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A mechanism-based explanation for blocking mechanisms in technological innovation systems

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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.

1. Introduction

The emergence of new technological fields is often studied by using the Technological Innovation System (TIS) framework (Bergek et al., 2008a). 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 et al., 2008a; Hekkert et al., 2007; Markard, 2018; Suurs and Hekkert, 2009). 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 et al., 2008a; Wieczorek and 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 et al., 2008a; Wieczorek and Hekkert, 2012). Systemic problems are understood as inadequate structural elements (Wieczorek and 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 et al., 2008a). Both concepts promise insights to guide policymaking in that they correct for systemic problems or dissolve blocking mechanisms.

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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 and 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)[1] has gained ground in the social sciences in the last decades (Hedström and 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 (Beach and Pedersen, 2016a; Falleti and Lynch, 2008; Hedström and 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 2). Next, we introduce the approach of MBE to elucidate why and how this is a useful framework for our study (Section 3). Section 4 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 analysis in innovation systems, mitigate the discussed explanatory gaps and lead to more precise information for policymaking (Section 6).

2. Innovation systems, systemic problems and blocking mechanisms

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 and Truffer, 2017). These contexts can be countries, sectors, regions or technological fields (Asheim and Isaksen, 2002; Carlsson and 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 and 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 and Edquist, 2010; Edquist and 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 and Edquist, 2010; Negro et al., 2012; Wieczorek and Hekkert, 2012; Woolthuis et al., 2005). We agree with Bergek et al.

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

(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 et al., 2008a; Hekkert et al., 2007)[2] is the most prominent framework for this task. Functional analysis postulates that key processes at system level 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 et al., 2008a; Hekkert et al., 2007).

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 and Hekkert, 2012) and blocking mechanisms (Bergek et al., 2008a). Instead of choosing one terminology over the other[3], 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 and 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 and 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 Fig. 1 below.

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[4] . 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 infrastructures (Wieczorek and 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 and 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 et al., 2008a). They are also considered to influence the functional dynamics of a TIS (Bergek et al., 2010, 2008a), as well as they are called structural weaknesses (Jacobsson and Bergek, 2011)[5] .

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. Fig. 2 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.

Similarly to systemic problems, the analysis of blocking mechanisms is an intermediary step to 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 et al., 2008a). 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.

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[2] 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.

[3] 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).

[4] Systemic instruments.

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

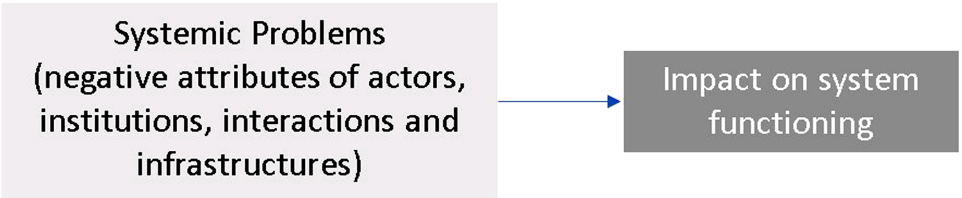

Fig. 1. Systemic problems' explanation for poor system functioning in TIS literature.

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 Fig. 2, 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 and 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[6] and the lack of clarity of conceptual explanations[7] .

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 and Johnson, 2000; Johnson and 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 1 have direct implications on how to explain the phenomena of TIS hindering factors.

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 and 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)[8] . Thus, the criticisms of generic or oversimplified policy recommendations (Bening et al., 2015; Kern, 2015) can be understood as consequence of these conceptual limitations.

2.3. 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

[6] More recently, TIS scholars have moved towards this direction (Bergek et al., 2015).

[7] For *ad hoc*, we mean case-by-case. De Oliveira and Negro (2019) is an exception in proposing an analytical method for this task.

[8] 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 and Steinmueller, 2018). This is another example of different uses for the same nomenclature. As mentioned in Section 2.1, systemic failure is also used in innovation system literature for discussing the analytical hindering factors.

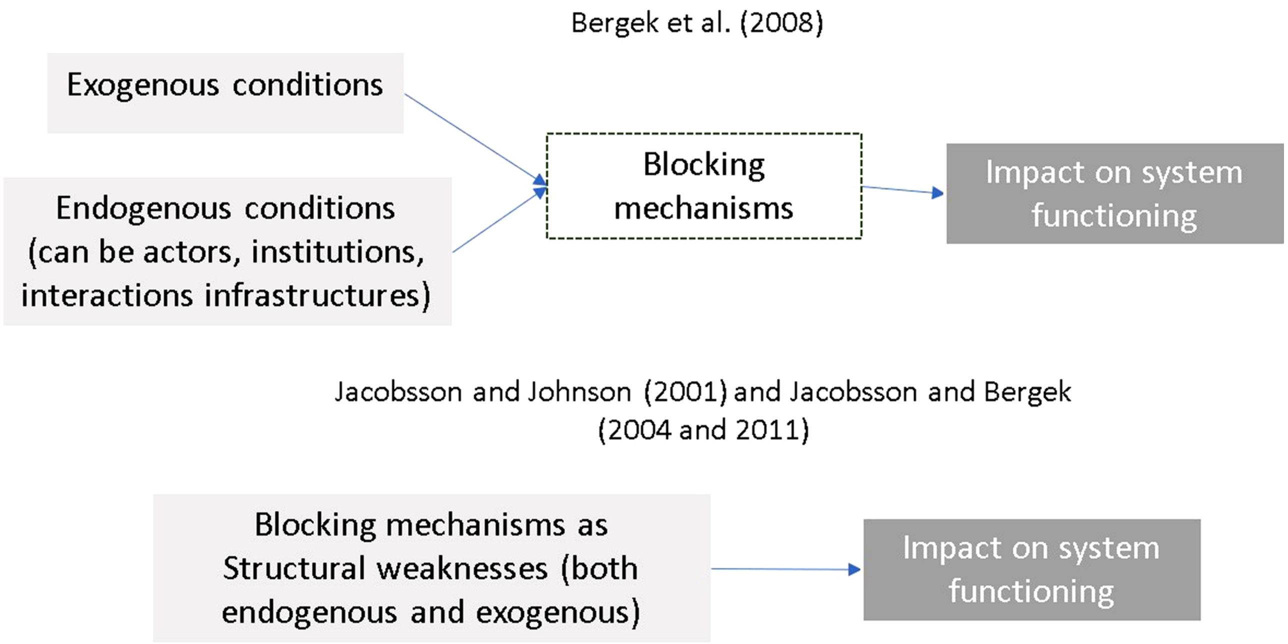

Fig. 2. Blocking mechanisms' explanation for poor system functioning in TIS literature.

Table 1
Conceptual limitations of systemic problems and blocking mechanisms.

Conceptual explanation	Direct interdependence of systemic problems	Direct interdependence 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	✓	✓

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 and 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. Fig. 3 presents their proposition.

This proposition seems to follow one of the understandings of blocking mechanisms, which sees blocking mechanisms as the causes of poor system functioning (see Fig. 2). 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. 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 and Ylikoski, 2010; Mayntz, 2004). This increased attention led

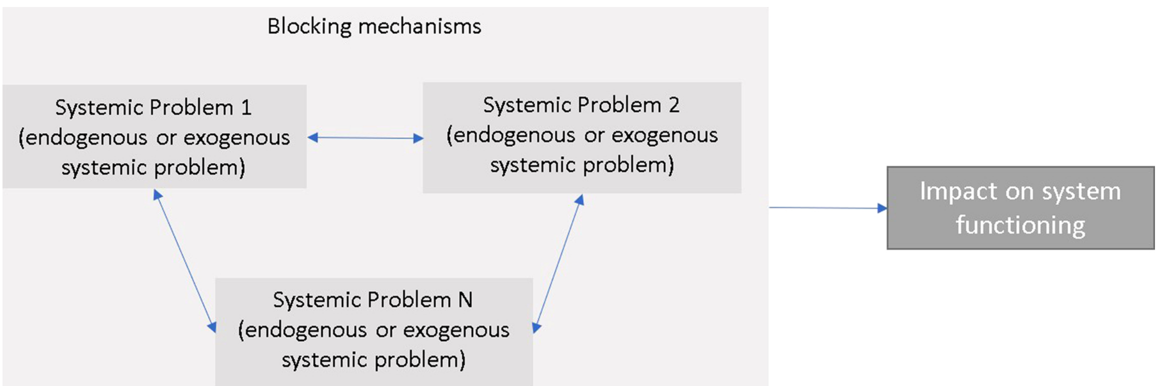

Fig. 3. Kieft et al. (2016) proposition to explain hindering factors in TIS.

to distinct framings of mechanisms (Bechtel and Abrahamsen, 2005; Bunge, 1997; Falleti and Lynch, 2009; Gerring, 2007; Glennan, 1996; Hedström and 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 (Beach and Pedersen, 2016a; Falleti and Lynch, 2009; Hedström and Ylikoski, 2010). Although the literature shows that there is no consensus about what mechanisms are[9] ; 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' (Beach and Pedersen, 2016a; Falleti and Lynch, 2009; Mahoney, 2016). This 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 and 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[10] 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 (Beach and 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 (Beach and Pedersen, 2016a). This also means that mechanisms are ontologically different from variables (Mahoney, 2016, 2001). Being conceptual constructions, mechanisms can be portable across a bounded population of cases that shares similar contextual conditions[11] (Beach and Pedersen, 2016a, 2016b; Falleti and Lynch, 2009). Contextual conditions are regarded as "enabling factors" (Beach and Pedersen, 2016a:89), "relevant aspects" or "initial conditions" (Falleti and Lynch, 2009:1152)[12] 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 and 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 and 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 (Beach and 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 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.

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 and Nikoleris, 2018; Weber and 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 and 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 and 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 and 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

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

[10] Mechanisms' parts must present productive continuity, i.e. causal connection between each activity (Beach and Pedersen, 2016a; Machamer et al., 2000).

[11] This requires causal homogeneity across the population of cases (Beach and Pedersen, 2016b).

[12] 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.

underlies the TIS literature for system functioning – as it is possible to observe for hindering factors in Figs. 1 and 2. TIS analyses explains system functioning either by presenting a longitudinal analysis of events (Hekkert et al., 2007; Negro et al., 2007) or by identifying the presence of inducement and blocking mechanisms (Bergek et al., 2008a). 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. (2016a) 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[13] . 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[14] .

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 (Beach and Pedersen, 2016a). This fact entails that the causal attributes must be defined and be compatible with the causal claim made[15] .

Obviously, TIS literature is the starting point for developing a mechanism-based framework for 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 Figs. 1, 2 and 3) 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, 2008a; Kieft et al., 2016; Markard and 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[16]. 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 (Fig. 2

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

[14] 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.

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

[16] 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.

and Fig. 3). 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-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, 2008a; 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[17] . 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[18] . 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 Fig. 4 below depicts our proposition.

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 2. First, the clear and explicit

[17] 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.

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

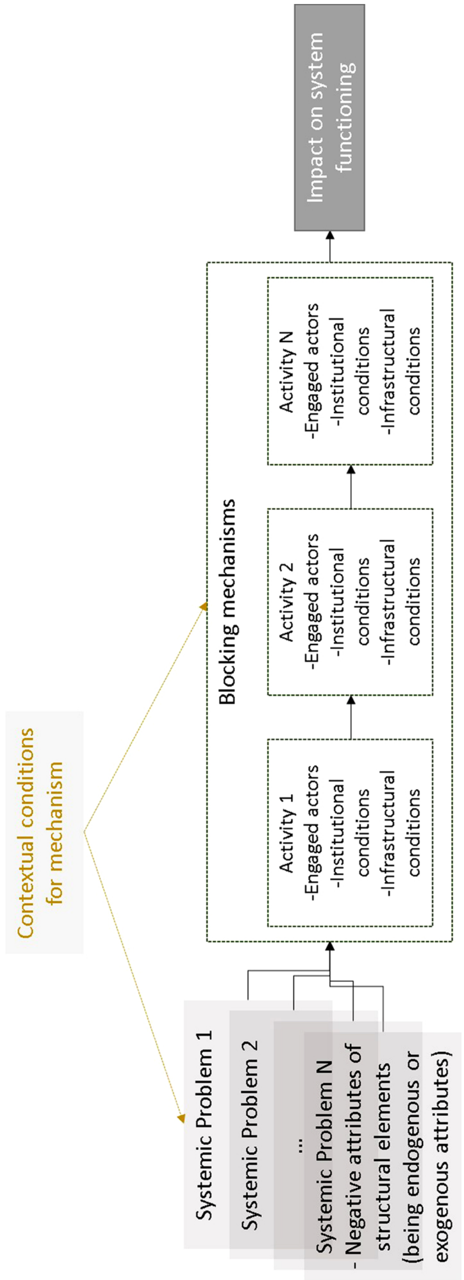

Fig. 4. Mechanism-based explanation for TIS hindering factors.

Table 2
Interdependence of TIS hindering factors.

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

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 Fig. 4, 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 2 below summarises the interdependencies that the framework explains.

As it is possible to see, the grey areas indicate how to interpret the conceptual explanation provided by the proposed framework in terms of types of interdependencies. 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[19] .

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., 2018, 2012; 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 informed as 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 (Howlett and Rayner, 2013; Rogge et al., 2017; Weible and 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 (Beach and Pedersen, 2019, 2016a). As analyses may lead to the identification of several different mechanisms, they can be more comprehensive in terms of interdisciplinary knowledge – for the conceptualisation of activities – and of data collection – for supporting the conceptual claims. Section 5 below illustrates part of these implications.

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 and Jacobsson, 2003; Jacobsson and Bergek, 2004; Jacobsson and Johnson, 2000; Johnson and Jacobsson, 2001)[20] . These studies investigate the development of renewable energy

[19] 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.

[20] These studies have more than 2500 citations on Google Scholar as in15/11/2018.

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 (Beach and Pedersen, 2019, 2016a, 2013; Bennett and 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 (Beach and 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[21] .

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 (Beach and Pedersen, 2016a)

Thus, we conduct the illustrative case by following the guidelines of the process-tracing methodology (Beach and Pedersen, 2016a, 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 Fig. 4.

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 Fig. 5). 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).

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 Fig. 6). 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 Fig. 5.

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[22], bringing external influences into the focal innovation system. Johnson and Jacobsson (2001:19)

[21] For more details, see Bennett (2014) and Beach and Pedersen (2016a).

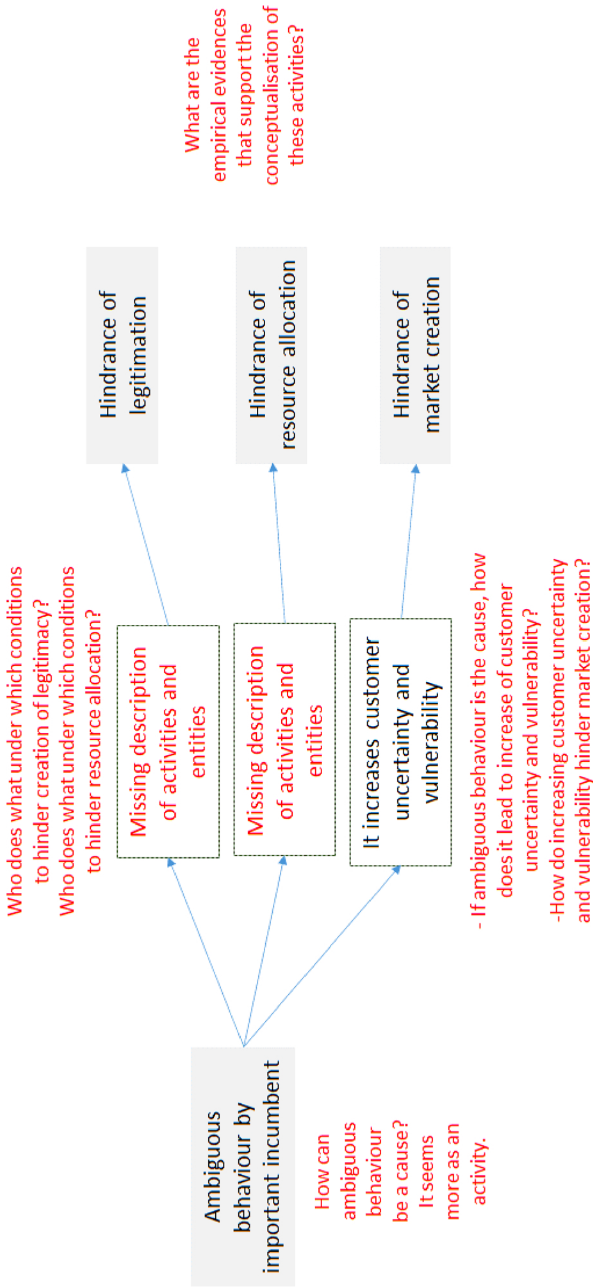

Fig. 5. Example of ambiguous behaviour blocking mechanism and gaps in explanation.

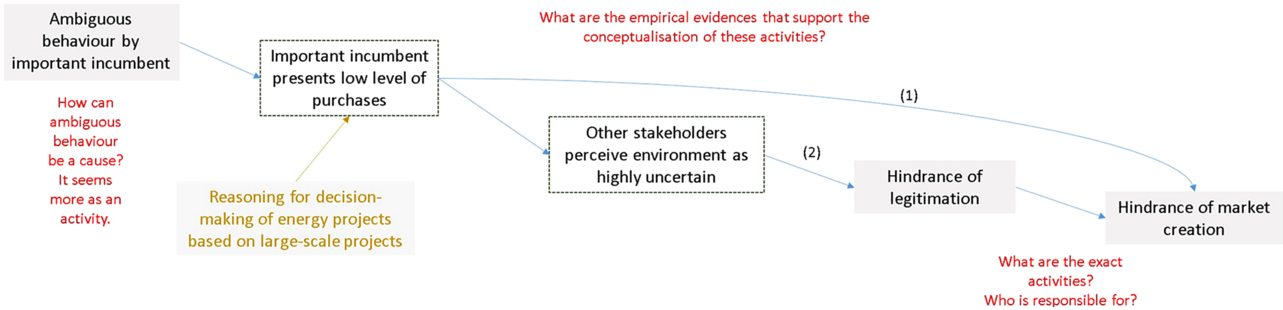

Fig. 6. Two pathways possibly caused by ambiguous behaviour influenced by an exogenous condition.

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 33) to renewable energy innovations (light grey box with yellow text in Fig. 6). As these renewable energy innovations present smaller scales, it may lead to less interest in these innovations. Therefore, this sectoral decision-making reasoning[23] represents an important exogenous influence on the ambiguous behaviour of these actors.[24]

By now it is easy to see that describing the exact mechanism helps to explore the gaps in the argumentation and in empirical data[25] . 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 Fig. 7)[26] .

Lastly, the interdependence of TIS hindering factors can be demonstrated if we take the example of ambiguous behaviour and open up the *hindrance of the legitimation* box[27] . 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 Fig. 8).

Therefore, for this example, applying the MBE led us from the simple understanding of mechanism (Fig. 5) 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 Fig. 9 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).

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) (Beach and 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

[22] The innovation system of renewable energy technology (the specific case analysed) is one of them. However, it plays in power and nuclear sectors, which comprise other types of technologies and activities.

[23] It can also be understood as common practices or routines (Nelson and Winter, 1982)

[24] 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.

[25] The more detailed explanation of Fig. 6 compared to Fig. 5 indicates that this explanation was not presented in a clear manner, although analyses provided this understanding in different publications.

[26] 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 behaviour. The two blocking mechanisms are the lock-in to established technologies (which include the ambiguous behaviour) and lack of long-term governmental vision.

[27] This represents the red question of how and which activities blocked legitimation in Fig. 5.

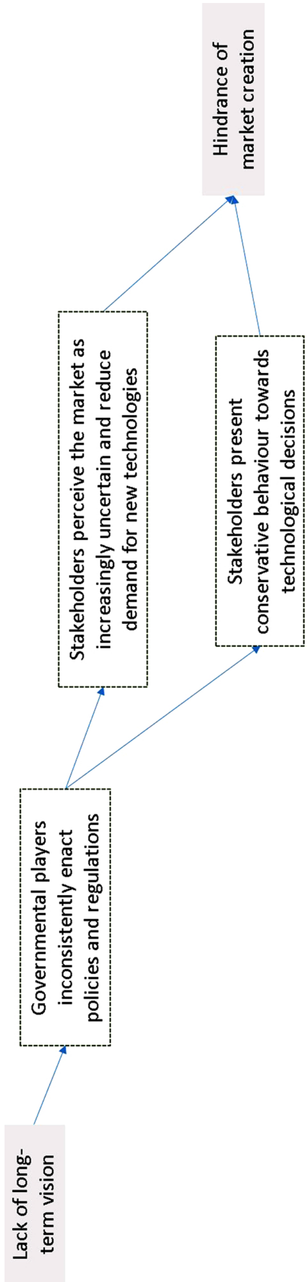

Fig. 7. Example of ambiguous behaviour by government as blocking mechanism.

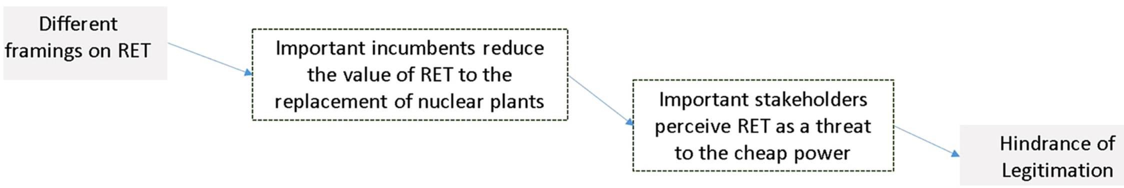

Fig. 8. Nuclear trauma blocking mechanism hindering legitimation.

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 et al., 2008a; Wieczorek and 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 Fig. 4). 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 (Beach and Pedersen, 2016a; Falleti and 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 2 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 et al., 2008b; Suurs and Hekkert, 2009). 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 et al., 2008b), 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 Fig. 9).

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 Fig. 9).

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

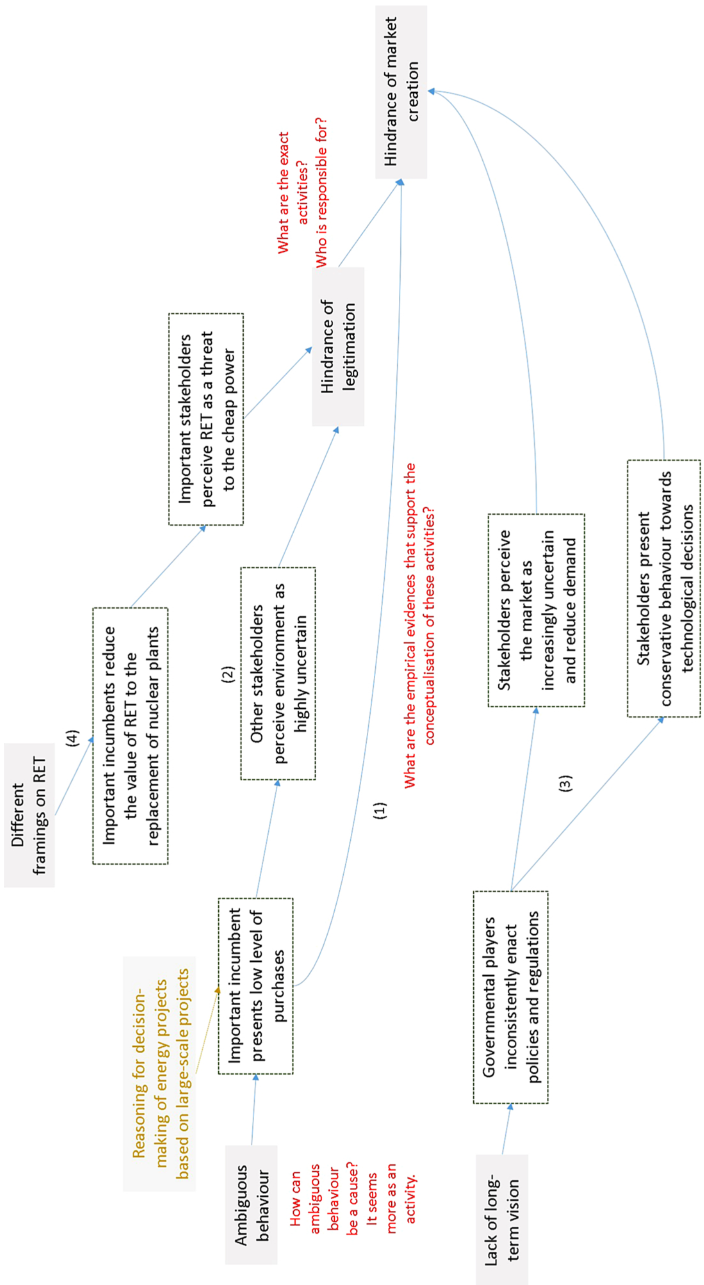

Fig. 9. Example of pathways of blocking mechanism hindering market creation.

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 Fig. 9, 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 and 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 et al., 2016a; Dewald and Truffer, 2011; Karltorp, 2016; Konrad et al., 2012; Yap and 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 (Beach and Pedersen, 2016b, 2016a). It also requires different methods. As discussed, process-tracing is the most prominent family of methods applied to study mechanisms (Beach and Pedersen, 2016a, 2013; Bennett and Checkel, 2014). Following this, we expect to see similar mechanisms across cases, particularly for technologies with comparable characteristics[28] . 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 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.

Declaration of Competing Interest

The authors report no declarations of interest.

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[28] 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)

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