodigestão anaeróbia de dejetos de suínos: aprendendo com o passado para entender o presente e garantir o futuro*. http://www.infobibos.com/Artigos/2008_1/Biodigestao/index.htm

Papachristos, G. (2018). A mechanism based transition research methodology: Bridging analytical approaches. *Futures*, *98*, 57–71. https://doi.org/10.1016/j.futures.2018.02.006

Pasini, K. B. (2011). *Projetos de mecanismo de desenvolvimento limpo (MDL) em aterros sanitários: contribuições das tecnologias ambientais para o desenvolvimento sustentável.* (J. C. S. Andrade, M. V. G. D. Q. Ferreira, & A. C. S. Júnior (Eds.)). Universidade Federal da Bahia.

Patana, A. S., Pihlajamaa, M., Polvinen, K., Carleton, T., & Kanto, L. (2013). Inducement and blocking mechanisms in the

Finnish life sciences innovation system. *Foresight*, *15*(6), 428–445.

Perez, C., & Soete, L. (1988). *Catching up in technology: entry barriers and windows of opportunity*.

Peters, B. G. (2015). *Advanced Introduction to Public Policy*. Edward Elgar.

Pietrobelli, C., & Rabellotti, R. (2009). The Global Dimension of Innovation Systems: Linking Innovation Systems and Global Value Chains. In *Handbook of Innovation Systems and Developing Countries Building Domestic Capabilities in a Global Setting* (p. 25). https://doi.org/10.4337/9781849803427.00015

Pinch, T. J., & Bijker, W. E. (1984). The Social Construction of Facts and Artefacts: or How the Sociology of Science and the Sociology of Technology might Benefit each Other. *Social Studies of Sciece*, *14*, 399–441.

Planko, J., Cramer, J. M., Chappin, M. M. H., & Hekkert, M. P. (2015). Strategic collective system building to commercialize sustainability innovations. *Journal of Cleaner Production*, *112*, 2328–2341. https://doi.org/10.1016/j.jclepro.2015.09.108

Polzin, F., Migendt, M., Täube, F. a., & von Flotow, P. (2015). Public policy influence on renewable energy investments—A panel data study across OECD countries. *Energy Policy*, *80*, 98–111. https://doi.org/10.1016/j.enpol.2015.01.026

Poole, M. S., Van de Ven, A. H., Dooley, K., & Holmes, M. E. (2000). *Organizational Change and Innovation Processes: Theory and Methods for Research*. Oxford University Press.

Querol, M. A. P. (2011). *Learning Challenges in Biogas Production for Sustainability : An activity theoretical study of a network from a swine industry chain*. Helsingin yliopisto.

Querol, M. P., Seppänen, L., & Jackson Filho, J. M. (2015). Understanding the motivational perspectives of sustainability: a case of biogas production. *Production*, *25*(2), 266–277. https://doi.org/10.1590/0103-6513.095212

Ramos-Mejía, M., Franco-Garcia, M.-L., & Jauregui-Becker, J. M. (2017). Sustainability transitions in the developing world: Challebeninges of socio- technical transformations unfolding in contexts of poverty. *Environmental Science and Policy*. https://doi.org/10.1016/j.envsci.2017.03.010

Rathmann, R., Szklo, A., & Schaeffer, R. (2012). Targets and results of the Brazilian Biodiesel Incentive Program - Has it reached the Promised Land? *Applied Energy*, *97*, 91–100. https://doi.org/10.1016/j.apenergy.2011.11.021

Reddy, S., & Painuly, J. . (2004). Diffusion of renewable energy technologies—barriers and stakeholders' perspectives. *Renewable Energy*, *29*(9), 1431–1447. https://doi.org/10.1016/j.renene.2003.12.003

Reichardt, K., Negro, S. O., Rogge, K. S., & Hekkert, M. P. (2016). Analyzing interdependencies between policy mixes and technological innovation systems: the case of offshore wind in Germany. *Technological Forecasting and Social Change*, *106*(106), 11–21. https://doi.org/10.1016/j.techfore.2016.01.029

Reichardt, K., Rogge, K. S., & Negro, S. O. (2017). Unpacking policy processes for addressing systemic problems in technological innovation systems: The case of offshore wind in Germany. *Renewable and Sustainable Energy Reviews*, *80*, 1217–1226. https://doi.org/10.1016/j.rser.2017.05.280

Rico, J. A. P., & Sauer, I. L. (2015). A review of Brazilian biodiesel experiences. *Renewable and Sustainable Energy Reviews*, *45*, 513–529. https://doi.org/10.1016/j.rser.2015.01.028

Rip, A., & Kemp, R. (1998). Technological change. In S. Rayner & E. L. Malone (Eds.), *Human choice and climate change. Vol. II, Resources and technolog* (pp. 327–399). Battelle Press.

Rocha, M. H., Capaz, R. S., Lora, E. E. S., Nogueira, L. A. H., Leme, M. M. V., Renó, M. L. G., & Olmo, O. A. del. (2014). Life cycle assessment (LCA) for biofuels in Brazilian conditions: A meta-analysis. *Renewable and Sustainable Energy Reviews*, *37*, 435–459. https://doi.org/10.1016/j.rser.2014.05.036

Rogge, K. S., Kern, F., & Howlett, M. (2017). Conceptual and empirical advances in analysing policy mixes for energy transitions. *Energy Research & Social Science*, *33*, 1–10. https://doi.org/10.1016/j.erss.2017.09.025

Rogge, K. S., & Reichardt, K. (2013). *Towards a more comprehensive policy mix conceptualization for environmental technological change: a literature synthesis* (S 3; Working Paper Sustainability and Innovation).

Rogge, K. S., & Reichardt, K. (2016). Policy mixes for sustainability transitions: An extended concept and framework for analysis. *Research Policy*, *45*(8), 1620–1635. https://doi.org/10.1016/j.respol.2016.04.004

Rosenbloom, D., Markard, J., Geels, F. W., & Fuenfschilling, L. (2020). Opinion: Why carbon pricing is not sufficient to mitigate climate change—and how "sustainability transition policy" can help. *Proceedings of the National Academy of Sciences*, *117*(16), 8664–8668. https://doi.org/10.1073/PNAS.2004093117

Rotmans, J., & Loorbach, D. (2010). Toward a Better Understanding of Transitions and Thier Governance. In *Transitions to Sustainable Development: New Directions in the Study of Long Term Transformative Change*. Routledge.

Rotolo, D., Hicks, D., & Martin, B. R. (2015). What is an emerging technology? *Research Policy*, *44*(10), 1827–1843. https://doi.org/10.1016/j.respol.2015.06.006

Salles-Filho, S. L. M., Castro, P. F. D. De, Bin, A., Edquist, C., Ferro, A. F. P., & Corder, S. (2017). Perspectives for the Brazilian bioethanol sector: The innovation driver. *Energy Policy*, *108*, 70–77. https://doi.org/10.1016/j.enpol.2017.05.037

Sandén, B. A., & Hillman, K. M. (2011). A framework for analysis of multi-mode interaction among technologies with examples from the history of alternative transport fuels in Sweden. *Research Policy*, *40*(3), 403–414. https://doi.org/10.1016/j.respol.2010.12.005

Sartori, G. (1970). Concept Misformation in Comparative Politics. *The American Political Science Review*, *64*(4), 1033–1053.

Schmidt, T. S., & Dabur, S. (2014). Explaining the diffusion of biogas in India: a new functional approach considering national borders and technology transfer. *Environmental Economics and Policy Studies*, *16*(2), 171–199. https://doi.org/10.1007/s10018-013-0058-6

Schneider, A., & Sidney, M. (2009). What Is Next for Policy Design and Social Construction Theory? *Policy Studies Journal*, *37*(1), 103–119. https://doi.org/10.1111/j.1541-0072.2008.00298.x

Schnicke, H.-P. (2015). *Comercialização de subprodutos de uma planta de biogás* (Coletânea de Publicações Do PROBIOGÁS). Ministério das Cidades.

Schot, J., & Geels, F. W. (2008). Strategic niche management and sustainable innovation journeys: theory, findings, research agenda, and policy. *Technology Analysis & Strategic Management*, *20*(5), 537–554. https://doi.org/10.1080/09537320802292651

Schot, J., & Steinmueller, W. E. (2018). Three frames for innovation policy_ R&D, systems of innovation and transformative change. *Research Policy*, *47*, 1554–1567. https://doi.org/10.1016/j.respol.2018.08.011

Scott, W. R. (1995). *Institutions and organizations*. SAGE.

Sharif, N. (2006). Emergence and development of the National Innovation Systems concept. *Research Policy*, *35*, 745–766. https://doi.org/10.1016/j.respol.2006.04.001

Silveira, B., Chernicharo, C., Cabral, C., Suidedos, C., Platzer, C., Silva, G., Possetti, G. R. C., Heike, H., Moreira, H. C., Adamatti, H. B., Miki, M., Silva, M. da, Takahashi, R., Miki, R., Rosenfeld, S., Araújo, V. de S. F., Valente, V. B., & Villani, W. (2015). *Guia técnico de aproveitamento energético de biogás em estações de tratamento de esgoto* (Coletânea de Publicações Do PROBIOGÁS). Ministério das Cidades. https://doi.org/10.1017/CBO9781107415324.004

Silveira, S., & Johnson, F. X. (2016). Navigating the transition to sustainable bioenergy in Sweden and Brazil: Lessons learned in a European and International context. *Energy Research & Social Science*, *13*, 180–193. https://doi.org/10.1016/j.erss.2015.12.021

Sixt, G. N., Klerkx, L., & Griffin, T. S. (2018). Transitions in water harvesting practices in Jordan's rainfed agricultural systems: Systemic problems and blocking mechanisms in an emerging technological innovation system. *Environmental Science and Policy*, *84*, 235–249. https://doi.org/10.1016/j.envsci.2017.08.010

Smil, V. (2016). Examining energy transitions: A dozen insights based on performance. In *Energy Research & Social Science* (Vol. 22). https://doi.org/10.1016/j.erss.2016.08.017

Smith, A., & Raven, R. (2012). What is protective space? Reconsidering niches in transitions to sustainability. *Research Policy*, *41*(6), 1025–1036. https://doi.org/10.1016/j.respol.2011.12.012

Smits, R., & Kuhlmann, S. (2004). The rise of systemic instruments in innovation policy. *International Journal of Foresight and Innovation Policy*, *1*(1/2), 4. https://doi.org/10.1504/IJFIP.2004.004621

Sorrell, S. (2018). Explaining sociotechnical transitions: A critical realist perspective. *Research Policy*, *47*, 1267–1282. https://doi.org/10.1016/j.respol.2018.04.008

Souza, C. (2005). Federalismo, desenho constitucional e instituições federativas no Brasil pós-1988. *Rev. Sociol. Polít.*, *24*, 105–121.

Sovacool, B. K. (2016). How long will it take? Conceptualizing the temporal dynamics of energy transitions. *Energy Research & Social Science*, *13*, 202–215. https://doi.org/10.1016/j.erss.2015.12.020

Stephan, A., Schmidt, T. S., Bening, C. R., & Hoffmann, V. H. (2017). The sectoral configuration of technological innovation systems: patterns of knowledge development and diffusion in the lithium-ion battery technology in Japan. *Research Policy*, *46*(4), 709–723. https://doi.org/10.1016/j.respol.2017.01.009

Strassburg, U., Marques de Oliveira, N., Rocha JR, W. F. da, Oliveira, N. M. de, & JR, W. F. da R. (2015). Cadeia do Biogás no Oeste do Paraná: À luz da nova economia institucional. *Revista de Estudos Sociais*, *17*(35), 63–82. https://doi.org/10.19093/RES.V17I35.2344

Strunz, S. (2018). Speeding up the energy transition. *Nature Sustainability*, *1*(August), 390–391. https://doi.org/10.1038/s41893-018-0120-2

Suarez, F. F., & Utterback, J. M. (1993). *Patterns of Industrial Evolution, Dominant Designs, and Firms' Survival*.

Suurs, R. A. A. (2009). *Motor of sustainable innovation - Towards a theory on the dynamics of technological innovation systems*. Universiteit Utrecht.

Suurs, R. A. A., & Hekkert, M. P. (2009a). Competition between first and second generation technologies: lessons from the formation of a biofuels innovation system in the Netherlands. *Energy*, *34*(5), 669–679. https://doi.org/10.1016/j.energy.2008.09.002

Suurs, R. A. A., & Hekkert, M. P. (2009b). Cumulative causation in the formation of a technological innovation system: the case of biofuels in the Netherlands. *Technological Forecasting and Social Change*, *76*(8), 1003–1020. https://doi.org/10.1016/j.techfore.2009.03.002

Suurs, R. A. A., Hekkert, M. P., Kieboom, S., & Smits, R. E. H. M. (2010). Understanding the formative stage of technological innovation system development: the case of natural gas as an automotive fuel. *Energy Policy*, *38*(1), 419–431. https://doi.org/10.1016/j.enpol.2009.09.032

Svensson, O., & Nikoleris, A. (2018). Structure reconsidered: Towards new foundations of explanatory transitions theory. *Research Policy*, *47*, 462–473. https://doi.org/10.1016/j.respol.2017.12.007

Tigabu, Aschalew D., Berkhout, F., & van Beukering, P. (2015a). Technology innovation systems and technology diffusion: Adoption of bio-digestion in an emerging innovation system in Rwanda. *Technological Forecasting and Social Change*, *90*(PA), 318–330. https://doi.org/10.1016/j.techfore.2013.10.011

Tigabu, Aschalew D., Berkhout, F., & van Beukering, P. (2015b). Functional evolution and accumulation of technological innovation systems: the case of renewable energy in East Africa. *Science and Public Policy*, *42*(5), 614–631. https://doi.org/10.1093/scipol/scu073

Tigabu, Aschalew Demeke, Berkhout, F., & van Beukering, P. (2015). The diffusion of a renewable energy technology and innovation system functioning: Comparing bio-digestion in Kenya and Rwanda. *Technological Forecasting and Social Change*, *90*(PA), 331–345. https://doi.org/10.1016/j.techfore.2013.09.019

Tilly, C. (2001). MECHANISMS IN POLITICAL PROCESSES. *Annu. Rev. Polit. Sci*, *4*, 21–41.

Turner, J. A., Klerkx, L., Rijswijk, K., Williams, T., & Barnard, T. (2016). Systemic problems affecting co-innovation in the New Zealand Agricultural Innovation System: Identification of blocking mechanisms and underlying institutional logics. *NJAS - Wageningen Journal of Life Sciences*, *76*, 99–112. https://doi.org/10.1016/j.njas.2015.12.001

Unruh, G. C. (2000). Understanding carbon lock-in. *Energy Policy*, *28*(12), 817–830. https://doi.org/10.1016/S0301-4215(00)00070-7

Van de Ven, A. H., Polley, D. E., Garud, R., & Venkataraman, S. (1999). *The innovation journey*. Oxford University Press.

Van de Ven, A. H., & Poole, M. S. (1990). Methods for Studying Innovation Development in the Minnesota Innovation Research Program. *Organization Science*, *1*(3), 313–335. https://doi.org/10.1287/orsc.1.3.313

van Driel, H., & Schot, J. (2005). Radical Innovation as a Multilevel Process: Introducing Floating Grain Elevators in the

Port of Rotterdam. *Technology and Culture*, *46*(1), 51–76.

van Lente, H., & Rip, A. (1998). The Rise of Membrane Technology: From Rhetorics to Social Reality. *Social Studies of Science*, *28*(2), 221–254. https://doi.org/10.1177/030631298028002002

van Welie, M. J., Truffer, B., & Yap, X.-S. (2019). Towards sustainable urban basic services in low-income countries: A Technological Innovation System analysis of sanitation value chains in Nairobi. *Environmental Innovation and Societal Transitions*, *33*, 196–214. https://doi.org/https://doi.org/10.1016/j.eist.2019.06.002

Victor, D. G., Geels, F. W., & Sharp, S. (2019). *Accelerating the Low Carbon Transitions -The Case for Stronger, More Targeted and Coordinated International Action*.

Waldner, D. (2014). What makes process tracing good - causal mechanisms, inference, comparative politics. In A. Bennett & J. T. Checkel (Eds.), *Process Tracing From Metaphor to Analytic Tool* (pp. 126–152). Cambridge University Press.

Walrave, B., & Raven, R. (2016). Modelling the dynamics of technological innovation systems. *Research Policy*, *45*, 1833–1844. https://doi.org/10.1016/j.respol.2016.05.011

Watts, D., Albornoz, C., & Watson, A. (2014). Clean Development Mechanism (CDM) after the first commitment period_ Assessment of the world's portfolio and the role of Latin America. *Renewable and Sustainable Energy Reviews*, *41*, 1176–1189. https://doi.org/10.1016/j.rser.2014.07.146

Weber, K. M., & Rohracher, H. (2012). Legitimizing research, technology and innovation policies for transformative change: Combining insights from innovation systems and multi-level perspective in a comprehensive "failures" framework. *Research Policy*, *41*(6), 1037–1047. https://doi.org/10.1016/j.respol.2011.10.015

Weber, K. M., & Truffer, B. (2017). Moving innovation systems research to the next level: towards an integrative agenda. *Oxford Review of Economic Policy*, *33*(1), 101–121. https://doi.org/10.1093/oxrep/grx002

Weible, C. M., & Sabatier, P. A. (2017). *Theories of the Policy Process* (C. M. Weible & P. A. Sabatier (Eds.); Fourth Edi). Westview Press.

Wellinger, A., Murphy, J., & Baxter, D. (2013). *The biogas handbook : science, production and applications* (J. P. M. and D. B. A. Wellinger (Ed.)). Woodhead Publishing Limited.

Wesseling, J. H., & Van Der Vooren, A. (2017). Lock-in of mature innovation systems: the transformation toward clean concrete in the Netherlands. *Journal of Cleaner Production*, *155*, 114–124. https://doi.org/10.1016/j.jclepro.2016.08.115

Wieczorek, A. J. (2014). *Towards sustainable innovation - Analysing and dealing with systemic problems in innovation systems*. Utrecht University.

Wieczorek, A. J. (2017). Sustainability transitions in developing countries: Major insights and their implications for research and policy. *Environmental Science and Policy*, *84*, 204–216. https://doi.org/10.1016/j.envsci.2017.08.008

Wieczorek, A. J., & Hekkert, M. P. (2012). Systemic instruments for systemic innovation problems: A framework for policy makers and innovation scholars. *Science and Public Policy*, *39*(1), 74–87. https://doi.org/10.1093/scipol/scr008

Wieczorek, A. J., Hekkert, M. P., Coenen, L., & Harmsen, R. (2014). Broadening the national focus in technological innovation system analysis: the case of offshore wind. *Environmental Innovation and Societal Transitions*, *14*, 128–148. https://doi.org/10.1016/j.eist.2014.09.001

Wieczorek, A. J., Negro, S. O., Harmsen, R., Heimeriks, G. J., Luo, L., & Hekkert, M. P. (2013). A review of the European offshore wind innovation system. *Renewable and Sustainable Energy Reviews*, *26*, 294–306. https://doi.org/10.1016/j.rser.2013.05.045

Williamson, J. (1990). *Latin American adjustment : how much has happened?* Institute for International Economics.

Wirth, S., Markard, J., Truffer, B., & Rohracher, H. (2013). Informal institutions matter: Professional culture and the development of biogas technology. *Environmental Innovation and Societal Transitions*, *8*, 20–41. https://doi.org/10.1016/j.eist.2013.06.002

Woolthuis, R. K., Lankhuizen, M., & Gilsing, V. (2005). A system failure framework for innovation policy design. *Technovation*, *25*(6), 609–619. https://doi.org/10.1016/j.technovation.2003.11.002

Yap, X. S., & Truffer, B. (2018). Shaping selection environments for industrial catch-up and sustainability transitions: A systemic perspective on endogenizing windows of opportunity. *Research Policy*, *48*(4), 1030–1047. https://doi.org/10.1016/j.respol.2018.10.002

Yaqoot, M., Diwan, P., & Kandpal, T. C. (2016). Review of barriers to the dissemination of decentralized renewable energy systems. *Renewable and Sustainable Energy Reviews*, *58*, 477–490. https://doi.org/10.1016/j.rser.2015.12.224

Zeng, S., Liu, Y., Liu, C., & Nan, X. (2017). A review of renewable energy investment in the BRICS countries: history, models, problems and solutions. *Renewable and Sustainable Energy Reviews*, *74*, 860–872. https://doi.org/10.1016/j.rser.2017.03.016

ACKNOWLEDGEMENT

Doctoral research is never an easy journey and is only possible due to the support of many people. This situation becomes more evident when one leaves his country to walk this pathway abroad and far from the security of home and friends. Thus, acknowledging the people that walked by you or provided instrumental support in any phase is the minimum I can do here.

First, I am immensely grateful for the opportunity my promoter Marko Hekkert and co-promoter Simona Negro provided me when accepting my research proposal. The exceptional and intellectually exciting Copernicus environment could not be better for my journey.

Simona, I am sure that this thesis would not exist without your continuous support, stimulus and care. I truly appreciate all the effort and time you put into me and my research. Thank you so much!

I have also to thank the different people that took part in various stages of my intellectual journey, with discussions, ideas, corrections, suggestions and informal conversations. I thank all these people in the name of Lea Fünfschilling (my co-promoter). It includes a special thanks to the committee of my thesis. Thank you for the comments, suggestions and the time you dedicated to my research.

Another advantage of putting yourself in a completely different environment is the possibility of expanding your horizons. This extraordinary experience is only possible because of our personal connections. So, I have a special thanks to my Copernicus colleagues, Utrecht friends, and Maastricht Friends. I already miss you, and all of you were important to my academic and personal trajectories.

Here, I have also to thank the specific support I had in Maastricht from Veronique Vasseur. She opened the ICIS doors at Maastricht University for me and made my life easier in a new city. I am also thankful for the support from all ICIS researchers and professors.

Family is that core part of everyone’s life that allows people to move forward even in difficult times. To be at this stage, looking at all my mother and my two brothers passed, it is a profound achievement. I would not be without the incommensurable strenght and force of my mother. I have also to thank my two brothers for their continuous support, even from far away. I love all of you.

Finally, this research would not be possible without the financial support of CNPq (Brazilian National Council for Scientific and Technological development) within the Science without Borders programme. Therefore, I hope Brazil turns the page and comes back to the point of promoting research as a country's developmental strategy.

ANNEX

Annex 1– Sectoral institutional changes for the third phase of Brazilian Biogas Innovation System

Policy or Program	Year	Description	Source
Innovation Law	2004	It aimed to promote innovation by creating a propitious environment, by stimulating interactions and by stimulating innovation in companies	http://www.planalto.gov.br/ccivil_03/_ato2004-2006/2004/lei/l10.973.htm
Power Sector Reform	2004	It introduced the scheme of national power auctions for expanding the generation and transmission capacity, new rules for trading electricity and new institutional actors	http://www.planalto.gov.br/ccivil_03/_ato2004-2006/2004/lei/l10.848.htm
Incentives for Renewable Energy	2004	It promoted renewable energy resources by providing partial exemption of power grid-use tariffs according to the source	http://www2.aneel.gov.br/cedoc/ren2004077.pdf
Public-Private Partnerships Law	2004	It regulated the Public-Private Partnerships.	http://www.planalto.gov.br/ccivil_03/_ato2004-2006/2004/lei/l11079.htm
National Agroenergy Plans	2004-2005	Defined the main guidelines for agroenergy in Brazil (mainly focused on bioethanol and biodiesel).	https://docsagencia.cnptia.embrapa.br/cana/AGROENERGIA.pdf and http://www.agricultura.gov.br/arq_editor/file/Desenvolvimento_Sustentavel/Agroenergia/Programas/PNA%20-%202ed%20portugu%C3%AAs.pdf
National Biodiesel Program (PNPB)	2005	It defined the main guidelines for the promotion of biodiesel production and use	http://www.planalto.gov.br/ccivil_03/_ato2004-2006/2005/Lei/L11097.htm
National Law for Federative Consortiums	2005	It regulated the consortiums between federative entities.	http://www.planalto.gov.br/ccivil_03/_Ato2004-2006/2005/Lei/L11107.htm
Social Label Law	2005	It promotes via fiscal and financing incentives the purchase of biodiesel from small producers	http://www.planalto.gov.br/ccivil_03/_ato2004-2006/2004/decreto/d5297.htm
"Law of Good"	2005	It regulated the fiscal incentives for investing in innovation	https://www.planalto.gov.br/ccivil_03/_Ato2004-2006/2005/Lei/L11196.htm
Embrapa Agroenergy	2006	It created a specific subsidiary of Embrapa to research agroenergy topics	https://www.embrapa.br/agroenergia/historia
Environmental Regulations	2006-2008	Licensing rules for small scale rural, sanitation, agroindustries and landfill projects	http://www.siam.mg.gov.br/sla/download.pdf?idNorma=5956 , http://www.aesa.pb.gov.br/legislacao/resolucoes/conama/377_06_licenciamento_esgotamento.pdf , http://www.siam.mg.gov.br/sla/download.pdf?idNorma=6315 , http://www.siam.mg.gov.br/sla/download.pdf?idNorma=8931
Expansion of Power Sector Incentives for Renewable Energy	2007	It has expanded the 2004 regulation to total exemption of grid-use tariffs for renewable power from residues.	http://www2.aneel.gov.br/cedoc/ren2007271.pdf
National Policy of Basic Sanitation (PNSB)	2007	It has created the institutional framework for sanitation activities, including the main services and principles, obligations of service providers, the shared governance structure between all the federative entities. The universalization of services was included as main target for sanitation services planning.	http://www.planalto.gov.br/ccivil_03/_ato2007-2010/2007/lei/l11445.htm
Restructuration of STI	2007	It changed the governance of STI sectoral funds	http://www.planalto.gov.br/ccivil_03/_Ato2007-2010/2007/Lei/L11540.htm

Sectoral Funds			
National Policy of Climate Change (PNMC)	2009	It institutionalized the climate change field in Brazil, with voluntary targets for mitigation of greenhouse gases emissions and defining five sectoral mitigation plans, including energy and agriculture sectors	http://www.planalto.gov.br/ccivil_03/_ato2007-2010/2009/lei/l12187.htm
Natural Gas Sector Law	2009	It emulated power sector regulatory framework with free-markets environment and similar classification of players	http://www.planalto.gov.br/ccivil_03/_ato2007-2010/2009/lei/l11909.htm
National Policy of Waste Management (PNRS)	2010	It has created the regulatory framework for waste management services, with two relevant modifications: the permission for landfills as last option and the obligation of dumps extinction by the year of 2014 (not achieved).	http://www.planalto.gov.br/ccivil_03/_ato2007-2010/2010/lei/l12305.htm

Annex 2– Logic tests with empirical evidences for Blocking mechanism 1

Contextual factor (a)	**The inexistence of biogas national agenda influencing the misalignment of funding conditions**
Prior observations and/or theoretical background	Given the competition for financial resources, technologies which have institutionalized agendas (e.g. biodiesel) are more likely to have more clear rules in financial infrastructure.
Evidences from empirical observations	Several claims by interviewees and in some documents discussed the impact of the inexistence of a national biogas agenda. While counterfactual examples, such as specific funding lines for other renewable energy with specific policy of national agenda, increased or confidence in this contextual factor.

Contextual factor (b)	**Negative or unfavourable macroeconomic conditions/policies set the negative environment for financial resource availability and accessibility**
Prior observations and/or theoretical background	The history of BBIS in Brazil shows the high relevance of macroeconomic conditions for financial resource allocation and current economic crisis has been reported as an important factor by several interviewees.
Evidences from empirical observations	(i) reduction of funding availability by public players due to crises or unfavourable macroeconomic conditions (This is represented by the huge cuts off in national' and states' budgets occurred mainly from 2014) (ii) reduction of availability of financial resources by other players due to crises or unfavourable macroeconomic conditions (the revision of investment plans by utilities and private companies) (iii) Worsening of funding conditions (the increase in interest rates and reduction of debt quota by BNDES in some lines)

Part (1)	**Limited access to financial resources due to misalignment of funding and biogas investors conditions**
Prior observations and/or theoretical background	Availability and accessibility of resources are fundamental tasks for technological development (references). Empirically, the access to biogas players historically struggle to access funding due to few funding lines specific conditions for funding and weak capacity to provide guarantees
Evidences from empirical observations	(i) for various types of project there is no specific financial lines or conditions (the only one is the Low Carbon Agriculture plan. There is a possibility to use some of BNDES and FINPE funding lines, but then the problem are the financial guarantees) (ii) claims for other financial mechanisms that reduce misalignment (several claims for specific financial mechanisms were made in the interviews and in several documents, e.g. Jende et al. 2016, ABiogás policy proposal, EPE's studies) (iii) the counterfactual example of specific conditions for other bioenergy technologies that have institutionalised agendas

Uniqueness of evidences analysed	We understand the inexistence of biogas-specific funding lines as consequence of several causes. In that sense, this evidence is not very unique, other alternative explanations may come to this point. Particularly because there is one specific funding line implemented. However, the direct claim about the need to more specific funding conditions for biogas projects of different actors, from technology suppliers to governmental bodies, during the interviews and in public documents represents a very distinct evidence of the hard conditions for biogas players accessing financial resources. Therefore, we understood it as a highly unique. Finally, the counterfactual observations do not contribute much for the explanation since they may result from many different causes. However, these examples highlight the non-binary feature of the misalignment, i.e. although they present specific funding conditions, there is still misalignment in some cases. For instance, small-scale projects tend to have more hard access to funding. Therefore, we confirm the existence of our mechanism because of the combinations of evidences supported the comprehension of the functioning of the mechanism.

Annex 3 – Logic tests with empirical evidences for Blocking mechanism 2

Contextual factors (a) and (b)	**Low cooperation among Brazilian firms and lack of political coordination create an hard environment for developing networks structures**
Prior observations and/or theoretical background	Studies indicated these two factors as important weak points of n the Brazilian National Innovation System (BNIS) Cassiolato, 2015 and Mazzucato and Penna, 2016)
Evidences from empirical observations	For the low cooperation among firms, some interviewees mentioned (e.g. R2 stated that "Brazilians hide information fearing the concurrence, the culture of not sharing is very strong among us") and some documents also found out (e.g. Jende et al. 2016) this problematic factor For the lack of political coordination, the existence of different biogas programs within national government and contradiction between federative levels evidenced the problem

Part (1)	**Players struggle develop network structures**
Prior observations and/or theoretical background	Fragmented supportive actions for biogas technologies across BBIS and few network and intermediary structures
Evidences from empirical observations	We observed highly localized actions of networks. Apart from few exceptions (e.g. ABiogás has been trying to have more influence high level political actors, and Itaipu-based networks have been relatively many interactions with several types of actors), most of the interactions cannot reach new players. This is particularly true for national political actors of different sectors. The main empirical observations were: (i) Few formal networks (but increasing recently), (ii) few long-term and overarching projects (projects that encompass different sectoral players and governance levels), (iii) launching of PROBiogás program and other initiatives (ANEEL's strategic R&D and NPD from ABBM) addressing this specific problem, (iv) confirmation of the existence of this problems and mentions about the difficult to create common ground even within associations by interviewees
Uniqueness of evidences analysed	Indeed the existence of few networks and long-term projects is consequence of several causes (low uniqueness), however initiatives addressing this problem highlights the its importance and existence (initiatives are very recent and have not solved it yet) and interviewees (from different sectors and activities) mentioned the problem (both evidences present higher uniqueness). These evidences uphold the confirmation of this part.

Part (2)	**Players struggle to find information/resources and spaces for exchange**
Prior observations and/or theoretical background	Lack or weak network structures avoid the creation or diffusion of system resources (Musiolik et al. 2012)

Evidences from empirical observations	We identified relevant knowledge gaps (e.g. adaptation of small-scale biogas technologies) and lack of system resources (e.g. business models and institutional arrangements). For the former, important issues such as the supply of auxiliary equipment and services and technological gaps (as the adaptation of biogas production and treatment technologies for Brazilian reality) were observed throughout the interviews and documents (e.g. PROBIOGÁS studies). For the latter, the difficult to define business models and institutional arrangements were constant observations in the interviews. In addition, initiatives also tried to address this problem (ANEEL's strategic R&D created a space for interactions as well as associations, PROBiogás and RedeFerti).
Uniqueness of evidences analysed	The knowledge gaps and lack of system resources are naturally expected to be there for a emerging technological field. However, similarly to previous part, the existence of initiatives to address these points suggests that they are important blocking activities. Therefore, we think we have high level of uniqueness to confirm the existence of this part.

Annex 4 – Logic tests with empirical evidences for Blocking mechanism 3

Part (1)	Entrepreneurs struggle to define the best project designs and business models
Prior observations and/or theoretical background	Given the feature of emerging technological field, dominant designs and business models are not established yet.
Evidences from empirical observations	Our previous narrative indicated the inability of some feedstock suppliers and intermediary players to perform key activities to support demand for biogas technological solutions (e.g. the estimation of biogas potential, proper specification of technologies and identification business opportunities). Our main observations were: (i) inability of feedstock suppliers and intermediary players to estimate biogas potential (it was mentioned by interviewees and observed in different events (e.g. news about biogas projects and few number of studies over the biogas potential); (ii) inability to design business models and consequently produce and capture value of biogas technologies (it was mentioned in the interviews and reported in documents the crucial role of theses tasks given the inter sectoral feature of biogas projects and the requirement of knowledge about different regulations and rules. interviewees underpinned the lack of this knowledge); and (iii) inability to recognize the effective demand and the functional and technical specifications of technologies (this was a common mistake discussed by interviewees, particularly due to different feedstocks and types of biodigesters. We also identified projects with this type of problem)
Uniqueness of evidences analysed	We considered the value of these evidences as high unique because they directly demonstrated the assumption (struggle to specify projects due to lack of knowledge). We understand that there is no other alternative explanation. The combination of the empirical evidences increased our reliability on the existence and of the existence and functioning of the mechanism.

Part (2)	Players perceive biogas projects as uncompetitive and complex
Prior observations and/or theoretical background	Competitiveness and complexity are key values for BBIS actors, and the struggle for recognize these values affect actors' perception on biogas technologies
Evidences from empirical observations	The main observations are based on the interviews. Interviewees claimed that biogas projects are still expensive (similar to what was found by Jende et al 2016), require a coordinated public policy (since it groups problems from decentralized energy and intersectoral feature) and are case-by-case analyses. Moreover, the observed high prices of biogas energies in current projects reinforce the low competitiveness character of the biogas energies.
Uniqueness of evidences analysed	The observations based on the interviews' data cannot be considered high unique; interviewees may have other interests in stating this problem. However, the high current prices and low number of projects indicate the uncompetitiveness and complexity of biogas (common problems for emerging technologies). Our evidences are somewhat unique but do not present high level of uniqueness. However, we considered sufficient to confirm this part.

Part (3)	Players decide not to invest in biogas projects (reduce demand)
Prior observations and/or theoretical background	Strategic decision of actors is hugely based on their expectations Budde et al 2012, Borup et al 2006

Evidences from empirical observations	The evidences for this part were mainly the different events that demonstrated the difficult to invest in biogas projects. For instance, the few number of R&D projects that presented some level of success in the ANEEL's strategic R&D (2012-2016), the very few biogas projects in national power actions (no projects in 2015 and 1 project in 2016) and no project in the regional auctions of Sulgás (2016). In addition, interviewees also confirmed the lack of interest in biogas projects due to low competitiveness and complexity of projects.
Uniqueness of evidences analysed	The existence of very few projects may be consequence of several factors. Thus, these evidences not necessarily show the causal link between part two or three,. However, the few number of projects in auctions definitely indicate low competitiveness of the source and also the low demand for biogas technologies. In addition, the information from interviews shed some light on this link , although once more it may be biased. The current empirical observations suggest the existence of the part but more empirical data is necessary to fully assure this part.

Annex 5 – Logic tests with empirical evidences for Blocking mechanism 4

Contextual factor (a)	**Low knowledge about biogas technologies and projects**
Prior observations and/or theoretical background	Exposition to knowledge affects the expectations (Budde et al 2012 and brown and Michael 2003).
Evidences from empirical observations	Different interviewees confirmed that important actors (e.g. public agencies and bodies) do not have recent knowledge on biogas technologies and that some companies still do not know how to design biogas projects.
Part (1)	**Players frame problems and solutions according sectoral assumptions**
Prior observations and/or theoretical background	Actors have different cognitive frames which they use to define problems and solutions (Hoppe 2010) Geel and Raven 2011
Evidences from empirical observations	These different frames were observed many times in the events. For example, energy sector players (especially incumbents) define the rules of commercialization based on large-scale projects. Sanitation agencies focus on the value of environmental treatment of biogas technologies and not on the biogas production efficiency (important for energy use). Players in agriculture sector have as main criteria the cost/benefit analysis of the new investment.
Uniqueness of evidences analysed	We understand these events (defining conditions for specific values of biogas,) as a direct consequence of different ways of evaluating problems and solutions, therefore presenting high uniqueness and confirming the described activities.
Part (2)	**Firms act inconsistently**
Prior observations and/or theoretical background	Divergent and contradictory behaviour among the different firms in emerging technological fields is a crucial factors for field development.
Evidences from empirical observations	We easily observe several projects that presented biogas production efficiency (due to focus on environmental treatment) but were promoted also as an energy solution. Additionally, partial solutions are also promoted by companies (e.g. selling (an inadequate) biodigester without pay attention for operational conditions) , which decreases the trust of biogas solutions (part (4)).
Uniqueness of evidences analysed	We understand the development of projects like those as a very inconsistent action by firms. Because it focus on short-term but undermines long-term credibility. Thus, we are confident to confirm this part.
Contextual factor (b)	**Rigid organizational structures**
Prior observations and/or theoretical background	Innovative knowledge requires absorptive capacity from organization, which is also dependent on the organization structure (Cohen and Levinthal 1990)
Evidences from empirical observations	Two interviewees mentioned this factor (interviewees G1 and G6) and initiatives took form of organizational instruments (Howlett 2011) (e.g. the PROBiogás program (2013) and the creation of specific committees along biogas policies in states, for instance São Paulo (2012) and Rio Grande do Sul (2016))
Part (3)	**Public bodies produce contradictory policies, regulations and guidelines**
Prior observations and/or theoretical background	Divergent behaviour of public bodies is a well studied topic for both innovation and policy analyses.
Evidences from empirical observations	We observed actions towards the development of biogas projects of different public bodies that contradict each other. The most evident was the unsynchronised regulations of biomethane by ANP counteracting the Rio de Janeiro state level policy highlight the differences on ANP's value of protection of gas consumers and market development of Rio de Janeiro's policy. Another example was the first version of net-metering regulation (2012), which presented low maximum installed capacity favouring solar technologies.
Uniqueness of evidences analysed	These observations strongly confirm the contradiction of actions of public bodies as a consequence of different framings by actors. We understand that these observations are presently mostly because of

	the misalignment of understandings about the possibilities of biogas technologies and the sectoral frames.
Part (4)	**Players perceive environment for biogas projects as highly uncertain**
Prior observations and/or theoretical background	High levels of uncertainty blocks the development of technological fields
Evidences from empirical observations	The evidences for this part are based on the narrative of absence of biogas national agenda, lack of biogas-specific regulations and lack of trust on biogas technologies. In other words, the sequence of events demonstrated that the previous contradictory actions result in high level of technological uncertainty (via projects that do not live up to promises) and political uncertainty (given the unpredictability public bodies' actions). These problems are the reasons why actors in BBIS perceive biogas as an uncertain technology. In addition, some interviewees (mostly from governmental bodies and utilities) demonstrated some uncertainty about the biogas environment.
Uniqueness of evidences analysed	These sequences of events show rather clearly, leaving little room for alternatives, that actors in BBIS sense the biogas environment as uncertain due to divergence in actions.
Part (5)	**Players cannot foresee future pathways for biogas technologies**
Prior observations and/or theoretical background	Future perspective of possible socio-technical trajectories is an important guide for actions in emerging technological fields, especially if they present many possibilities of socio-technical configurations as for biogas technologies.
Evidences from empirical observations	We found only one player that developed projection for biogas technologies (EPE's studies) but we did not find any technological roadmap. Moreover, targets and goals for biogas technologies are also very limited (e.g. ABC program has a very shy target for biogas in swine manure treatment systems. Also, some targets are very localised and consequence of projects). Interviews also corroborate the lack of future vision in the biogas field.
Uniqueness of evidences analysed	The few number of projections and the targets is a string evidence that in an environment of uncertainty players do not engage in future speculations.
Part (6) = Part (2) of bm3	**Players perceive biogas projects as uncompetitive and complex**

Annex 6 – Logic tests with empirical evidences for Blocking mechanism 5

Part (1)	**Few Brazilian players offer biogas-specific services**
Prior observations and/or theoretical background	Ancillary services and equipment are important system resources for an emerging technological field
Evidences from empirical observations	For this part, the main empirical observations were the confirmation of entrepreneurs during the interviews and statement in some documents (e.g. PROBiogás studies mentioned the need to offer local services and RedeFerti tries to develop local capabilities for laboratorial services). Interviewees mentioned, for instance, the difficulty to find national suppliers of ancillary equipment for biogas projects (e.g. valves and gas cleaners, which are simple equipment utilized in other industries, but hardly found in adequate specification for biogas projects).
Uniqueness of evidences analysed	Although the evidences do not provide a definitive level of uniqueness, they are very likely consequence of the low national supply. A definitive evidence would require access to detailed data of biogas projects to check the provider of these services.

Contextual factors (a) and (b)	**The combination of low innovative character of Brazilian firms with their short-termism value and rent-seeking behaviour produces a conservative environment for firms acquire new knowledge**
Prior observations and/or theoretical background	Studies of BNIS
Evidences from empirical observations	Again, interviews were the most important source of evidences. Interviewees corroborate the lack of motivation to invest and the impact of short-termism in innovation of Brazilian firms. Additionally, they mentioned that the Brazilian business environment leads to rent-seeking behaviour. The very few companies with R&D investment in biogas activities also support this contextual factor.

Part (2)	**Few Brazilian firms supply biogas technologies**
Prior observations and/or theoretical background	Bioenergy technologies require local technological development because of the highly relevance of local and regional conditions for projects.
Evidences from empirical observations	The promoted lists of technology suppliers in the websites of PROBiogás and Associations contain mostly international companies. The national market struggles to offer biodigesters, gas upgrading systems, mixers, motors, and it varies considerably across feedstock, use of biogas and project scale

Uniqueness of evidences analysed	We regard this evidence of highly unique as we cannot find other explanation for it; Therefore, this part is confirmed.

Part (3)	**Entrepreneurs have to develop the capabilities by themselves (and are subject to higher services costs)**
Prior observations and/or theoretical background	The development of local capabilities is essential for an emerging technological field. In addition, alignment complementarity to existent structures would make these development easier.
Evidences from empirical observations	Several evidences pointed out this contextual factor. First, there was explicit claims by interviewees on this issues (interviewees constantly mentioned the difficulties of operating biogas projects (e.g. need to hire services, labour and develop own capabilities), the low offer and the geographic concentration of biogas services as factors to increase costs). Second, we observed the low offer of biogas-specific courses (few specific and recent trainings, most in south region). Then, the low availability of skilled labour (observed in documents and confirmed by interviewees). Finally, some initiatives try to o mitigate this problem (e.g. utilities develop their own structure, creation of task forces as laboratory rounds CIBiogás, and PROBIOGÁS studies)
Uniqueness of evidences analysed	Apart from the initiatives that explicitly try to solve the problems, the observations by themselves tend to present low uniqueness. For instance, interviewees also mentioned that this problem is partly result of incipient market. However, the combination of observations comprise a strong evidence to confirm our description.

Contextual factors (c) and (d)	**The low familiarity of international biogas companies with the Brazilian conditions of biogas projects and business environment entails higher costs for project development Costs of importation of technologies and services is influenced by macroeconomic conditions**
Prior observations and/or theoretical background	Macroeconomic conditions are important factors to define the costs of knowledge imports.
Evidences from empirical observations	For the low familiarity of international companies, there were explicit mentions by interviewees and statements in documents (e.g. several interviewees mentioned the need for technology adaptation given the conditions of Brazilian biogas projects and the difficulty by international companies to understand the institutional frameworks. In contrast, documents brought the information on the lack of motivation by international companies due to the limited biogas market in Brazil and the impediment of using BNDES funding for international equipment). For macroeconomic conditions, the main observations are the impact of exchange rate and financial conditions on importation of knowledge (some documents mentioned the exchange rate effect and interviewees mentioned the difficulty to find funding for foreign technologies)

Part (4)	**Entrepreneurs need to acquire external knowledge**
Prior observations and/or theoretical background	Importation of knowledge is very common for emerging technological fields and especially in developing countries
Evidences from empirical observations	Once more, interviews came across this point (there was a widespread recognition that there is still a high dependency in external technologies). Additionally, the main lists of suppliers indicate several international companies. Finally, during the mapping of events, we found several resolutions defining special conditions for importing biogas equipment.
Uniqueness of evidences analysed	In term of uniqueness, the existence of specific resolutions for importing equipment in special conditions would be sufficient by itself. However, in combination with the claim of interviewees and the evidence of higher number of international suppliers, these evidences become even stronger.

Part (5) = Part (2) of bm3	**Players perceive biogas projects as uncompetitive and complex**

Part (6) = Part (3) of bm3	**Players decide not to invest in biogas projects (reduce demand)**

CURRICULUM VITAE

Luiz Gustavo Silva de Oliveira was born in Rio de Janeiro (1984), Brazil. In 2002, he started his bachelor’s in electrical engineering at the Federal Fluminense University (UFF) in Niteroi, when he entered the energy world and worked for more than 14 years.

After his bachelor's graduation, he started his double academic and professional life. At Dalkia Brasil, he worked with energy efficiency and decentralised energy projects. Meanwhile, he started his Master in Energy Planning at the Federal University of Rio de Janeiro (2009). His master's research comprised the analysis of agricultural wastes energy deployment for Brazil, including developing different scenarios. Before his master's graduation, he moved to the Brazilian government energy planning agency (2010), the Energy Research Office (EPE), in Rio de Janeiro.

At EPE, first, he joined the energy demand team, working with energy efficiency planning and analysis, distributed generation, and energy demand modelling. Then, after a few years, he joined the team that developed the waste the first official waste to energy studies, with the publication of biogas potential, market and scenario studies. Finally, he worked on the preliminary scenario analysis of Brazil's 2050 long-term energy plan.

These years of combined academic and professional experience in the private and public sectors contributed to his curiosity about how to inform strategic decision-making to foster clean energy technologies, particularly waste-to-energy technologies like biogas technologies. Hence, Luiz Gustavo applied to the Science without Borders grant scheme and decided to move abroad and develop his PhD research at Utrecht University, which has led to this thesis.

Meanwhile, he also worked as a consultant for private companies, government, and international organisations. The most relevant project he was involved in was the ‘Key option for mitigation of GHG emissions in Brazil’, led by the Brazilian Ministry of Science, Technology and Innovation and the United Nations Environmental Programme. He joined the team responsible for the scenario analyses of sanitation and waste-to-energy sectors in this project. The outcomes of this project informed the Brazilian negotiations at COP 2015 in Paris.

In 2019, Luiz Gustavo returned to Brazil to work as the Local Consultant for the International Energy Agency (IEA). In this position, he leads the IEA analyses on Brazil and supports IEA operations and projects in Brazil and other Latin American countries. He has also been working as an independent consultant for governments, think tanks and companies. For example, the Brazil Energy Programme (2020) was a flagship project, an international collaboration between the UK and Brazilian governments. In this project, he joined the waste-to-energy workstream and was responsible for the barriers, policy recommendations, business models and strategic analyses.


A