THESIS FOR THE DEGREE OF LICENTIATE OF ENGINEERING

# Evaluating transformative innovation policy: towards an integrated framework


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# Abstract

Past reviews show that the current practice of science, technology, and innovation policy evaluation lags behind the development of innovation theory. The emergence of the transformative innovation policy paradigm, which aims at addressing transformative change or 'grand challenges', implies new challenges for policy evaluation. These include, among other aspects, assessing (i) behavioural additionality, i.e., going beyond the traditional input–output analysis to address how policy changes the behaviour of actors involved in or affected by a policy measure and affects learning at the system level, and (ii) the directionality of change, i.e., how policy mixes are impacting the process and direction of socio-technical systems.

The purpose of this licentiate thesis is to understand how evaluation can be made more transformative in order to assess policy interventions targeting system innovation, while also addressing the aforementioned challenges. Based on the literature on sustainability transitions, combined with insights from the literature on theory-based policy evaluation, I propose an integrated framework for evaluating such programmes. The integrated framework is composed of three main components: (i) a programme theory, which describes how the programme was conceptualized, including its goals, system boundaries, desired transition pathways, and theories of change; (ii) a system analysis, which focuses on a set of transformative processes that describe changes in socio-technical systems; and (iii) an assessment of the unfolding transition pathway(s).

This licentiate thesis also includes a first attempt to apply the framework. In order to do this, I analyse the case of the BioInnovation Strategic Innovation Programme (SIP), a programme funded by Vinnova (the Swedish Innovation Agency), whose vision is that Sweden will have transformed into a bioeconomy by 2050. The programme focuses on system innovation in three main areas: chemical and energy, construction and design, and materials. Building on preliminary findings of this empirical application, I reflect upon the methodological and conceptual implications of such an approach and indicate opportunities for further research.



Keywords: transformative innovation policy, policy evaluation, directionality, behavioural additionality.

## List of papers covered in the licentiate

This licentiate thesis was designed as a monograph. Nonetheless, some of the work developed so far by me together with colleagues have been covered in:

1. Haddad, C. R., Nakic, V., Bergek, A., Hellsmark, H., 2021. The policymaking process of transformative innovation policy: a systematic review. Manuscript submitted to Environmental Innovation and Societal Transitions.

2. Haddad, C. R., Bergek, A., 2020. A functions approach for evaluating transformative innovation policy, 11th International Sustainability Transition Conference, 18-21 August – Vienna, Austria.

3. Bergek, A., Haddad, C. R., 2021. Evaluating transformative innovation policy outcomes as unfolding processes of change in socio-technical configurations. Manuscript submitted for a compilation book on transformative metrics.

I have made the following contributions to these papers:

In Paper 1, all co-authors were involved in defining key words, performing the search in the database, and defining the included papers to be fully read and analysed in the systematic review. The analysis and writing process were performed collaboratively. In this thesis, I included excerpts written by both me (included in Section 1.1.3 and Section 2.2) and Bergek. The text from Bergek was slightly changed and placed in Section 1.3. In Paper 2, the framework was developed collaboratively by me and Bergek. In the writing process, Bergek was responsible for writing the theoretical background of the paper that provides the basis for the integrated framework, which was then written by me. Some of this background was included in the introduction of the licentiate (Section 1). I have expanded the text in order to cover a larger volume of the literature. I also made some changes in this first draft of the integrated framework while writing the licentiate. A new version is being developed to be submitted to a journal. Paper 3 was also developed collaboratively between me and Bergek, in both its conceptualization and writing process. Bergek performed the final restructuring of the paper, which was then submitted as a book chapter. I have summarized this chapter in Section 3.2.4 of this licentiate thesis. Some excerpts were also used in Section 1.2.

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# 1 Introduction

The overall aim of this licentiate thesis is to understand how transformative innovation policy can be evaluated. Transformative innovation policy focuses on addressing how policies can drive innovation towards sustainable transitions and is considered a new paradigm of innovation policy. In this introductory section, I discuss some of the background of such an approach, reflecting upon previous approaches to innovation policy, i.e., the neoclassical and the innovation system approach. I also introduce some of the key points regarding how the evaluation of science, technology, and innovation (STI) policy has developed over time. This provides the foundation to discuss evaluation challenges emerging with this new paradigm and what has been addressed by the innovation policy literature so far.

## 1.1 Three approaches of innovation policy

Two approaches (or paradigms,[1] as highlighted by Diercks et al. (2019)) have been central in innovation studies: the linear model and the innovation system approach (Chaminade and Edquist, 2010). In recent discussions, these approaches have also been called Framing 1 (innovation for growth), or the science and technology approach, and Framing 2 (national systems of innovation), or innovation systems policy paradigm, respectively (Diercks et al., 2019; Schot and Steinmueller, 2018). Building upon these previous innovation policy approaches, a supposedly new policy paradigm is emerging, referred to as transformative innovation policy (Diercks et al., 2019). Below, I discuss the main characteristics of each framing separately, while highlighting their shared characteristics.

### 1.1.1 The science and technology policy approach

The linear model of innovation was one of the first theoretical frameworks aimed at understanding the relationship between economy and science and technology (Godin, 2006), and was influenced mainly by neoclassical economics and, later on, new growth theory (Chaminade and Edquist, 2008). This approach to innovation has been the most accepted one throughout the period since

[1] A policy paradigm is defined by Hall (1993, p. 279) as being ‘a framework of ideas and standards that specifies not only the goals of policy and the kind of instruments that can be used to attain them, but also the very nature of the problems they are meant to be addressing’.

World War II (Kline and Rosenberg, 1986). For neoclassical theorists, innovation is seen as a linear sequence of phases (Chaminade and Edquist, 2008), in which 'one does research, research then leads to development, development to production, and production to market' (Kline and Rosenberg, 1986, p. 285). Over the years, it has been expanded to include insights from new growth theory and evolutionary theory,[2] and was later defied by the innovation system approach, as will be discussed below.

From a neoclassical perspective, the standard rationale for policy intervention is that of market failure (Smith, 2000). According to Nelson (1959) and Arrow (1972), science knowledge is characterized by three properties: uncertainty (one cannot fully know the outcome), inappropriability (firms cannot fully appropriate the benefits resulting from their inventions), and indivisibility (which implies that in order to create knowledge, previous investment is needed). Due to these characteristics, private actors fail to efficiently allocate resources to the extent that would be socially and economically desirable, and hence policymakers need to intervene (Chaminade and Edquist, 2008). As such, governments should intervene to fix markets by investing in areas portrayed by positive or negative externalities, information asymmetries and capital market failures (Jacobsson et al., 2017; Mazzucato, 2016). Table 1 brings a summary of these market failures.

According to Kline and Rosenberg (1986), the linear model and the market failure theory are unrealistic in many ways. While the market failure approach brings useful insights, especially in cases where 'putting patches' on existing market trajectories is the goal (Mazzucato, 2016), it has many shortcomings. For instance, this approach has been criticized for not accounting for feedback paths that occur in the innovation process, either from individual users or from sales figures. In addition, it does not provide practical guidance for policymakers in terms of how large subsidies need to be or what areas interventions should focus on (Chaminade and Edquist, 2008).

### 1.1.2 The innovation system approach

The early 1980s was characterized by the emergence of evolutionary economics and the notion of interactive innovation processes (Martin, 2012). This was driven, among other things, by the

[2] For example, by acknowledging that there is no perfect information when it comes to R&D activities and that the justification for government intervention is stronger for science in comparison with technology (Chaminade and Edquist, 2010).

perceived limitations of neoclassical economics, and resulted in a broader view on innovation (Isaksen, 1999) as well as an increased focus on 'opportunity enhancing' (Georghiou, 1998) innovation policies. While this did not directly influence the rationales of innovation policy, it did result in increased attention to policies directed at increasing collaboration and technology transfer between firms and other actors.

In the late 1980s, the evolutionary and interactive perspective on innovation converged with a revived discussion about the merits of industrial policy, which resulted in the development of various 'innovation systems' frameworks and an increased focus on 'systemic' innovation policies (Smits and Kuhlmann, 2004). In general, an innovation system involves the creation, diffusion and use of knowledge, and is formed by its components, as well as their relationships, characteristics and attributes (Carlsson et al., 2002).

Freeman (1987), building upon the concept of a 'national system of political economy,' was the first to publish the concept of 'national innovation systems' (Martin, 2012). According to Freeman (1987, p. 1), a National Innovation System (NIS) is defined as 'the network of institutions in the public and private sectors whose activities and interactions initiate, promote, and diffuse technologies'. The concept was later developed further with the publication of two books by Lundvall (1992) and Nelson (1993), showing different applications in the study of NIS. Other approaches to systems of innovation emerged, including the technological (Carlsson and Stankiewicz, 1991), sectoral (Malerba, 2002) and regional innovation systems (Cooke et al., 1997).

With these 'systemic' approaches to innovation policy came a shift in rationales for government intervention from market failures to various system failures or weaknesses that may characterize spatially or cognitively delineated innovation systems (Chaminade and Edquist, 2010).[3] On the one hand, these include structural deficiencies related to capabilities, networks, infrastructure, and institutions (cf., e.g., Carlsson and Jacobsson, 1997; Jacobsson and Johnson, 2000; Tödtling and Trippl, 2005; Woolthuis et al., 2005) (see Table 1). On the other hand, they include problems related to key innovation processes (or 'functions') (Bergek et al., 2010; Wieczorek and Hekkert, 2012), which have a direct influence on the development, diffusion and use of new technologies.

[3] Spatially delineated systems include regional and national innovation systems. Cognitively delineated systems include technological and sectoral innovation systems. For a discussion about spatial and cognitive proximity, see Boschma (2005).

These include, in short, the development and diffusion of knowledge within the system; entrepreneurial experimentation to reduce technological, market and political uncertainty; the formation of markets; the guidance of actors' search processes; the mobilization of financial, human and physical resources; the legitimation of technologies and actors; and the development of positive external economies (Bergek, 2019; Bergek et al., 2008a).

Table 1. Overview of market and structural system failures.

| | List of failures | Description |
|---|---|---|
| **Market failures** | Information asymmetries | Occur when one of the parties in a transaction has more or better information than the other and, hence, can take advantage of them. |
| | Positive externalities | While investments from one actor can contribute to other actors without any costs, the full value of an activity cannot be appropriated, which can lead to underinvestment. |
| | Negative externalities | Relates to the costs accrued by other actors without these costs being compensated. This can lead to an overinvestment in activities that benefit an individual actor. |
| | Capital market failure | Refers to the propensity to take risks, which could lead to under-investment in high-risk technologies. |
| **Structural system failures** | Infrastructural failure | Refers to the physical infrastructures needed for innovation, including communication and energy, science and technology, transport, etc. |
| | Institutional failure | Relates to both formal and informal, i.e., 'hard' and 'soft', institutions, which constitute the selection environment that hinders or stimulates innovation. |
| | Interaction failure | Occurs when the different actors within a system interact too much or too little, preventing innovation. |
| | Capabilities failure | Refers to a lack of capability (competence, capacity, or resources) of firms to adapt to new technologies and market demands. |

*Source: adapted from Woolthuis et al. (2005) and Jacobsson et al. (2017).*

### 1.1.3 The transformative innovation policy approach[4]

Building upon these previous innovation policy approaches, a supposedly new policy paradigm is emerging, referred to as transformative innovation policy (TIP) (Diercks et al., 2019). According to Diercks et al. (2019, p. 881), 'this emerging policy paradigm can be seen as layered upon, but not fully replacing, the earlier policy paradigms of science and technology policy and innovation system policy'. The authors further argue that, as a new paradigm, TIP brings changes in both the policy agenda (i.e., the overall policy objectives, domains and logic) and the understanding of the innovation process (i.e., the actors involved in the innovation process and the activities contributing to the generation of innovations).

[4] Text adapted from the following submitted manuscript: Haddad et al. (2021). Major changes were made in the text before being included in this licentiate thesis.

Regarding *policy agenda*, transformative innovation policy goes beyond the idea of economic growth and conventional innovation systems and instead calls for directionality in innovation studies and the need to address 'Grand Challenges' in terms of innovation policy (Diercks et al., 2019). As such, transformative innovation policy objectives include 'societal challenges such as climate change, growing inequality, demographic change and resource scarcity' (Diercks et al., 2019, p. 882). The 2015 Paris Agreement and the development of the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs) marked the call for innovation policies directed towards broader societal goals, as framed in the literature of sustainability transitions (Fagerberg, 2018; Steward, 2012). Additionally, transformative innovation policy targets 'policy domains beyond economic and industrial policy' and can also impact a set of other functional policy domains, such as healthcare, environment, agriculture, and education (Diercks et al., 2019, p. 890). Moreover, in terms of policy logic, previous innovation policy approaches that focused on an economic policy agenda had a pro-innovation bias and did not acknowledge the negative outcomes emerging with new innovations (Diercks et al., 2019). In contrast, a societal policy agenda considers both negative and positive outcomes.

This implies an even broader view on the *innovation process*, where 'system innovations' or 'sustainability transitions' of entire societal sectors of production and consumption (rather than specific technologically or spatially delineated innovation systems) are in focus, as described in the multi-level perspective (MLP) (Geels, 2002). As such, TIP also involves multiple actors; not only the 'triple helix' of university–industry–government relations (cf. Etzkowitz and Leydesdorff, 2000), but also other 'social partners', such as economic operators and civil society (Steward, 2012). Accordingly, Fagerberg (2018) argues that to successfully use innovation policy for transitions, policymakers should mobilize different types of actors in different sectors and combine different knowledge, skills, institutions and demand in a networked environment. Moreover, when it comes to the activities contributing to the generation of innovation, Diercks et al. (2019) point out that transformative innovation policy, similarly to the innovation system approach, acknowledges the importance of both the supply side and the demand side of innovation. On the one hand, some innovation results from scientific breakthroughs, and advances in science can influence the direction of innovation (Godin and Lane, 2013). On the other hand, all innovations are not science-based or science-driven, and many innovations can be linked to an extensive use of demand-driven instruments (Fagerberg, 2018). TIP therefore combines supply-side instruments with demand-side instruments aimed at 'increasing the demand for innovations, defining new functional requirement for products and services or better articulating demand' (Edler and Georghiou, 2007, p. 952).[5] Beyond this perspective, Kivimaa and Kern (2016) argue that the innovation and technology policy debates need to go past the supply- and demand-side instruments to consider 'a wider range of policy instruments combined in a suitable mix which may contribute to sustainability transitions' (p. 205). The authors propose, thus, to expand the concept of 'motors of innovation' to 'motors of creative destruction' and include policies that address both the creation and development of innovations and the destruction of incumbent regimes.

This also follows Weber and Rohracher's (2012) call for a broader approach to innovation policy 'that is geared towards inducing and realizing long-term processes of transformative change towards sustainability' (p. 1045). The authors propose that policies for transformative change should draw not only on the market and system failures perspective, but also on transformational system failures. This latter category of failures brings, in addition to the first two, four new rationales, which are derived from the multi-level perspective:

- Directionality failures point to the need to build innovations that are efficient and effective, but that also contribute to the direction of change.
- Demand articulation failures are related to the need to address demand and its influence on transformative change.
- Policy coordination failures refer to the lack of coordination of policies among different policy levels and domains.
- Reflexivity failures concern the inability of the system to adapt self-governance processes and cope with uncertainties underlying transformative change.

In sum, TIP emerges as an attempt to address the shift of the agenda for innovation towards 'a range of situated socio-technical transitions' (Steward, 2012, p. 331), as framed in the sustainability transitions literature (Schot and Steinmueller, 2018). Additionally, it changes the policy discourse towards combining a broader understanding of the innovation process with a societal policy agenda (Diercks et al., 2019). As a consequence of the changes in the policy agenda

[5] Demand-side policies 'include public procurement of innovation, direct or indirect financial support for the purchase of innovations, various kinds of training, and awareness mechanisms to build up and broaden absorptive capacity for innovation and the shaping of conducive regulatory framework conditions' (Edler et al., 2012b, p. 33).

and the understanding of the innovation process, Haddad et al. (2021) identify five distinguishing characteristics of transformative innovation policy, as summarized in Table 2.

Table 2. Distinguishing characteristics of transformative innovation policy.

| Distinguishing characteristic | Description |
|---|---|
| Grand challenges and inclusive growth | Refers to the shift in the innovation policy agenda from a mainstream macroeconomics perspective towards that of socio-technical transitions and broader societal and environmental concerns. |
| Directionality | The focus on solving grand challenges implies that transformative innovation policy has a clearer direction than in most innovation system-based policy frameworks. |
| Multi-faceted policy intervention | Reflects the need for a more varied and complex set of policy instruments to address grand challenges, i.e., policy mix, also including policies for regime destabilization. |
| Multiple actors and global networks | In order to address a wider societal agenda, a broader set of actors than one only including governmental agencies and 'triple helix' constellations is needed. This broader set would include, e.g., the civil society and other 'social' actors. |
| Multi-level governance | Calls for the need for a meta-governance approach, i.e., a mix of different (bottom-up and top-down) governance modes to orchestrate the transformative process. This would include experimentation, learning reflexivity and reversibility. |

*Source: Adapted from Haddad et al. (2021).*

## 1.2 Science, technology, and innovation policy evaluation[6]

Science, technology and innovation (STI) policy evaluation evolved relatively late as compared to other policy fields, such as education and psychology, whose evaluation practices were already established by the end of 1960s (Gök, 2010; Molas-Gallart and Davies, 2006). In contrast, early STI policy evaluation studies can be traced back to the 1960s in the United States and the 1970s in Europe (cf. Luukkonen, 2002; Roessner, 2002).

At that time, governments started to use R&D surveys and industrial R&D as a proxy to measure technological innovation. In the United States, the National Science Foundation (NSF), which conducted official innovation measurements in the country, launched a survey series to systematically collect data on R&D expenditure (Godin, 2008). Internationally, the Organization for Economic Co-operation and Development (OECD) took the lead in developing guidelines for R&D statistics in the form of the Frascati and Oslo manuals.

[6] Part of the text included in this subsection draws on Bergek and Haddad (2021) and Haddad and Bergek (2020).

### 1.2.1 The Frascati and Oslo manuals

In 1963, the OECD released the first version of the Frascati Manual, which contained data collection guidelines for using R&D statistics (OECD, 2015). The manual was the first to standardize the practice of surveys of research and development (OECD, 2015), and served as a landmark for the collection of standardized statistics among different countries. Godin (2008) points out that the Frascati Manual was responsible for spreading the use of expenditure on R&D as a proxy to measure technological innovation in other countries. By then, 'economists would make wide use of R&D statistics in their productivity studies (econometrics), and descriptive statistics on R&D would become the preferred measurement for many researchers in the field of technological innovation studies' (Godin, 2010, p. 24). The Frascati Manual is now in its seventh edition and is still used worldwide as a standard for R&D measurement (OECD, 2015).

While the Frascati Manual 'opened the way for measuring one key dimension of science, technology and innovation' (OECD, 2018, p. 3), there was still a need for a new set of STI output indicators (Freeman and Soete, 2009). From the 1980s until the mid-1990s, the OECD organized a series of conferences and workshops to discuss innovation measurement and indicators, which would lead to the development of first version of the Oslo Manual (OECD, 1992). The framework was officially approved in 1991 and adopted in 1992, when it was used to guide the first European Community Survey (CIS) (Gault, 2013). The manual's purpose was to harmonize national methodologies for the collection of standardized statistics on the innovation activities of firms (Godin, 2002). In 1997, the OECD published the second edition of the Oslo Manual (OECD/Eurostat, 1997), based on insights from the CIS evaluation and other similar innovation surveys (Gault, 2013). While the first version focused on collecting firm data on technological product and process innovation in manufacturing, the second included innovation in service sectors (Bloch, 2007; OECD/Eurostat, 2005).

Freeman and Soete (2009, p. 587) highlight that the development of the Oslo Manual 'was a central factor behind both a better understanding of the science and technology system and the changing nature of the innovation process itself' (cf. also Bloch, 2007). It should here be noted that the two first editions used Kline and Rosenberg's (1986) chain-link model of innovation as a conceptual framework and, thus, highlighted 'the interaction between the firm and other actors, where the completed innovation is the result of a (nonlinear) process involving testing, feedback and subsequent redesign' (Bloch, 2007, p 24).

The third edition of the manual was published in 2005 and focused on expanding the concept of innovation to include marketing and organizational innovation (OECD/Eurostat, 2005). This version also reflected an effort to address a broader (and systemic) understanding of innovation by including a chapter on innovation linkages (OECD/Eurostat, 2005). Moreover, Lundvall and Borrás (2005) point out that the manual served as an important step towards gathering information to investigate the innovative performance of countries, using a more systemic view of innovation policy. As such, surveys based on the manual can provide information on intermediate performance indicators, e.g., the diffusion of product innovations, which can be obtained by analysing 'the share of new products in total sales in firms in different sectors and countries' (Lundvall and Borrás, 2005, p. 613). The manual is now in its fourth edition and is still widely used for the measurement of innovation (OECD, 2018).

### 1.2.2 Additionality in STI policy

In parallel with the activities by the OECD, the concept of *additionality* started to be developed and used in the UK in the early 1980s as a way to measure 'the difference which government-sponsored programmes have made to the recipients, particularly companies, in terms of R&D activities' (Luukkonen, 2000, p. 711). The concept of additionality would then support the justification for public intervention, as it would show that governmental support towards private sector R&D would generate an acceptable return, greater than what would have happened without it (Buisseret et al., 1995). While the concept of additionality seems to have evolved largely independently of developments in STI theory, its origins can be traced to the neoclassical market failure rationale (Luukkonen, 2000). Thus, changing policy objectives have also influenced the type of additionality policymakers were aiming at.

For evaluation purposes, Georghiou (1994) differentiates between three types of additionality: input, output and behavioural additionality. The hallmark of the neoclassical perspective is the concept of *input additionality*. Input additionality refers to the extent to which public funding increases total R&D investments instead of replacing or 'crowding out firm's investments' (Georghiou and Clarysse, 2006). There is a strong tradition in this approach of demanding evidence that the public gets enough return on its investment (Georghiou, 1998) and that the results are significant enough to justify further funding (Clarysse et al., 2009). This raises the issue of whether firms would have invested this much in R&D anyway, or whether public funding actually creates inefficiencies such as increased costs (Bach and Matt, 2005; Clarysse et al., 2009; Georghiou and Clarysse, 2006). According to Clarysse et al. (2009, p. 1519), 'the main problem with input additionality is that it assumes a direct linear link between R&D input and innovation output', which does not correspond to reality.

A second type of additionality is named *output additionality* and emerged due to the criticism surrounding using input additionality as a dependent variable (Clarysse et al., 2009). Output additionality is connected to the commercialization of technologies, products and processes and measures whether the same outputs (in terms of, for example, patents, publications, product introductions, sales, etc.) would have been achieved without public support (Bach and Matt, 2005; Clarysse et al., 2009; Georghiou and Clarysse, 2006). A major criticism surrounding output additionality is that it requires many assumptions concerning determining outputs (Georghiou and Clarysse, 2006). For example, one could question if a patent or a publication is a result of R&D or the downstream effect of R&D on sales.

Both these types of additionality are typically evaluated at the level of projects or firms and with the use of before–after comparisons, control groups, etc. to be able to attribute observed effects to the studied R&D funding (Georghiou, 1998). While they provide a good way to measure the performance of firms that received public support, they ignore changes in the behaviour of firms and treat the firm as a black box (Georghiou and Clarysse, 2006). Therefore, they ignore short-term learning effects that lead to input and output additionality in the long term, i.e., the *behavioural additionality* (Buisseret et al., 1995; Georghiou, 2002).

Behavioural additionality (BA) is 'the hallmark of the evolutionary/structuralist perspective on innovation policy' (Gök and Edler, 2012, p. 309). It refers to the influence a policy intervention has on the actions of firms and other actors (Amanatidou et al., 2014; Bach and Matt, 2005; Georghiou and Clarysse, 2006). Initially, it was suggested that evaluations should assess changes in how firms organize and manage R&D (or innovation processes more broadly) (Clarysse et al., 2009; Georghiou, 1998), for example in terms of different scales, scopes, timings or collaboration partners (Bach and Matt, 2005; Georghiou, 1998; Georghiou and Clarysse, 2006). Later, the BA concept was expanded into an ambition to capture the indirect effects of policy, in particular in terms of the learning that takes place in firms because of public support (Clarysse et al., 2009),[7] which can result in new attitudes, skills and capabilities (Afcha Chávez, 2011; Georghiou and Clarysse, 2006). It was argued that such 'second-order' effects are more persistent than ordinary outputs (Gök and Edler, 2012) and can lead to new inputs and outputs further on (Clarysse et al., 2009).[8] Moreover, the focus on learning implied that input complementarities (Bach and Matt, 2005) and spill-overs (Clarysse et al., 2009) were emphasized over resource substitution and crowding-out effects.

In practice, BA evaluation is most often done at the level of (groups of) firms and using (qualitative and quantitative) data from surveys and interviews, case studies, and modelling (Afcha Chávez, 2011; Antonioli et al., 2014; Clarysse et al., 2009; Georghiou, 1998; Isaksen, 1999). In order to attribute the changes to specific policy interventions, it is common to use control groups of non-supported firms (cf. e.g. Afcha Chávez, 2011; Clarysse et al., 2009; Georghiou, 1998). In this way, Gök and Edler (2012) have shown that, in practice, evaluators still use traditional experimental and quasi-experimental approaches, which hinders the whole potential of BA. It has been noted that although such methods are useful when evaluating R&D funding and technology transfer organizations, it will probably not be possible to establish equally strong forms of attribution for other types of innovation policies (Georghiou and Clarysse, 2006).

[7] Autio et al. (2008) label behavioural additionality as 'second-order additionalities' to refer to the broader range of learning effects emerging from the implementation of R&D subsidies, while input and output additionality are named 'first-order additionalities'. According to Clarysse et al. (2009), different types of organizational learning include: experiential learning/learning-by-doing, congenital learning/absorptive capacity, and interorganizational learning/knowledge sharing between firms.

[8] Bach and Matt (2005) refer to this as 'cognitive capacity additionality' to distinguish it from the former (and less complex) kind of behavioural additionality.

### 1.2.3 Attempts towards systemic evaluation

During the 1980s and 1990s, technology foresight,[9] technology assessment,[10] benchmarks[11] and other formative approaches to evaluation were being used to support STI policy formulation in more complex settings (Kuhlmann et al., 1999; Molas-Gallart and Davies, 2006). According to Borrás and Edquist (2013), these approaches came as additional tools to orient innovation policymaking, which had so far focused on innovation indictors as sources of information to identify problems within the innovation system and guide the process of selection of policy instruments.

Kuhlmann et al. (1999) point out that the demand for formative evaluations grew especially in the late 1980s and was followed by an increasing interest in benchmarking exercises. This reflects a move away from 'individualistic intelligence gathering exercises' (i.e., single tools such as technology foresight and technology assessment) towards more integrated 'evaluation with strategy formulation' (Kuhlmann et al., 1999, p. 16). As such, it marks a shift from ex-post evaluation and impact assessment approaches towards more process-oriented evaluations (Molas-Gallart and Davies, 2006).

With the uptake of the innovation system approach among scholars and policymakers, 'the notion of innovation as the outcome of complex interactions and dynamics in the idiosyncratic socio-economic context of an economy' gained momentum, while the limitations of previous approaches were also being emphasized (Borrás and Laatsit, 2019, p. 313). For some scholars, it meant finally abandoning the linear view of innovation, which created a need to find new approaches to capture and explain the more complex relationships between innovation policies and their various

[9] Technology foresight can be defined as 'a systematic means of assessing those scientific and technological developments which could have a strong impact on industrial competitiveness, wealth creation and the quality of life' (Georghiou, 1996, p. 359). According to Metcalfe (1997), technology foresights reflect the concerns surrounding building technology support systems of firms, while letting innovation follow from market processes, which is very much aligned with the evolutionary perspective.

[10] Technology assessment helps to fine-tune R&D programmes by assessing their unintended impacts in order to minimize economic losses and predict problems that can emerge within the technological change process (Meyer-Krahmer and Reiss, 1992).

[11] Benchmarks include a set of measurements to assess the impact of policies in the performance of innovation systems (Molas-Gallart and Davies, 2006). They have been used by the European Commission to assess the impact of research, technology and development (RTD) in competitiveness and employment (European Commission, 2002), and by the OECD to assess the relationship between industry and science (OECD, 2002).

outcomes and impacts (Brown et al., 2016; Magro and Wilson, 2013; Rametsteiner and Weiss, 2006).

This came with an understanding that the effects of innovation policies should be evaluated at the system level rather than at the level of projects or firms (Arnold, 2004; Bellandi and Caloffi, 2010; Gök, 2010; Rametsteiner and Weiss, 2006; Russo and Rossi, 2009). For instance, Arnold (2004) proposed a framework that combines a summative and formative approach for the evaluation of systems, which is composed of three levels: (i) analysis of system health, comprising the formulation of hypotheses around the overall health of the innovation system (this is considered a top-down element of the evaluation); (ii) meso-level 'bottlenecks analysis' and evaluation, which consists of analysing and exploring the role of institutions, actors, clusters, etc.; and (iii) evaluating programmes and portfolios, which refers to the traditional evaluation of programmes, aiming at accountability and learning. It was also recognized that all innovation systems are influenced by a variety of interacting policies and that this creates a need for 'policy mix evaluation' (Magro and Wilson, 2013) and 'meta-evaluations' of previous programme-level evaluations (Edler et al., 2008). More specifically, Edler et al. (2008) proposed two methodological approaches for conducting secondary analysis of evaluations: meta-analysis[12] and evaluation synthesis. Magro and Wilson (2013), in turn, suggested using meta-analysis or other types of secondary analysis of individual evaluations to capture the systemic aspect of innovation policies.

Here, it should be noted that much of the literature on innovation systems is concerned with system analysis and assessment without any explicit policy evaluation focus. However, some of the frameworks developed for that purpose have also been used to evaluate policy instruments and policy mixes. There are two main approaches to this. The first approach studies how innovation network composition and interactions change as a result of a policy intervention, for example in terms of network composition, organization and cohesion or the relative centrality of different actors (Bellandi and Caloffi, 2010; Rametsteiner and Weiss, 2006; Russo and Rossi, 2009). This type of evaluation tends to combine qualitative and quantitative data and make use of social network analysis methods.

[12] Meta-analysis 'allows an improved comparison and understanding of interventions and their effects by taking into account the results of a large number of evaluations' (Edler et al., 2008, p. 175).

The second approach is closely connected to the systemic failures framework presented in Section 1.1.2. It thus either focuses on analysing structural system failures and evaluating to what extent a specific policy instrument addresses these failures (cf. Woolthuis et al., 2005), or investigates how policies influence key processes (or 'functions') in the innovation system (Bergek, 2004; Jacobsson and Perez Vico, 2010; Perez Vico and Jacobsson, 2012). This approach mainly uses qualitative evaluation methods, including surveys and case studies.

### 1.2.4 Attempts towards transformative evaluation[13]

Given the distinguishing characteristics of transformative innovation policy mentioned before (see Table 2), the evaluation of TIP also comes with additional analytical challenges. Among other aspects, the increased focus on directionality implies that there are new ends and goals against which policy programmes need to be evaluated. Instead of treating all innovation outcomes as positive, as under previous paradigms, there is a need to consider how policy interventions contribute to the ultimate goal of a policy in terms of the desired transition pathway(s) for a particular sector (Magro and Wilson, 2019; Schlaile et al., 2017), for example in terms of which actors are involved (e.g., incumbents *versus* new entrants) and which types of innovations are developed and diffused in the system (Geels et al., 2016). This implies asking neglected questions such as 'which way?'; 'who says?'; and 'why', and not only 'yes or no?'; 'how much?'; 'how fast?'; and 'where?' (Andersson et al., 2021; Stirling, 2009).

Moreover, the perspective on behavioural additionality becomes even broader, as there is an even larger focus on explaining how specific interventions cause certain impacts on targeted systems, and even more complex feedback loops between policy outputs, outcomes and impacts that need to be accounted for (Arnold et al., 2018; Kern and Rogge, 2018). In TIP evaluation, BA assessment therefore needs to go beyond evaluating the traditional economic, technological and scientific spheres usually addressed by input and output additionality (Amanatidou et al., 2014). Rather, it should also address the societal impact induced by the policy measure and its long-term effects on the behaviour of actors. In practice, however, most evaluations still use experimental and quasi-experimental approaches to analyse BA, which hinders the full potential of the concept (Gök and

[13] The text included here is based on Haddad and Bergek's (2020) conference paper, but contains new additions.

Edler, 2012). Thus, assessing BA would also include learning as a key outcome, especially learning at the system level.

Despite these challenges, the TIP evaluation frameworks suggested so far are quite similar to, or even build on, those used for innovation system analysis and evaluation of systemic policies, and rarely include the assessment of directionality and BA.

A number of authors adapt existing frameworks, such as systemic failures or TIS functions, to analyse or evaluate TIP-oriented policies.[14] For example, van Mierlo et al. (2010) complement Klein Woolthuis et al.'s (2005) framework with learning theories to evaluate a systemic instrument for the purpose of a socio-technical transition. Additionally, Janssen (2019) proposes an assessment scheme for transformative policy building on the principles of new industrial policy and on the TIS functions to assess the design and impact of 'narrowly targeted policy'. According to the author, what evaluators should be looking for are the improvements in the performance of the innovation systems brought about by policy contributions in strengthening the functions. Kivimaa and Virkamäki (2014) also apply the TIS functions in an analysis of the Finnish transport policy mix by identifying how policies relate to each function and influence the paths towards low-carbon systems. Building further on this approach, Kivimaa and Kern (2016) combine the TIS functions with elements of 'regime destabilization', which they argue are needed to better capture the destruction of incumbent regimes, and Kivimaa et al. (2017) use this framework to propose a client-oriented evaluation approach to assess the impacts of energy-efficiency policy mixes in Finland. Scordato et al. (2018) further add coordination, timing and scale elements to Kivimaa and Kern's (2016) framework in order to analyse the effect of a policy mix in inducing innovation and how instrument interaction accelerates sustainability transitions in the Swedish pulp and paper industry. Another approach using the innovation system analysis is proposed by Purkus and Lüdtke (2020), who combine it with learning-oriented and participatory evaluation approaches to propose an evaluation concept for sustainable forestry in Germany.

[14] It should be noted that some of these frameworks are focused on policy-mix evaluation rather than programme-level evaluation (cf. e.g. Edmondson et al., 2019; Kivimaa et al., 2017; Kivimaa and Kern, 2016; Kivimaa and Virkamäki, 2014) and assess the current policy mix in relation to a focal sector by preassigning policy instruments to particular failures or functions. Although this type of evaluation is not the focus of this paper, I consider these frameworks to also be relevant for programme-level evaluation.

In contrast, other frameworks are based more directly on transition-oriented frameworks. For example, Kern (2012) uses the MLP to make an *ex-ante* analysis of the impact of policies on processes at the niche and regime levels. Meelen and Farla (2013) combine insights from the transition management (TM), strategic niche management (SNM) and TIS functions to propose an integrated framework for analysing sustainable innovation policy. In such a framework, the interface between niche, regime, landscape and TIS indicates points of policy intervention. Another group of authors base their frameworks on Weber and Rohracher's (2012) transformational failures. For instance, Grillitsch et al. (2019) identify expected challenges related to policy design and implementation within each type of transformational failure and operationalize them in relation to the structural elements of a targeted innovation system. In a similar vein, Bugge et al. (2017) use the typology of transformational failures, combined with the concepts of SNM, to analyse how processes of 'shielding', 'nurturing', and 'empowering' developed and created systemic challenges in the context of assisted living experiments in the UK and Norway. Later, Bugge et al. (2018) develop an innovation policy framework based on transformational failures, governance modes and policy mixes to explore the effect of different governance modes on a transition in healthcare.

## 1.3 Research problem[15]

While useful for policy analysis, the suggested frameworks do not fully address the specific TIP-related evaluation challenges, such as directionality and behavioural additionality, but mainly build on previous approaches to evaluating systemic innovation policies. Most notably, three main gaps can be outlined. First, overall, there seems to be a disconnection between the general literature on innovation policy and the literature on policy evaluation. As noted by Magro and Wilson (2013, p. 1649), 'while in some respects evaluation approaches have followed a similar evolution to innovation policies, they have not yet reached the degree of sophistication required to capture the complex interactions that take place within policy systems'. As such, theory-based evaluation of STI policies is still lagging behind advances in innovation theory (Molas-Gallart and Davies, 2006). The emergence of TIP, in turn, makes this gap even more accentuated. If there were already methodological difficulties in establishing causal relationships and assessing the outcomes of

[15] Many of the insights developed here are based on the findings from Haddad et al. (2021).

policy of multiple policy instruments over a long period of time in systemic evaluations (Purkus and Lüdtke, 2020), the emergence of TIP makes things even more complex. While attempts at systemic evaluation bring important insights to the evaluation of systemic interventions (Arnold, 2004; Edler et al., 2008), they rarely intersect with the existing policy evaluation literature (Magro and Wilson, 2013). Many authors argue that there is a need to develop new evaluation frameworks and indicators that capture more of the complex, system-level transition dynamics in order to allow evaluators to understand what is happening in the focal socio-technical system and how policy influences the conditions for realizing transformative change (Amanatidou et al., 2014; Grillitsch et al., 2019; Hoppmann et al., 2014; Janssen, 2019; Kern, 2012; Mazzucato, 2016; Mazzucato, 2018). Additionally, policy evaluation needs to consider a broader set of impacts than previously (Amanatidou et al., 2014). Moreover, whilst current efforts towards evaluating TIP were pushed forward, they are still very similar to those from previous evaluation frameworks. Accordingly, the connection between the literature on innovation policy and policy evaluation is still an area to be further explored.

Second, the broadened scope of TIP implies a need for evaluation that considers the notion of behavioural additionality beyond the change in actors and firm behaviour and includes system-level effects such as experimentation and learning (Amanatidou et al., 2014; Magro and Wilson, 2019), as mentioned above. However, this concept, despite being a popular concept in innovation policy evaluation, still faces operational and theoretical problems, such as the lack of a consistent unit of analysis and the use of comparative statistics as the exclusive method to analyse BA (Amanatidou et al., 2014; Gök and Edler, 2012). Accordingly, Gök (2010) argues that current BA analysis still focuses on the micro level, i.e., on the behaviour of a particular firm, without analysing the implications of changes in the meso and macro levels, i.e., the behaviour of a population of firms and the long-term institutionalized routines or social technologies within the economy. Besides, BA has rarely been used in the frameworks targeting TIP evaluation. One exception is Janssen (2019, p. 83), whose impact framework to some extent allows for the analysis of additionality (in addition to output) by 'disentangling the contribution of policy efforts to the strengthening of technological innovation systems'. As such, the question of how to operationalize behavioural additionality is rarely discussed, perhaps because of the focus on evaluation as a tool for policy learning rather than accountability (Amanatidou et al., 2014; Magro and Wilson, 2019).

Third, while the aforementioned frameworks provide some attempts to include directionality in policy analysis, most of them do not discuss explicitly how to identify it. More specifically, the concept of directionality was introduced by Stirling (2008, 2009) as a call to find alternative ways to frame the direction of socio-technical change. According to him, actors gradually become blind to other alternative direction options than the one primarily chosen. However, even when the need to address directionality failures is acknowledged, the suggested operationalizations are rather vague and diverging. For example, some researchers study directionality as the capacity to build a shared vision (Bugge et al., 2017; Bugge et al., 2018; Scordato et al., 2018), others investigate the directionality challenges emerging from actors' interests and capabilities, networks and institutions (Grillitsch et al., 2019), and still others see directionality as a result of the alignment of actors and the adaptations in policy interventions in relation to the long-term target of TIP (Janssen, 2019).

More recent approaches, not specifically developed for evaluation purposes, have also shed some light on how directionality can be influenced and understood. For instance, Yap and Truffer (2019, p. 1030) propose an analytical framework based on the TIS approach to better understand 'whether, how and by whom the directionality of innovation systems can be influenced'. While directionality is related to the interplay of different functions, the authors focus on analysing the guidance of search function[16] and how actors influence different layers of the selection environment. Pel et al. (2020) analyse how to govern 'transitions directionality', i.e., the different possible socio-technical change paths, by combining insights from socio-technical multiplicity, divergent normative appraisals, and process dynamics.[17] These three angles are used together to trace challenges and enable a 'directionality-conscious transitions governance'. Andersson et al. (2021) propose a 'morphology' of socio-technical systems in order to understand the outcomes of directionality. This is composed of three main dimensions related to the boundaries of the investigation: (i) temporal, which can be related to prospective or retrospective studies: (ii) spatial, i.e., studies can focus on the local, national, or global level; and (iii) socio-technical, which is multidimensional

[16] Yap and Truffer (2019, p. 1031) argue that the guidance of search function has a more explicit connection with directionality and represents the 'top-down and bottom-up activities that different actors entertain in order to shape the sectoral selection environment in favour or against alternative trajectories'.
[17] According to Pel et al. (2020, p. 4): (i) socio-technical multiplicity refers to the socio-technical configurations pursued by actors; (ii) appraisal diversity relates to the 'full range of appraisals and evaluation schemes through which configurations are valued and compared'; and (iii) process dynamics is the experienced or anticipated turns towards the development trajectory.

and includes the technical, social, and spatial (or geographical space) configurations. Although these approaches bring interesting insights towards conceptualizing directionality, this is still an ongoing discussion. Apart from the latter study, which touches upon the outcomes of directionality, how evaluators can assess this concept in policy evaluations remains understudied.

## 1.4 Purpose and research questions

The overall purpose of this licentiate thesis is to study how transformative innovation policy can be assessed and evaluated. Based on the research problems previously highlighted, this purpose can be divided into three main research questions:

- How can policy evaluation and innovation policy literatures be integrated for the purpose of evaluating transformative innovation policy?
- Considering the notion of behavioural additionality in transformative innovation policy interventions, how can system-level effects be assessed?
- How can directionality of change be evaluated in the context of transformative innovation policy interventions?

## 1.5 Licentiate thesis outline

In this introduction, I have provided an overview of the background of transformative innovation policy and the current challenges surrounding the evaluation of policy interventions targeting system innovation. Section 2 discusses the research project and explains my methodological choices considering different evaluation approaches. Section 3 presents the theoretical framework which provides the basis for developing an integrated framework for evaluating transformative innovation policy, which is thereafter introduced in Section 4. Section 5 describes a first attempt to apply the integrated framework. Finally, Section 6 offers an overview of the findings and includes some critical considerations surrounding the limitations of both the integrated framework and empirical application. It also discusses some potential opportunities for future research.

# 2 Methodology

In this section, I introduce the research project that formed the basis for this licentiate thesis and my research process. This latter aspect encompasses three main steps: a literature review, the development of an integrated framework for evaluating transformative innovation policy, and a first attempt towards an empirical application of the framework.

## 2.1 The research project

This licentiate thesis is part of a research project funded by Vinnova, the Swedish Innovation Agency. Vinnova is the central player in terms of innovation policy in Sweden and has through the years been responsible for science-industry and inter-firm collaborations, as well as for the promotion of technology transfer activities (OECD, 2016). Vinnova has in the past years enforced both its policy discourse and resource allocation on ‘Grand Challenges’ (Grillitsch et al., 2018). As such, the agency has been gradually integrating the SDGs of the 2030 Agenda adopted by the United Nations into its operations (Vinnova, 2021b). Therefore, the agency not only aims to build innovation capacity in Sweden, but also to contribute to sustainable growth. Its current vision is ‘that Sweden is an innovative force in a sustainable world’ (Vinnova, 2021b).

Recently, Vinnova funded the Swedish Transformative Innovation Policy Platform (STIPP), the overall aim of which is to advance ‘the understanding of the dynamics and governance of sustainability transitions’ (STIPP, 2019). The platform involves the participation of senior and junior researchers from four Swedish universities: Lund University, Jönköping International Business School, Chalmers University of Technology and Linköping University. Initially, the platform will operate between 2018 and 2022 and will focus on the analysis of two transition areas: the transformation towards a bio-based economy and the development of smart cities (STIPP, 2019). Additionally, STIPP is organized around six interrelated research projects (RPs) that contribute to five different overarching work packages (WPs), as shown in Figure 1.

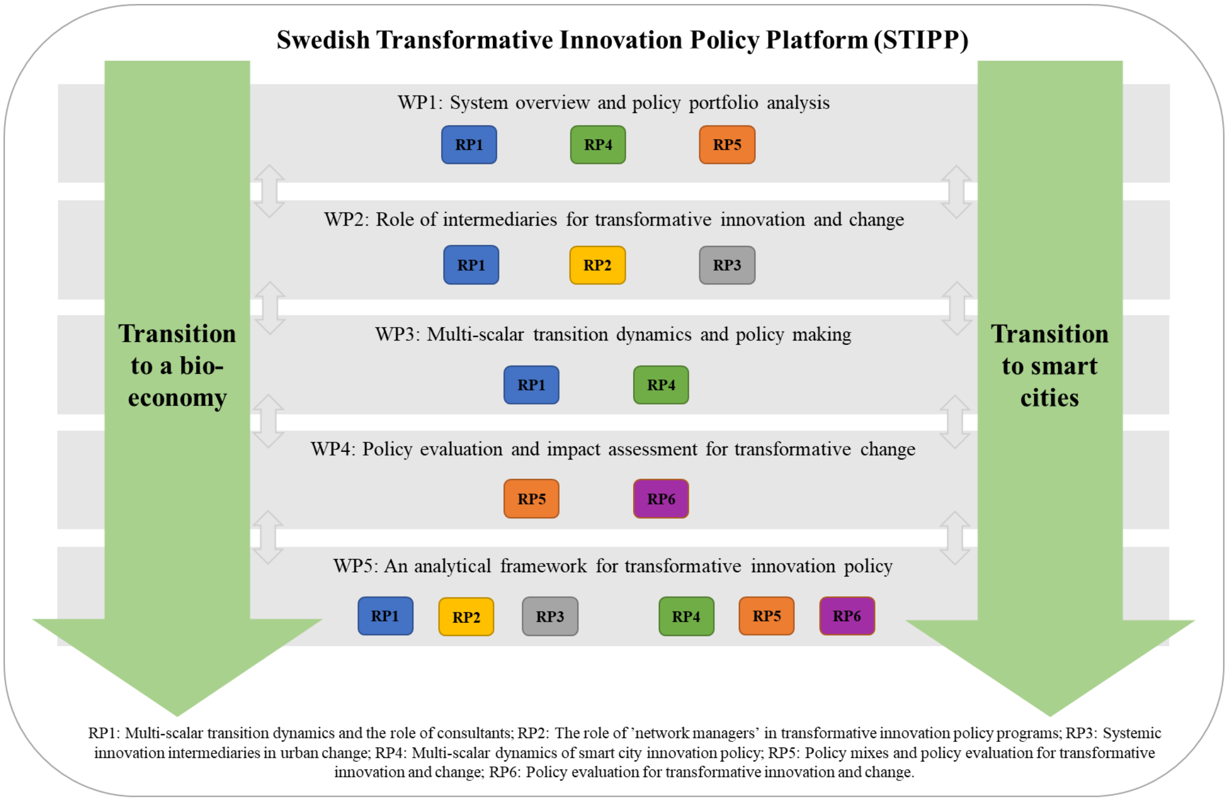


Figure 1. STIPP organization and rationale.

More specifically, this licentiate thesis focuses on RP6: Policy evaluation for transformative innovation and change, which is part of WP4: Policy evaluation and impact assessment for transformative change. The starting point for the research project is the fact that current approaches to evaluating innovation policy are not sufficiently adapted to assess transformative change. As such, the overall objective of RP6 is to study how transformative change can be assessed and evaluated (e.g., in relation to specific policy initiatives), taking the realities of both policy practitioners and network managers into account.

Empirically, the research project focuses on the study of transformative policy initiatives, e.g., the Strategic Innovation Programmes (SIPs),[18] possibly in comparison with a number of more traditional innovation policy initiatives in the same empirical field, such as the Challenge-Driven

[18] The SIPs are coordinated by Vinnova, with the support of the Swedish Energy Agency and the Swedish Research Council Formas, together with participating organizations, and are composed of 17 areas that are considered of strategic importance to Sweden (Vinnova, 2018).

Innovation and Vinnväxt programmes.[19] The starting point will be to study the composition and outcomes of the BioInnovation SIP[20] in terms of, e.g., who the initiators and members are, what types of projects and other activities have been funded by the SIP, which actors are involved in those projects and what has come out of the projects so far.

So far, this research has been guided by such frame. With that in mind, I describe below my steps towards answering the research questions introduced in Section 1.4. This includes, first, a literature review on transformative innovation policy; second, the development of an integrated framework for evaluating transformative innovation policy, which reflects the research gaps discussed in Section 1.3; and third, a first attempt to apply the developed integrated framework in the BioInnovation SIP case.

## 2.2 Literature review

The first step in my research process was the development of a systematic literature review on the policymaking process of transformative innovation policy, which I wrote together with my colleagues Valentina Nakic, Anna Bergek and Hans Hellsmark. The aim of this literature review was twofold: (1) to identify unique transformative innovation policy characteristics and the challenges they imply for policymakers throughout the policy cycle[21] and (2) to examine the literature's contribution to practical policymaking (cf. Haddad et al., 2021).

While following the guidelines provided by Petticrew and Roberts (2008) to conduct systematic literature reviews, we reviewed a total of 57 papers which were related to transformative change and to the innovation process. All the authors were involved in synthesizing the findings according to the papers' research purpose, methods, frameworks, results, and mention of the policy cycle stages. A full description of the methods, as well as the results in relation to each stage of the

[19] The Vinnväxt programme focuses on 'promoting sustainable regional growth by developing internationally competitive research and innovation milieus in specific growth fields' (Vinnova, 2016, p. 4). The Challenge-Driven Innovation programme, in turn, promotes the development of sustainable solutions by providing funding for collaborative projects that aim at developing solutions to societal challenges and contribute to the SDGs (Vinnova, 2019).

[20] The BioInnovation SIP aims target the transition towards a bio-based economy in Sweden by 2050 (BioInnovation, 2018b). This SIP targets three main areas: chemical and energy, construction and design, and material.

[21] In the paper, we used a six-stage policy cycle adapted from Howlett and Giest (2013) and Cairney (2012), which includes agenda-setting, policy formulation, legitimation, implementation, monitoring and evaluation, and policy learning.

policy cycle, can be found in Haddad et al. (2021). Given that the focus of this licentiate thesis is on evaluation, parts of the findings were used in order to describe the transformative policy approach (Section 1.1.3) and the licentiate's problem definition (Section 1.3). As such, the literature review acquainted me with the emerging topic of TIP and the main challenges involved in its evaluation.

## 2.3 An integrated transformative innovation policy evaluation framework

The second step of my research process was the development of an integrated transformative innovation policy evaluation framework, which reflects the three main research gaps raised in Section 1.3. In sum, these gaps include (i) the disconnection between innovation policy and policy evaluation literatures; (ii) the need to consider a broader notion of behavioural additionality which goes beyond the change in actors and firm behaviour to also include system-level effects; and (iii) how to capture directionality.

When it comes to choosing an evaluation approach, Purkus and Lüdtke (2020, p. 3) highlight that 'what evaluation approach – or combination of approaches – proves appropriate for a specific governance context depends on what aims and functional needs the evaluation seeks to address'. As will be discussed below, I found it more suitable to combine different approaches, which would allow connecting insights from the policy evaluation and the transformative innovation policy literature. The development of the integrated framework was a result of many months of discussion and research between me and Anna Bergek. So far, such a process has been quite deductive. In other words, the integrated framework is based on 'what is known about a particular domain and of theoretical considerations in relation to that domain' (Bryman and Bell, 2015, p. 55).

The first step towards developing the integrated framework was to go back to the literature on policy evaluation, and more specifically on innovation policy evaluation, in order to understand this mismatch between approaches and to determine how they could contribute to each other. This resulted in a second screening and analysis of papers (in relation to the literature review performed on transformative innovation policy, as described in the previous section). Some of the findings related to the evaluation of innovation policy were presented in the introduction (see Section 1.2). In relation to the evaluation literature, Section 2.3.1 brings an overview of the different perspectives on evaluation theory. This analysis led to the selection of my first methodological choice: the use of a theory-based approach to evaluation.

The second step was to study how to address behavioural additionality for transformative innovation policy, while the third step included the discussion surrounding directionality. Given that most TIP evaluation frameworks developed so far were departing either from the TIS functions and/or considering other sustainability transition frameworks, such as the MLP, SNM and TM (see Section 1.2.4), such approaches seemed to be a good starting point. Therefore, my second methodological choice was to focus on a socio-technical system approach.

Many adaptations have also been made along the way on the integrated framework, as a result of research findings and the feedback received in conferences and workshops, including: (i) the alternative session for the EU-SPRI Conference in June 2020; (ii) the 11th Sustainability Transitions Conference in August 2020 (Haddad and Bergek, 2020); (iii) the Transformative Metrics Workshop held by the Transformative Innovation Policy Consortium (TIPC) in October 2020; and (iv) a workshop organized by Anna Bergek and Joeri H. Wesseling, from Utrecht University, to discuss mission-oriented innovation policy and transformative innovation policy evaluation in January 2021.

The resulting integrated framework is composed of seven steps that will be introduced in Section 4. Below, I discuss in more detail the different perspectives on evaluation theory, as well as my two main methodological choices when it comes to developing the integrated framework: a theory-based approach and the socio-technical system approach.

### 2.3.1 Perspectives on evaluation theory[22]

In a general sense, policy evaluation 'is about comparing the intended and actual effects of public policies and can refer to insights regarding policy outcomes and/or impacts' (Knill and Tosun, 2012, p. 175). Policy evaluation can also involve monitoring and learning, which are linked to the last stages of the policy cycle (see Section 2.2). Rossi et al. (2019, p. 6) define evaluation research as the 'application of social research methods to systematically investigate the effectiveness of social intervention programmes in ways that are adapted to their political and organizational

[22] This section is based on a later version of Haddad and Bergek (2020) that is being prepared to be submitted to a journal.

environments and are designed to inform social action to improve social conditions'. Evaluation is also a governance and learning tool used by policymakers to generate lessons for further policy practices (Amanatidou et al., 2014; Flanagan et al., 2011). In this licentiate thesis and for developing the integrated framework, I use a broader understanding of evaluation.

Over the years, different evaluation types and approaches have emerged and many attempts to group and categorize the various theoretic perspectives have been made (Alkin, 2013; Edelenbos and Van Buuren, 2005; Stufflebeam, 2001). Policy evaluation can be performed in many ways and for different reasons (Knill and Tosun, 2012). Generally speaking, evaluations can be *formative*, with the purpose of improving a policy measure by continuously supporting learning and decision-making processes, or *summative*, with the aim of assessing policy impact by establishing cause-effect relationships (usually at the end of policy implementation) (Knill and Tosun, 2012). They can also be conducted *ex-ante*, i.e., before an intervention, or *ex-post,* i.e., after the programme was implemented (Khandker et al., 2010). Moreover, the literature distinguishes between evaluation functions, in which evaluation can serve for assessment or improvement, and between programme stages, in which the evaluation can focus on the programme process (by studying programme implementation) or programme outcome (by analysing the programme's impact in relation to its goals) (cf. Chen, 1996; Edler et al., 2012a).

Historically, scholars involved in epistemological discussion surrounding evaluation theory draw on three main philosophical paradigms:[23] post positivism, which gained more attention during the 20th century and represents a shift from the positivism thinking; constructivism; and pragmatism (Alkin, 2013). In a *positivistic* view (cf., e.g., Campbell, 1966; Cronbach and Shapiro, 1982), the systematic use of methods makes the study scientific (e.g. for determining accountability), and facts are preferred over value claims, since they are perceived as rationally defined (Alkin, 2013). Underlying the positivistic view was the logic of experimentation and a 'successionist' view on causality, which states that 'the reason that we know one event caused another event is that the first event took place before the other event regularly' or, in short, 'if p, then q; p, therefore q' (House, 2001, p. 311). This theory underlies the view of causality in experimental, e.g., random

[23] According to Mathison (2005), a paradigm is 'a worldview or perspective that, in the case of research and evaluation, includes conceptions of methodology, purposes, assumptions, and values… that typically consists of an ontology (the nature of reality), an epistemology (what is knowable and who can know it), and a methodology (how one can obtain knowledge)' (p. 289).

control trials (RCT), and quasi-experimental designs, which look for the impact or causal effect of a programme in outcomes, i.e., the so-called counterfactual or, in other words, 'what the outcome would have been for program participants if they had not participated in the program' (Gertler et al., 2011, p. 8).

According to Alkin (2013), adherents of *post positivism* believe that truth can be approached, but never reached, i.e., one can measure the truth, but not uncover it, given that 'a full understanding of truth can be approached but never reached' (p. 25). As such, they also believe that reality can be studied objectively, as do positivists, but they differ in that they believe that reality cannot be understood in its totality (Christie and Fleischer, 2009). Their view on causality is that 'causation is observable and that over time predictors can be established, but always some degree of doubt remains associated with the conclusion' (Christie and Fleischer, 2009, p. 24).

In a *constructivist* approach, 'claims, concerns and issues of stakeholders serve as organizational foci' (Guba and Lincoln, 1989, p. 50). These authors defend the idea of multiple realities and the view that stakeholders are involved in placing value. Guba and Lincoln (1989) call this constructivist approach the *Fourth Generation Evaluation*, which reflects the change in the role of the evaluator, from analyst of events, 're-constructor' of events, or a 'judge' to mediator and co-producer of social constructs (Amanatidou et al., 2014). This view follows an inductive logic, prefers qualitative methods, and sees causality as being impossible to distinguish, given that the relationship between cause and effect is bidirectional, i.e., everything affects everything else at once (Christie and Fleischer, 2009). This view on causality is also closely linked to the narrative approach, which views participants as active agents in an intervention that can influence and generate successful outcomes (Stern et al., 2012).

*Pragmatists* point out that objectivity and subjectivity are 'two positions on a continuum and argue that deductive and indictive logic should be used in concert' (Alkin, 2013, p. 17). On the one hand, pragmatism is similar to constructivism in its understanding that 'there are multiple explanations of reality, and at any given time there is one explanation that makes the most sense' (Christie and Fleischer, 2009, p. 25). On the other hand, it is related to post positivism in its view about external reality and the lack of an absolute truth, as well as on the view of causality in a sense that they believe that causes may be linked to effects. However, they argue, absolute certainty about causation is impossible. Moreover, both quantitative and qualitative methods are legitimate (Christie and Fleischer, 2009).

Another philosophical position also explored in evaluation, but not actually rooted in evaluation research, is *critical realism* (Pawson, 2013). Critical realism was developed by Roy Bhaskar, an English philosopher, and implies that the scientist's view is only a way to know reality and that observations are 'not theory-neutral (it is influenced by our socio-political situatedness)' (Bryman and Bell, 2015, p. 61). According to Pawson (2013, p. 15), critical realism explains 'nature's uniformities by unearthing the underlying mechanisms that give rise to them. To achieve this requires theory and it is generative theories that allow us to both know how to manipulate the experiment and explain the results we then observe'.[24] This philosophical position influenced, for instance, realist evaluation. Realist evaluation 'is a species of theory-driven evaluation that holds the view that programs are theories incarnate' (Astbury, 2013, p. 385). Realist evaluation is considered the 'European version' of theory-based[25] evaluation, which was primarily pushed forward by the Aspect Institute in the United States with the Theories of Change (ToC) framework (Connell et al., 1995; Fulbright-Anderson et al., 1998). However, while the realist evaluation is specified in realist terms and can be traced to the (European) critical realist movement, theories of change (and other theory-based approaches) are, in general, silent about their epistemological and ontological views (Astbury, 2013).

### 2.3.2 Theory-based approach

Based on the insights from evaluation theory, my first methodological choice was to use a theory-based approach to evaluation. The reasons why this seems suitable in the context of transformative innovation policy are twofold. First, as discussed in Section 1.2, innovation policy evaluation has been dominated by approaches that try to measure the effects of policy intervention by applying experimental and quasi-experimental methods, i.e., method-driven approaches. According to Stame (2004, p. 60):

[24] The concept of 'generative' will be later introduced in Section 3.1.4. In short, it derives from the notion that 'to infer a causal outcome (O) between two events (X and Y), one needs to understand the underlying mechanism (M) that connects them and the context (C) in which the relationship occurs' (Pawson et al., 2005p. 21-22).
[25] Theory-based is also referred to in the literature as theory-led, theory-oriented, or theory-driven evaluation.

> Theory-oriented evaluations present themselves as a new wave vis-à-vis method-oriented evaluations. In this new wave, what changes is the attitude toward methods. There are no more paradigm wars that are immobilizing the field; nor contention about pre-planned multi-method evaluations. All methods can have merit when one puts the theories that can explain a programme at the centre of the evaluation design. No method is seen as the 'gold standard'. Theories should be made explicit, and the evaluation steps should be built around them: by elaborating on assumptions; revealing causal chains; and engaging all concerned parties in this exercise.

Theory-based evaluation criticizes methods-driven and experimental-focused evaluations for lacking an explanation as to how and why outcomes come about (Blamey and Mackenzie, 2007; Rolfe, 2019). As such, it is 'seen as providing a key to unlock complex processes between policy intent and policy outcome, by examining implementation, the causal processes that generate outcomes and contextual factors that influence them' (Rolfe, 2019, p. 294).[26]

While 'theory' can be used in different ways, in general, there are two main types of theory that underlie policy evaluation: *programme theory* and *social science theory* (Knill and Tosun, 2012). 'Program theory focuses on the nature of the evaluand itself (i.e., the program, treatment, intervention, policy, etc. being evaluated)' (Donaldson and Lipsey, 2006, p. 66). As such, it relies on the assumptions that guide how the evaluand is implemented and will produce change (Astbury and Leeuw, 2010; Donaldson and Lipsey, 2006). Social science theory, in contrast, is not related directly to methods and practices of evaluation, but rather to the theories that address the social phenomena underlying a social programme and, hence, it can be very relevant to evaluation (Donaldson and Lipsey, 2006; Knill and Tosun, 2012). This is also known as the *policy theory* underlying an intervention[27] (cf. Molas-Gallart and Davies, 2006).

That said, this results in a second reason why the theory-based approach would be suitable: it offers a good way to connect with the policy theory part of the evaluation process. As such, the evaluator performs a programme evaluation, oriented by the insights from the transformative innovation policy literature. As will be discussed below, such an approach also aligns well with some of the philosophical roots of theory-based approach.

[26] See also Chen (1990) and Weiss (1997).
[27] In this thesis, I also use the term 'policy theory' given that is the term adopted in the innovation policy literature.

### 2.3.3 Socio-technical system approach

The *policy theory* underlying the integrated framework is, thus, that of transformative innovation policy. As mentioned previously, in this licentiate thesis, I use the innovation system and socio-technical system approaches[28] as starting theoretical frameworks. That said, the unit of analysis becomes that of the socio-technical system, which is at the heart of transition studies, and the subject of research is the changes occurring at the system level (Loorbach et al., 2017; Zolfagharian et al., 2019). The first main reason behind the use of such frameworks for policy theory is that most work developed so far focusing on evaluating transformative innovation policy builds on existing systemic failures or TIS functions or other transition frameworks (see Section 1.2.4).

More specifically, I depart from the TIS framework, given that I was already acquainted with the literature and Anna is one of the key scholars involved in developing the original framework. Since the functions framework is connected to innovation performance (Bergek et al., 2008a), it seems a suitable option for assessing system-level effects beyond the change in actors and firm behaviour, i.e. behavioural additionality. Moreover, I, together with Anna, reviewed some of the main criticisms surrounding the TIS framework and how other approaches, such as the MLP and SNM, could be used to address some of its flaws (cf. Markard and Truffer, 2008). This resulted in some conceptual adjustments in the TIS framework (this will be further elaborated in Section 3.2.4), including the need to broaden the technological system towards a socio-technical system and how to incorporate the directionality concept more clearly within the functions.

The second reason is related to the methodological and philosophical aspects of transitions studies. While these seem to be still underdeveloped, an analysis involving multiple transitions studies indicated that all philosophical paradigms (i.e., positivism, constructivism, pragmatism and critical realism) have been used in the field (cf. Zolfagharian et al., 2019). This indicates that the field accommodates different methodological traditions and, hence, can be aligned with the theory-based approach to evaluation. Most notably, some authors have suggested that critical realism can offer support for transitions frameworks (cf. Papachristos, 2018; Sorrell, 2018; Svensson and Nikoleris, 2018). Geels (2021) has also suggested that such frameworks already use some elements

[28]According to Geels (2004), socio-technical systems widens the concept of sectoral systems of innovation in order to more explicitly incorporate the user side as part of the analytic focus, and not only the production side as in the latter approach.

from critical realism. For example, the functions of the (technological) innovation system framework have the analytical basis to make both formative and summative assessments of many of the mechanisms related to socio-technical transition processes (Markard and Truffer, 2008). The MLP and SNM, in turn, address niche and regime level processes needed for a transition to unfold (Markard et al., 2015; Markard and Truffer, 2008; Smith and Raven, 2012), which the TIS framework does not necessarily address. These aspects are related to the notion of generative causality (see Section 3.1.4), which aims at understanding the mechanisms that make an intervention work (Pawson, 2013).

## 2.4 Example of application: the BioInnovation SIP in Sweden

The third and last step of my research process so far was the empirical application. As discussed in Section 2.1, the initial empirical focus of the project was on the BioInnovation SIP. Accordingly, this licentiate thesis includes a first attempt to apply the integrated framework that will be introduced in Section 4. Thus, this first attempt does not include a full evaluation of BioInnovation. Below, I describe the strategies I used for data collection and analysis in relation to the three main components of the framework: programme theory, systems analysis, and transition pathways (see Section 4).

Regarding the first component, in order to explicate programme theory, I conducted a document analysis of different programme documents and reports describing the design and implementation of BioInnovation as a whole. These documents were obtained from Vinnova and from the official BioInnovation websites (BioInnovation, 2020f). ‘Document analysis is a systematic procedure for reviewing or evaluating documents – both printed and electronic (computer-based and Internet-transmitted) material’ (Bowen, 2009, p. 27). Additionally, it involves an iterative process of skimming, reading, and interpreting, whilst combining elements of content and thematic analysis. Content analysis refers to the process of organizing information into categories related to the question under scrutiny, whereas thematic analysis regards the identification of patterns within the data, which then become the categories for analysis (Bowen, 2009). For the thematic analysis, instead of identifying themes emerging within the data, I used the themes from the combined socio-technical system approach. This includes the functions of the innovation system and additional transformative processes related to actor networks and institutions, as will be described in Section 3.2.3 and 3.2.4. Table 3 illustrates the themes used in the content and thematic analysis.

The second component encompasses a socio-technical analysis. As pointed out by Turnheim et al. (2015, p. 243), 'socio-technical transitions studies seek to analyse the multiple dimensions of change, including a broad range of technological, economic, political, socio-cultural aspects at different levels and temporalities'. This analysis includes understanding how the socio-technical system is behaving in terms of a set of key processes, which include the aforementioned functions and structural processes. The analysis was in the projects' final reports, available on both BioInnovation's and Vinnova's project database in March 2021 (BioInnovation, 2021; Vinnova, 2021a), along with findings from two preliminary analyses made by Coenen et al. (2017) and Grillitsch et al. (2019). This means that the analysis only included projects finalized up to this date. I also added a few ongoing projects that have reported preliminary results. A list of completed projects included in the analysis is available in Appendix B: List of projects. The document analysis was mainly qualitative, also using thematic and content analysis, following the themes introduced in Table 3. Some additional quantitative indicators were used to support some of the socio-technical system analysis, but to a limited extent. In order to build the Context-Mechanisms-Outcome configuration (CMOc), which is one of the steps within the second component, I followed the realist evaluation literature guidelines, as will be introduced in Section 3.1.2.1.

In relation to component three, the analysis follows from the findings from the previous analysis. As such, no additional document analysis was performed at this stage. More specifically, the findings from the socio-technical system analysis informed the identification of transition pathways, based on the pathway patterns described in Geels and Schot (2007) and Geels et al. (2016) (see Section 3.2.1.1).

Table 3. Themes used for thematic analysis.

| **Themes** | **Abbreviation** |
|---|---|
| Knowledge development and diffusion | KDD |
| Entrepreneurial experimentation | EE |
| Market formation | MF |
| Influence on the direction of search | IDS |
| Resource mobilization | RM |
| Legitimation | LEG |
| Development of positive externalities | DPE |
| Actor networks | AN |
| Institutions | INS |

# 3 Theoretical framework

As discussed in Section 2, in order to address the three research problems highlighted in Section 1.3, I made two methodological choices: to use a theory-based evaluation and to take a socio-technical system approach. While the former sheds light on how to perform the evaluation of programmes, the latter provides insights to explain the social phenomena behind a policy intervention. That said, in this section, I provide an overview of the main theoretical foundations of each approach and sketch the theoretical framework that serves as basis for the development of the integrated framework.

More specifically, in Section 3.1 I analyse the two most influential approaches to theory-based evaluation: theories of change (ToC) and realist evaluation. I also highlight insights on how these approaches can be combined and discuss causal attribution in theory-based evaluation. Section 3.2, in turn, introduces the main theoretical frameworks adopted in this licentiate thesis: TIS and MLP and SNM. I also explain how these approaches can be combined to inform transformative processes that the evaluator should be looking for, by suggesting conceptual adjustments in the TIS framework. Section 3.3 summarizes the main points and provides the basis to introduce the integrated framework, by connecting back the findings from this chapter with the licentiate research problems.

## 3.1 Theory-based evaluation

The most influential theory-based evaluation approaches are 'Theories of Change' and 'Realistic Evaluation' (Blamey and Mackenzie, 2007).[29] The ToC approach is aimed at developing a visual and narrative model of the intervention under evaluation, by analysing how inputs and activities create expected outputs and how the intervention then generates long-term outcomes (Rolfe, 2019). According to Weiss (1995), a programme's theories of change is the combination of implementation theory and programme theory.[30] The former refers to how the programme is

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[29] In the literature, 'Realist Evaluation' and 'Realistic Evaluation' are used simultaneously to refer to the same evaluation approach.

[30] The literature uses different terms to describe the same type of theory or, concomitantly, similar terms to refer to theories that are different epistemologically (cf. Astbury and Leeuw, 2010; Blamey and Mackenzie, 2007; Knill and Tosun, 2012). Pawson and Tilley (1997), for instance, use the term 'middle-range' theory to refer to Weiss' definition of 'program theory'.

carried out, i.e., it tests the theoretical assumption of whether ‘the program is conducted as planned, with sufficient quality, intensity, and fidelity to plan’ (Rogers and Weiss, 2007, p. 72). The latter, in turn, is related to the participants’ responses to programme activities (Weiss, 1997), and to the ‘hypothesized causal links between mechanisms released by an intervention and their anticipated outcomes’ (Blamey and Mackenzie, 2007, p. 445).

Building on the realist theory of science, the ‘realist evaluation is the European version of theory-based evaluation, and its ontological stance puts it clearly as a third, “realist” way opposed to both the positivist-experimentalist and the nominalist-constructivist traditions in evaluation’ (Alkin, 2013, p. 361). Realist evaluation can be both summative and formative, favours a multiple methods approach without any predefined preference for quantitative versus qualitative methods, and allows for the evaluation of both processes and impacts (Pawson and Tilley, 1997). While *policy theory* would be similar to both ToC and RE, programme theory in RE is less about the ‘nuts and bolts’ of programmes and its linkages, and more about the responses leading to behaviour change (Blamey and Mackenzie, 2007). Therefore, programme theory in RE is developed in realist terminology of context, mechanisms, and outcome configurations (CMOc) and, as such, should be developed as an *if-then* proposition (Pawson, 2013).

Below, I describe in more detail how a ToC evaluation and a realist evaluation should be undertaken.

### 3.1.1 Undertaking a theory of change evaluation

The theory of change is developed collaboratively with stakeholders, i.e., programme staff, managers, and funders. Even though some authors highlight that stakeholders’ beliefs are the primary source of theory (Weiss, 1997), others add that it can be complemented with project documentation and existing research (Mason and Barnes, 2007; Rolfe, 2019). In ToC, the role of the evaluator is to ‘facilitate the articulation of the relevant theories and to highlight conflicting and discrepant theories’ (Blamey and Mackenzie, 2007, p. 443). While there is no consensus on the number of steps needed to perform a theory of change evaluation, it can essentially be summarized in four main stages, as suggested by Rolfe (2019) and illustrated in Figure 2.

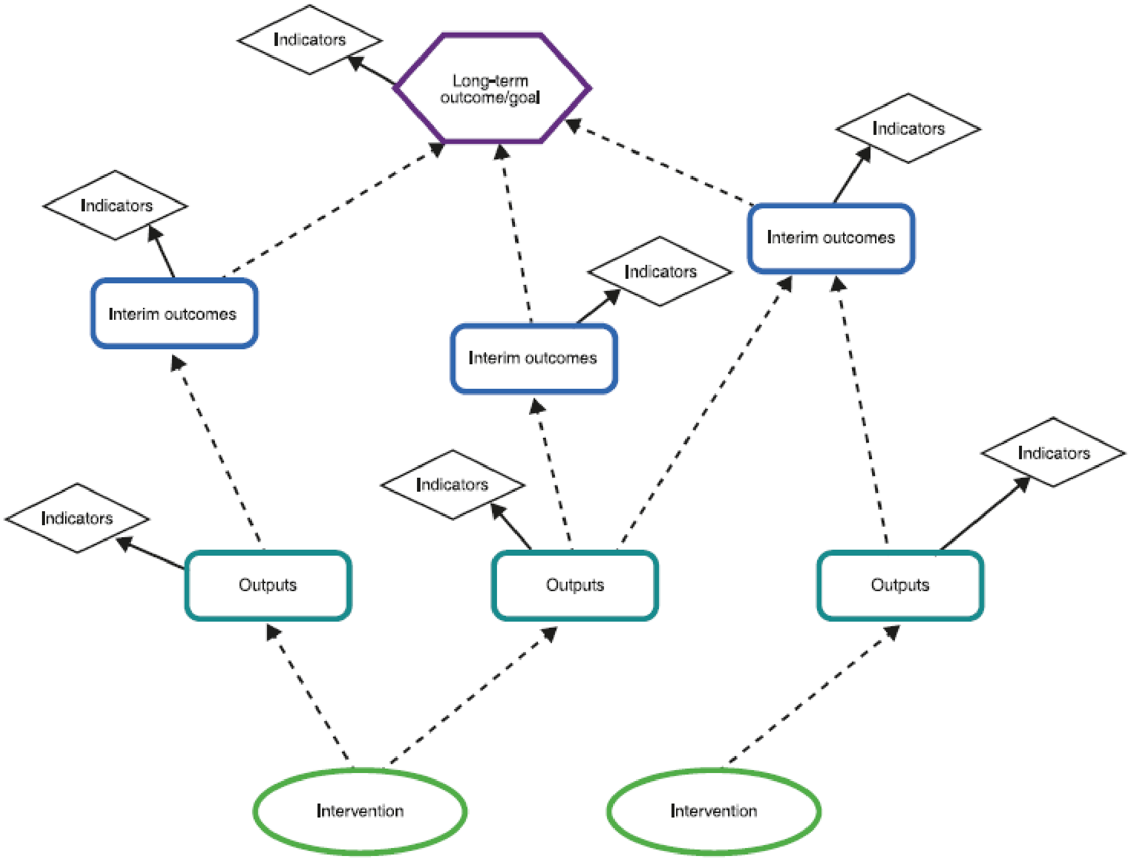


Figure 2. Generic theory of change (ToC) model.
*Source: Rolfe (2019, p. 296) adapted from Anderson (2005).*

First, after agreeing on the long-term goal of the programme, stakeholders are encouraged to discuss, in a process of backwards mapping, the necessary outcomes, outputs, activities and inputs to achieve the desired goal. As such, 'stakeholders make explicit their theories of what (outcome) they hope to achieve (in the long, medium and short term), how (action) they expect to achieve them and why the proposed actions should deliver intended outcomes (rationale)' (Mason and Barnes, 2007, p. 156). Additionally, there is also an effort to understand the context in which the programme operates. Second, based on the resulting programme theory, three criteria are assessed: plausibility, doability and testability. The first and second criteria test, respectively, whether the programmes' underlying logic is realistic and if the resources that are available can be used as the model suggested. The third criterion assesses the extent to which the elements of the ToC can be measured, i.e., if the theories of change are articulated in a way that it is open to evaluation and if the outcomes of the programme have a high degree of specificity (Blamey and Mackenzie, 2007). Third, the implementation of the programme is assessed by a range of indicators in order to establish causal attribution,[31] which can potentially show if some of the elements of the programme theory work. Finally, the data is reviewed in a collaborative manner to assess inputs, activities, outputs, outcomes, and the impact of the programme.

#### *3.1.1.1 Representing theories of change*

The process of documenting the ToC produces a generic ToC model, as illustrated in Figure 2. However, there are different ways to represent a ToC. Belcher et al. (2020), building on Earl et al. (2001), suggest that the documentation of a ToC model can be done in a set of nested spheres, based on the relative influence of a programme (see Figure 3):

- *Sphere of control* involves research definition, design, and implementation, as well as the intended outputs. It represents the highest level of influence of a programme.
- *Sphere of influence* represents what the project cannot control directly, but can exert influence on, as it involves different actors and processes working simultaneously. It goes beyond the programme's boundary.
- *Sphere of interest* falls outside the influence of the programme and represents the indirect changes which may manifest as changes in the social, economic, or environmental conditions.

Funnell and Rogers (2011), in turn, highlight four broad approaches:

- *Outcome chain logic model* represents an intervention in terms of a sequence of results, i.e., from initial results towards the ultimate outcomes and impacts. This approach was mainly used in the first representations of programme theory, e.g. Weiss (1972).
- *Pipeline logic model* usually represents an intervention as a linear process in order to understand the causal processes in terms of inputs, outputs, outcomes, and impacts. Such a form of representation is indicated for cases 'when the activities are all up front, and then the rest of the results simply happen like a row of dominos' (Funnell and Rogers, 2011, p. 241).

[31] Note that this does not mean that the evaluation rules out all threats to validity; it just shows what processes lead to the outcomes observed. In addition, if one of the steps is not supported by the data, it can show where the theory breaks down (Rogers and Weiss, 2007; Weiss, 1997).

- *Realist matrices* is an approach developed by Pawson and Tilley (1997) to represent, in a table, the CMOc hypotheses. Such a representation will be elaborated further in Section 3.1.2.
- *Narratives* show programme theory as a series of propositions that describe how the programme works and why it is needed. The narrative can be a complement to diagrams, as it explains how inputs lead to outcomes and how participants are involved in the programme (Funnell and Rogers, 2011).

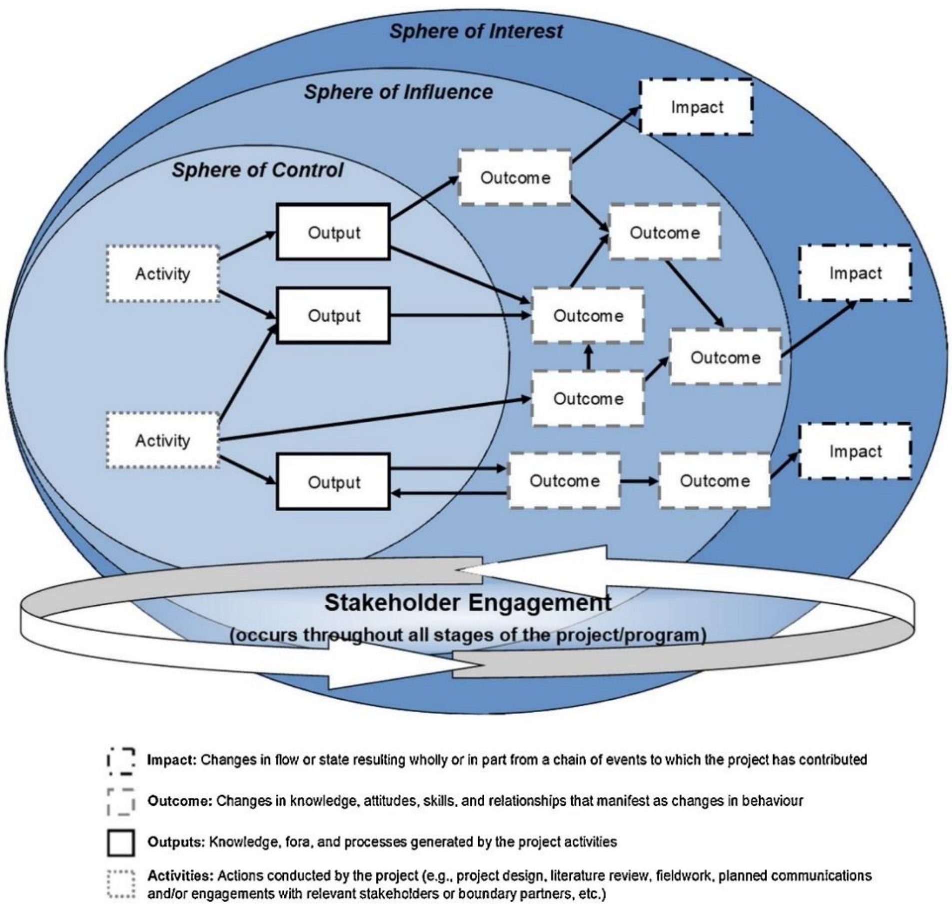


Figure 3. Theory of change spheres, representing the logic flow from activities and outputs towards outcomes and impact.
*Source: Belcher et al. (2020, p. 11).*

The authors also list a set of approaches that can be used to represent complicated and complex programmes. In the case of complicated programmes, Funnell and Rogers (2011) show how to adapt the aforementioned logic models to include the complicated aspects underlying programme theory. This is the case, for instance, in interventions that involve multiple organizations, and these organizations can variously influence programme impact. Other examples include: (i) when one wants to illustrate how interventions that are subsequent to a previous one are linked and path-dependent; (ii) or when an intervention has conflicting objectives (also known as simultaneous causal strands) and one needs to represent these in the logic model so both causal paths are acknowledged and completed.

In terms of complex interventions, Rogers (2008, p. 29) acknowledges that 'complex program theory may be used to represent recursive causality (with reinforcing loops), disproportionate relationships (where at critical levels, a small change can make a big difference – a "tipping point") and emergent outcomes'. In this case, logic models are used as 'organizing heuristics rather than as a formula for implementation' (Funnell and Rogers, 2011, p. 264). I refrain from discussing all the options for representing complex programme theories,[32] given that they are many and describing all options here is beyond the goal of this thesis. Promising options would include diagrams and approaches from systems thinking, e.g. network theory and system dynamics (cf. Funnell and Rogers, 2011).

#### *3.1.1.2 Advantages and disadvantages of theories of change*

The main advantage of developing a ToC evaluation is the ability to collect data to see how and how much change has occurred in each step of the sequence of causes and effects (Rogers and Weiss, 2007; Weiss, 1997). As such, it also has the potential to indicate breaking points and shed light on the causes of programme success and/or failure. In addition, it helps to provide a better idea of programme strategies and complexity (Blamey and Mackenzie, 2007). Nonetheless, the literature has also reported many challenges. First, the involvement of a broad set of stakeholders in developing theories can lead to conflicting views, which makes it harder to reach consensus (Mason and Barnes, 2007). Second, some authors have highlighted that, in practice, ToC evaluations fail to go beyond implementation theory and end up focusing on activities and intermediate outcomes rather than on the mechanisms of change, which are, in turn, specified by programme theory (Blamey and Mackenzie, 2007; Rogers and Weiss, 2007; Rolfe, 2019). Third,

[32] See Funnell and Rogers (2011) for the description of five different ways to represent complex programme theory: (1) fixed ultimate outcome and emergent programme theory; (2) structured processes for developing emergent programme theory; (3) generic theory of change with emergent theory of action; (4) vertical integration of outcome chains from different agencies; (5) diagrams and concepts from systems approaches.

many ToC evaluations end up developing linear and simplistic models that are mainly descriptive and based on practitioners' views, failing to include other perspectives, e.g., from programme clients, intended beneficiaries, existing research theories, etc. (Rogers and Weiss, 2007). Fourth, ToC can be very time-consuming and resource-intensive (Mackenzie and Blamey, 2005; Rolfe, 2019).

### 3.1.2 Undertaking a Realist Evaluation

In a realist evaluation, the evaluators develop the theory with a more limited and selected number of stakeholders and, as such, are less concerned with reaching consensus and focus less on the role of implementers themselves (Blamey and Mackenzie, 2007). They, in contrast, play a more active role in suggesting theories, based on their own knowledge and experience. Similarly to the ToC approach, there is no consensus on what steps must be followed in order to undertake a realist evaluation (Blamey and Mackenzie, 2007). However, it can be summarized, based on the work of Pawson and Tilley (1997), in four main steps (Blamey and Mackenzie, 2007; Rolfe, 2019), as illustrated in Figure 4.

First, the evaluator, together with programme stakeholders and discussions undertaken through 'realist interviews', tries to understand what the aim of the programme is, as well as its nature, target audience, context and predominant theories (Blamey and Mackenzie, 2007). At this point, the evaluator formulates a set of middle-range theories that 'account for the processes that explain how an intervention leads to a particular outcome' (Marchal et al., 2012, p. 194). Second, these middle-range theories take the form of hypothesized 'Context-Mechanism-Outcome Configurations' (CMOc), which explains how potential causal mechanism may operate to generate outcomes in a particular context. In other words, 'CMOc is a hypothesis that the program works (O) because of the action of some underlying mechanisms (M), which only comes into operation in particular contexts (C)' (Pawson, 2013, p. 23). Third, the evaluator collects data using mixed methods, including both quantitative and qualitative data collection and realist interviews, to analyse and test these CMOc. Fourth, the evaluator refines the programme specification by exploring how CMOc play out (Blamey and Mackenzie, 2007; Rolfe, 2019). The point here, instead of producing universally valid findings, is to help policymakers understand in which conditions the programme worked (or not) and how (Marchal et al., 2012; Pawson and Tilley, 1997).

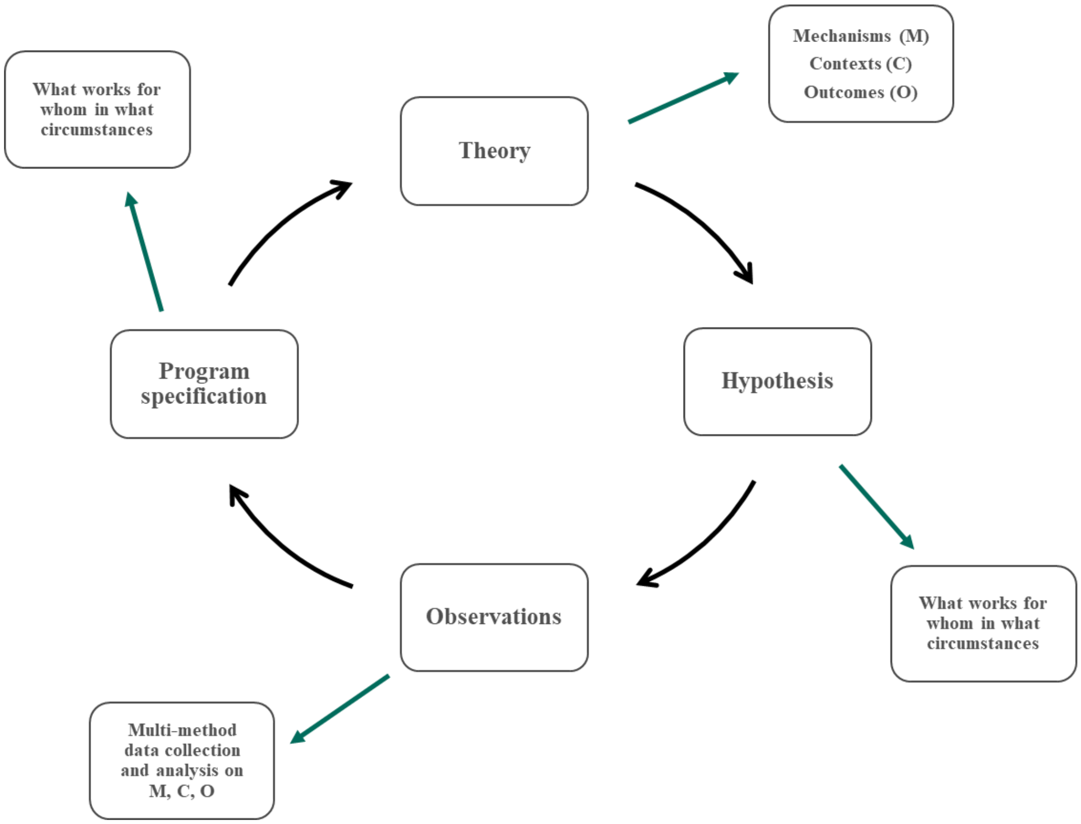


Figure 4. Realist evaluation cycle.
*Source: Pawson and Tilley (1997, p. 85).*

#### *3.1.2.1 Unpacking the concept of CMOc*

Identifying, representing, and testing CMOc is not a simple task. While I discussed above the idea behind realist evaluation and CMOc, here I would like, first, to elaborate further on alternative ways in which mechanisms can be conceptualized to reflect more complex settings. In a recent work, Westhorp (2018) proposes five ways to construct mechanisms in open systems.[33] Within these five ways, two are related to the classic realist construct: (i) 'the powers and liabilities of things', which entails that each level of a system is composed of its own 'powers and liabilities'

[33] It is worth noting that Westhorp (2018, p. 48) defines a system as 'a set of interacting or interdependent component parts forming a complex or intricate whole'. As such, a system is described by its structure, which means, in realist terms, that both the identification and the description of the elements and their relationships are necessary for a system to exist. These systems have four different levels: (i) material, in which the laws of physics and chemistry predominate; (ii) the individual humans, in which psychology, emotion and cognition play a role; (iii) the group level, e.g., families and organizations; and (iv) institutional level.

which can, in turn, impact higher or lower levels of systems; (ii) Pawson and Tilley's (1997) construct of 'reasoning and resources', which relates to the 'reasoning' and the 'resources' of programme implementers and participants, e.g., social and cultural conditions.[34] The other three build on examples discussed by Pawson and Tilley and others and can be summarized as: (iii) forces, i.e., something that exerts pressure, e.g., gravity or laws and regulations; (iv) interactions, which is a result of transfers that alter the initial state of an element, e.g., gunpowder explosion or a contract between a buyer and a seller; (v) feedback or feedforward processes, in which later stages are a result and depend on earlier stages, e.g., stock market crash.

A second point is related to what constitutes a context. According to Westhorp et al. (2011, p. 8), 'context refers to features of participants, organization, staffing, history, culture, beliefs, etc. that are required to 'fire' the mechanism (or which prevent intended mechanisms from firing)'. Other contextual elements include, for example, population groups (i.e., 'for whom' a programme works), geographical and community settings, and specific events. Additionally, Rolfe (2019, p. 307) points out that 'outcomes of 'earlier' mechanisms become context for 'later' mechanisms'. The author exemplifies using the community participation case: the implementation of a national policy generates the context within which community participation processes happen. These processes, in turn, function as a context for other mechanisms to generate wider social outcomes.

A third point is related to the representation and testing of CMOc. As mentioned in Section 3.1.2, Pawson and Tilley (1997) suggest that the evaluator build a CMOc table with the multiple CMOc hypotheses. This can take the form of a realist matrix, in which the columns represent, separately, context, mechanism and outcomes, and each row corresponds to a hypothesis in the form of C1+M1=O1, C2+M2=O2, which represents an if-then proposition[35] (Astbury, 2013; Marchal et al., 2012). By testing the propositions, the evaluator can refine the CMOc according to the evidence

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[34] Westhorp (2018) argues that the theory and practice of RE has emphasized the individual level of Pawson and Tilley's 'reasoning and resources'. Nonetheless, other scholars have expanded that to also include mechanisms operating at institutional and societal levels, e.g., Marchal et al. (2010).

[35] In this licentiate thesis, I use a modification of such formula to address 'large multi-layered and multi-faceted complex social systems' with long and interrelated chains of causality, as suggested by Byrne (2018, p. 104). The author modifies the original C+M=Oc formula to C&Ms → Oc, in which (i) & represents interaction rather than addition; (ii) the 's'in M refers to the plurality of mechanisms that might be operating; and (iii) the → indicates the directional path of causation rather than the = sign, which he argues is non-directional. Pawson also acknowledges the directional sign instead of an = sign (Pawson, 2013; Pawson and Manzano-Santaella, 2012). Additionally, as highlighted by Byrne (2018), these modifications do not aim, at all, at altering the principles of RE.

found. Accordingly, a hypothesized $C_1M_1O_1$ configuration could be then unpacked in $C_{1a}M_1O_{1a}$ and $C_{1b}M_1O_{1b}$, indicating that $M_1$ could also produce different outcomes ($O_{1a}$ and $O_{1b}$) in different contexts ($C_{1a}$ and $C_{1b}$) (Pawson and Manzano-Santaella, 2012). The best way to look for evidence is to explore both positivist and constructivist sides, by including quantitative and qualitative methods to allow for both outcome and processes evaluation (Pawson and Manzano-Santaella, 2012). There are a few available methods listed in the literature, including:[36] qualitative comparative analysis (QCA), social network analysis (SNA), process tracing, content analysis, thematic analysis, meta-analysis, narrative techniques, etc.

#### *3.1.2.2 Advantages and disadvantages of realist evaluation*

One of the main advantages of the realist approach is its potential to understand and explain how programs work (Astbury, 2013). According to Pawson and Tilley (1997), RE also seeks to explore what is inside the black box problem by explaining why programs work or fail, rather than just analysing outcome descriptions, as is commonly done in experimental evaluation. In this regard, van der Knaap et al. (2008) highlight that RE allows for a better understanding of the social and behavioural mechanisms underlying programme theory. Moreover, by following the notion of generative causality, as will be discussed in Section 3.1.4, RE has the potential to identify which CMOc within a programme triggered a specific effect (Blamey and Mackenzie, 2007). However, some challenges have also been pointed out. First, some authors argue that RE can be difficult to codify and there is always confusion when operationalizing the approach in practice, especially in identifying and representing the CMOc (Dalkin et al., 2015; Rolfe, 2019). Aspects such as what really constitutes a mechanism and how to interpret context, rather than just as an external factor, remain a challenge (Marchal et al., 2012; Westhorp, 2018). Second, some studies have struggled to identify meaningful theories due to, for instance, practitioners' lack of clarity regarding the intervention or confusion surrounding the academic literature (Adams et al., 2016; Marchal et al., 2012; Rolfe, 2019). Third, RE can also be very time- and resource-intensive due to the efforts required to identify and explore CMOc (Blamey and Mackenzie, 2007). Finally, evaluating the

[36] Discussing the use of these different methods for evaluation goes beyond the scope of this paper. See Dixon-Woods et al. (2004) and Pope et al. (2007) for an overview of different evaluation methods, and Beach and Pedersen (2018) for process tracing.

findings can become inaccessible to practitioners due to complicated jargon, i.e. CMOc (Rolfe, 2019).

### 3.1.3 Combining theory of change (ToC) and realist evaluation (RE)

Some authors have also been exploring the possibility and feasibility of combining ToC and RE (Blamey and Mackenzie, 2007; Rolfe, 2016, 2019). According to Rolfe (2019), combining ToC and RE might not be applicable to every situation and, as such, the evaluation needs to be adapted according to the evaluation purpose, context and audience. In this way, he also suggests the extension of the RE mantra (i.e., what works for whom in which circumstances, how and why?) to 'the choice of evaluation methodology' (p. 313).

Based on the reflections from Blamey and Mackenzie (2007), Rolfe (2016), and later on Rolfe (2019), proposes a way to combine both the ToC and RE methodologies in order to analyse the impact of community participation (CP) policies at the national and local levels. He proposes five main steps. First, he suggests using ToC to develop the programme's overview in terms of implementation theory, based on a literature review of the history and impacts of CP policies. This would produce a generic ToC model. Second, building on the generic model, the RE approach could be used to identify mechanisms and relevant contextual factors within the ToC model. This could be done via realist interviews and document analysis. Based on the evidence found, it could result in a map of possible mechanisms and contextual factors. Third, collaborative workshops could be developed at the local level, together with participant community organizations, to reflect on the impacts of the intervention and develop local ToC models. Based on data collected on selected indicators, the model could then be revised to assess impacts. This would result in local ToC models and evidence on the impacts produced by the policies at the organizational level. Forth, he proposes using ToC tests based on plausibility and doability on the data collected at the local level to assess the impact of CP policies on the generic ToC model. Finally, the data from the local-based ToC models and findings could then be used in RE analysis to develop and refine CMOc. Figure 5 illustrates the combined ToC-RE evaluation cycle.

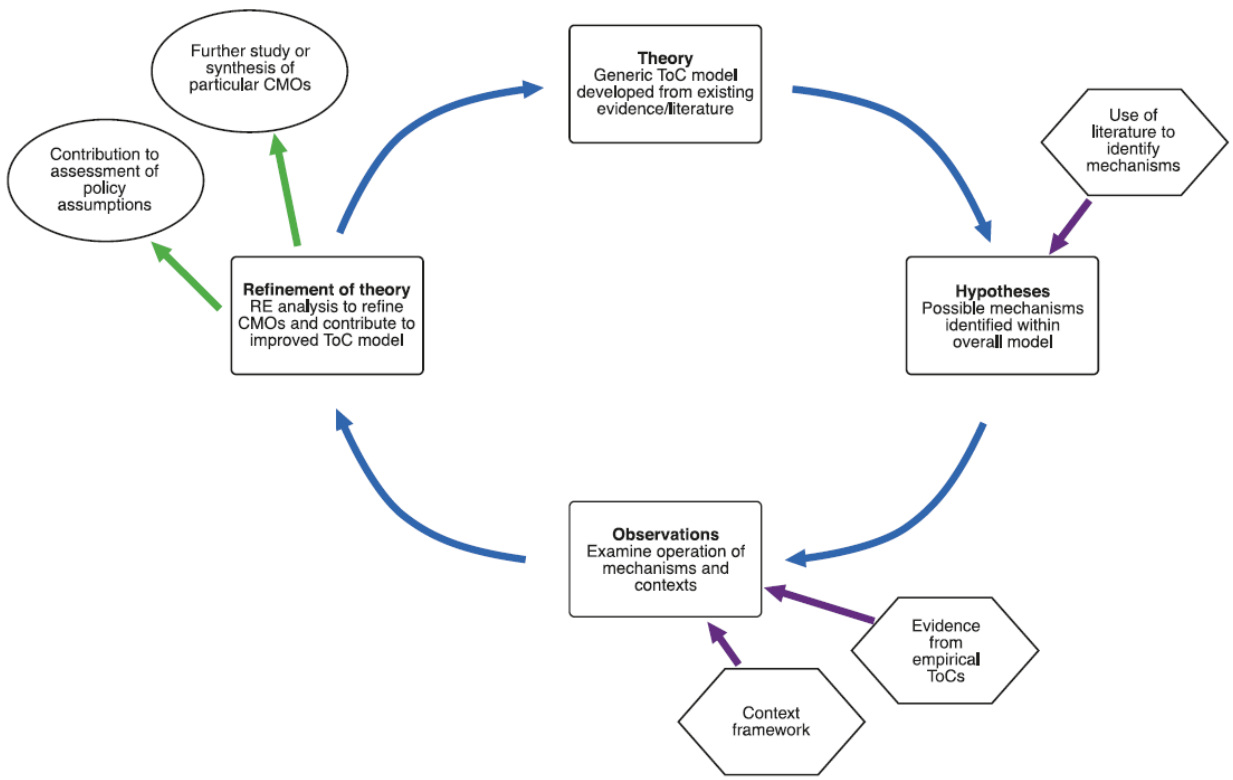



Figure 5. Combined ToC-RE evaluation cycle.
*Source: Rolfe (2019, p. 312).*

#### *3.1.3.1 Advantages and disadvantages of combining ToC and RE*

There are many advantages of combining the two approaches, as summarized in Table 4. To begin with, it has the potential to better address complex programmes by using ToC to get a broader overview of how the programme is being addressed, while RE can examine the causal processes generating change (Blamey and Mackenzie, 2007; Rolfe, 2019). Accordingly, RE can ensure that ToC models go beyond implementation theory and more clearly address elements of programme theory and mechanisms of change. In addition, RE can help address some of the conflicting issues between stakeholders by highlighting the role of the evaluator. ToC, in turn, can provide a framework to 'identify, frame and prioritize context and mechanism by developing a complete model of an intervention' (Rolfe, 2019, p. 300), and can provide more accessible ways to communicate the evaluation findings with stakeholders. However, aspects such as time and resources needed can still be an issue in this combined model. Moreover, more research should be done (also in different fields) to reflect on additional challenges that can emerge by testing the value of combining ToC and RE and applying it in practice (Rolfe, 2019).

Table 4. Summary of strengths and weaknesses of combining theories of change and realist evaluation.

| **Approach** | **Strengths** | **Weaknesses** |
|---|---|---|
| Theory of change | Provides a better understanding of how programmes work and if and how change has occurred<br>Explains what factors were responsible for the programmes' successes and failures | Time- and resource-demanding<br>Risk of ending up with superficial theories rather than focusing on mechanisms of change<br>Difficult to reach consensus among different stakeholders<br>Can lead to very linear approaches to evaluation |
| Realist evaluation | Helps to understand how programmes work<br>Looks inside the black box problem<br>Clearer view on causality | Time- and resource-demanding<br>Difficult to identify and conceptualize CMOc, as well as meaningful theories<br>Difficult jargon |
| ToC-RE combination | Has the potential to yield policy and methodological learning<br>RE can ensure that ToC models go beyond implementation theory<br>RE can help address some of the conflicting issue between stakeholders<br>ToC can help in identifying, framing, and prioritizing mechanisms and contextual factors | Time- and resource-demanding<br>More research should be developed, also in different fields, to assess the value of combining the two approaches |

### 3.1.4 Causal attribution in theory-based evaluation

When it comes to the assumptions surrounding causal attribution, the ToC approach follows the idea that, if the activities and outcomes predefined in the plan and agreed upon among different stakeholders as being plausible are delivered accordingly, then the attribution claim can be strengthened (Mackenzie and Blamey, 2005). In this way, Rogers and Weiss (2007) argue that 'if the evaluation can show the series of micro-steps that lead from inputs to outcomes, then causal attribution for all practical purposes seems to be within reach' (p. 70). However, as they point out, it does not eliminate all threats to validity. Alternatively, Mackenzie and Blamey (2005) argue that another way to attribute outcome changes to the intervention is to combine the information gathered from the ToC with primary and secondary outcome data in order to determine whether the resulting change is due to the exposure of the target groups to the intervention. In this case, the data analysis can provide further evidence to attribute the outcomes to the intervention. Either way, 'for both approaches it is important that the changes from the initial to the final theory articulation process are captured so that explanations are based on what has actually been delivered' (Mackenzie and Blamey, 2005, p. 163).

According to Rolfe (2019), while the ToC approach does not follow a specific concept of causality, RE follows a generative model of causation (Pawson, 2006; Pawson and Tilley, 1997). This model focuses 'on a cumulative and iterative process of theory building, testing and refinement in relation to specific programme subcomponents' (Blamey and Mackenzie, 2007, p. 450). Accordingly, RE 'focuses on building and verifying a theory about how processes and mechanisms work in particular contexts to generate effects and changes' (Gates and Dyson, 2017, p. 31). As suggested by Hind (2010), one can use additionality in conjunction with theory-based evaluation in order to determine attribution. In this case, rather than trying to prove attribution definitively, the generative approach can help unpack the different pieces of evidence that suggest additionality. This helps 'to provide greater rigor in relation to the analysis of causation and, therefore, what was additional' (Hind, 2010, p. 32). Figure 6 shows the realist causal proposition, i.e., 'causal outcomes follow from mechanisms acting in contexts', axiom (Pawson and Tilley, 1997, p. 58).

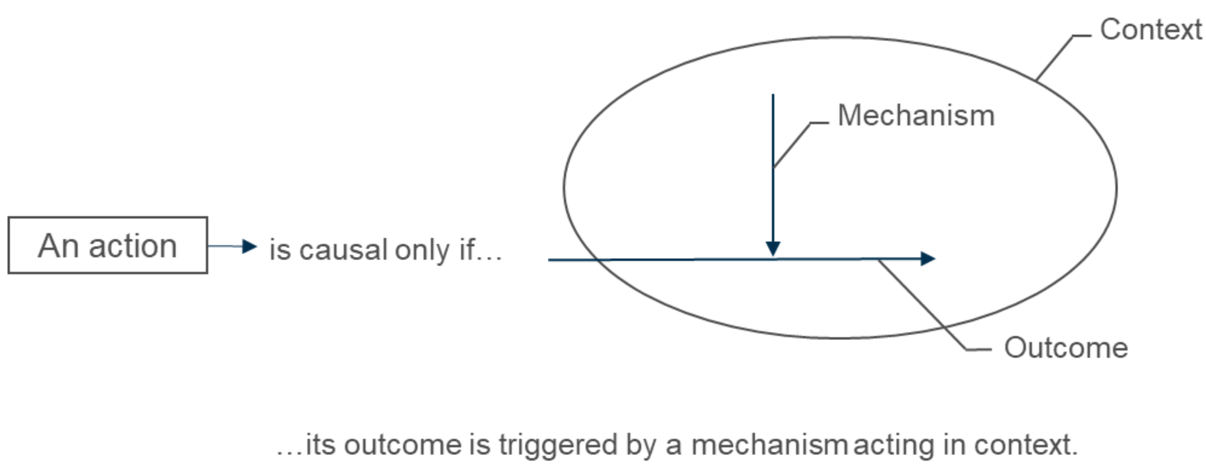



Figure 6. Generative causation.
*Source: Pawson and Tilley (1997, p. 58).*

Following this realist perspective, Falleti and Lynch (2009) argue that 'recent advances in qualitative and quantitative methodology suggest that causal explanations must be contextually bounded' (p. 1143). A causal explanation can thus only be gasped by considering the interaction between causal mechanisms and context, independently of the method applied. While there is still much confusion in disentangling mechanisms, context and outcomes in RE (Astbury, 2013), Falleti and Lynch (2009) provide some practical advice concerning specifying causal mechanisms, and further discuss the definition of context. First, causal mechanisms are distinct only from independent and dependent variables, e.g., the links between input and outcomes. Instead, they try to uncover social processes that connect inputs and outcomes, and are portable and comparable across different contexts. As such, 'mechanisms tell us how things happen: how actors relate, how individuals come to believe what they do or what they draw from past experiences, how policies and institutions endure change, how outcomes that are inefficient become hard to reverse (…)' (Falleti and Lynch, 2009, p. 1147). Second, following Pawson's (2000) concept of context, Falleti and Lynch (2009, p. 1152) define context as being 'the relevant aspects of a setting (analytical, temporal, spatial, or institutional) in which a set of initial conditions leads (probabilistically) to an outcome of a defined scope and meaning via a specified causal mechanism or set of causal mechanisms'. Therefore, causal processes can play out in:

- A given temporal context, which can include aspects related to sequencing (when things happen), tempo and duration (how long things take), and starting points (when things start).
- Specific periods, which can be based on the origination of new institutions, historical social, political, and economic background conditions, or exogenous events that change the original conditions in which the institution operates; and
- On multi-layered contexts, i.e., when these different layers of context vary and interact.

Based on these insights, I adopt, on the whole, a generative approach to causality, with the vision that a theory-based evaluation should be both summative and formative, and that it should favour a multiple methods approach to allow the assessment of both process and impact. While fulfilling all of these requirements go beyond the scope of this licentiate thesis, future work will need to reflect on that as much as possible. Some initial steps into applying this view are taken in Section 5.

It is worth mentioning that while I, in general, take a generative approach to causality, I might also include other ways of thinking about it when investigating causal relationships (e.g., when testing programme theories). As noted by Davidson (2000, p. 24), establishing causality comes with its own challenges, and one of the main weaknesses of a theory-based evaluation is its 'overreliance on the validity of a program theory that rested on prior knowledge, either from the social science literature or from program staff'. Therefore, the author suggests that the evaluator should look for alternative causal explanations rather than just the predicted ones. This is similar to Hind's (2010) suggestion to use additionality in conjunction with theory-based evaluation by analysing different pieces of evidence. Gates and Dyson (2017, p. 38) argue that the different ways of thinking about causality are 'often mixed in methodological approaches and particular circumstances'. For instance, theory-based evaluation could also be used together with experimental and quasi-experimental evaluation to allow for 'virtually bulletproof causal attributions' (Davidson, 2000, p. 26). Alternatively, Byrne (2009) suggests accounting for causality at multiple levels by, for instance, combining a complex system's view with the generative thinking on causality.

## 3.2 Perspectives on socio-technical transitions

Below, I discuss the three of the most dominant schools of thought related to socio-technical transitions: strategic niche management, the multi-level perspective, and the technological innovation system approach. I also provide a short overview on transition management, which is the fourth central analytical concept on the topic (Loorbach et al., 2017).

### 3.2.1 The multi-level perspective

The multi-level perspective (MLP) builds upon concepts such as strategic niche management (Hoogma, 2000; Kemp et al., 1998; Smith, 2003) and transitions management (Kemp and Loorbach, 2006; Kemp and Rotmans, 2005). Strategic niche management (SNM) was introduced in the end of the 1990s and assumes that 'sustainable innovation journeys can be facilitated by modulating of technological niches, i.e. protected spaces that allow nurturing and experimentation with the co-evolution of technology, user practices, and regulatory structures' (Schot and Geels, 2008, p. 538). Transitions management (TM), in turn, focuses on long-term sustainable transformation processes and emphasizes the notion of reflexive governance, i.e. 'knowledge integration, anticipation of long-term systemic effects, adaptivity of strategies and institutions, iterative participatory goal formulation and interactive strategy development' (Kemp and Loorbach, 2006, p. 103).

In the MLP framework, transitions are conceptualized as major changes in the socio-technical configurations through which important sectoral societal functions are fulfilled (Geels, 2002; Geels, 2004), which unfold at multiple levels: niche, regime and landscape (Geels, 2002). Since policy can mainly influence the niche and regime levels, I focus on these. On the one hand, socio-technical transitions are dependent on the development and upscaling of new technologies and solutions. In the transition literature, this is assumed to happen through the gradual build-up and institutionalization of socio-technical ‘niches’. Niches can be thought of as ‘protected spaces’, which temporarily shelter emerging innovations from mainstream selection pressures (Smith and Raven, 2012; Smith et al., 2010). As such, they allow promising technologies to be developed and used in an experimental setting, where technology, user practices and regulations can be explored in a co-evolutionary way (Schot and Geels, 2008), and they can, thus, be seen as ‘local breeding spaces for new technologies’ (Kemp et al., 1998, p. 185). On the other hand, the transitions literature emphasizes the stability and inertia of established socio-technical configurations, which originate from socio-technical systems, actor networks and regime rules (Geels, 2004). Socio-technical transitions therefore require ‘windows of opportunity’ to open up in the regime to allow niche innovations to break through (Geels, 2002). This implies that some (or all) elements of the established socio-technical configurations, and in particular the regime, have to be weakened (Turnheim and Geels, 2013).

Taken together, this means that we need to consider both niche development processes and regime destabilization processes when assessing the behavioural additionality of transformative innovation policies. Niche development processes are described in more detail in the strategic niche management framework and will, therefore, not be discussed further here. Regime destabilization has recently begun to receive increased attention in the literature, and there are now a few frameworks that address this issue in more detail. Some of these associate regime-level change primarily with a weakening (or reconfiguration) of core regime rules (cf. Ghosh and Schot, 2019; Turnheim and Geels, 2012), while others also include changes in actor networks and/or socio-technical systems (cf. Kern, 2012; Kivimaa et al., 2017; Kivimaa and Kern, 2016; Lazarevic et al., 2020).

#### *3.2.1.1 Transition pathways*

While the sustainability transition notion implies a direction towards a more sustainable socio-technical configuration than the existing one, extant literature does not provide much guidance on how to assess that directionality. However, it has been suggested that one way forward could be to identify '"the right" transformation pathway(s) … for relevant (sub-)systems' (Schlaile et al., 2017, p. 6).

In the sustainability transitions literature, transition pathways are seen as 'unfolding socio-technical patterns of change within societal systems as they move to meet human needs in a low-carbon fashion' (Rosenbloom, 2017, p. 39). Transitions can unfold in many ways, as they can happen gradually, in a step-by-step basis, or chaotically, involving the disruption of the existing regime and the replacement of key technologies (Lindberg et al., 2019). While there are different ways to analyse transition pathways (Geels et al., 2016; Geels and Schot, 2007; Ghosh and Schot, 2019; Lindberg et al., 2019; Turnheim et al., 2015), I follow the framework from Geels and Schot (2007) and Geels et al. (2016), as they bring a more comprehensive view on transition pathways.[37]

In an early work, Geels and Schot (2007) proposed a typology of transition pathways based on the timing and nature of multi-level interactions. The authors distinguished four transition pathways, in addition to the 'zero proposition', in which the regime remains stable and reproduces itself: (0) *reproduction process* represents the business-as-usual process, in which the regime is reinforced and stabilized and no niche innovations break through, even if they are present; (1) *transformation path* refers to moderate landscape pressures that happen when niche innovations have not yet been developed, leading to a reorientation of the regime by regime actors; (2) *de-alignment and re-alignment* develops when there is a major landscape pressure that erodes the regime (i.e. de-aligns it) and allows for multiple niche innovations to compete; when one niche innovation becomes dominant, it takes over the regime and re-aligns it; (3) *technological substitution* refers to major landscape pressures that occur when disruptive niche innovations are sufficiently developed, and are able to substitute the existing regime; (4) *reconfiguration* refers to the adoption of symbiotic niche innovations by the regime, which is further adjusted in the event of landscape pressures. A fifth proposition accounts for shifts between pathways, in which disruptive landscape pressures lead to a sequence of transition pathways, e.g. starting from transformation and then shifting to substitution or de-alignment and re-alignment (Geels and Schot, 2007).

[37] Ghosh and Schot (2019) argue that the literature on pathways relies too much on niche developments as the source of regime shift, which, in their view, reflects a 'western bias'. As such, they propose a framework to explore regime transitions, which they see as being an intermediate between regime optimization and transition pathway. However, their framework is too focused on the institutional dimension and does not explore further how actors and changes in technologies influence regime shifts.

Table 5. Summary of transition pathways typology to analyse unfolding transitions.

| **Transition pathway** | **Multi-level interactions** | **Actors and social groups** | **Technologies and socio-technical system** | **Rules and institutions** |
|---|---|---|---|---|
| Reproduction | No external landscape pressure | Actors reproduce rule structures through their actions | Emerging technologies have little change to break through | Institutional infrastructure is reproduced |
| Transformation | Outsiders criticize the regime and incumbent actors adjust regime rules | Established actors re-orient themselves | Established & emerging technologies co-exist *or* Emerging technology outcompetes established | Limited change (layering) or substantial change (conversion /displacement) |
| De-alignment and re-alignment | Changes in deep structures create strong pressure on regime; incumbents lose faith and legitimacy | New actors enter after established actors exit | Competing emerging technologies replace established | Institutions are disrupted by shocks (disruption) |
| Substitution | Newcomers develop novelties, which compete with regime technologies | New entrants outcompete established actors | Emerging technology outcompetes established | Limited change (layering) or creation of new institutions (disruption /displacement) |
| Reconfiguration | Regime actors adopt component innovations, developed by new suppliers | Established actors & new entrants form alliances | Established & emerging technologies are combined | From limited change (layering) to substantial changes (drift/conversion) |

*Source: Adapted Geels and Schot (2007) and Geels et al. (2016).*

This transition pathways typology was later reformulated in order to account for ‘endogenous enactment’, by emphasizing the role of actors and social groups, rules and institutions, and technologies and socio-technical systems (Geels et al., 2016). Therefore, the reformulated typology reflects the reorientation of the socio-technical regime as being a result of ‘landscape pressure, societal debates and tightening institutions’, as well as of ‘the moves and countermoves of actors and social groups, which are constrained by ‘rules of the game’ and oriented towards reproducing or modifying elements of socio-technical systems’ (Geels et al., 2016, p. 897). The ‘rules of the game,’ in turn, emerge through different processes or historical trajectories, which are distinguished between layering, drifting, conversion, displacement, and disruption. Layering indicates limited institutional change, as elements are just added (layered) to existing ones; drifting refers to when there are changes in the environment without necessarily altering the elements of the policy mix in place; conversion means maintaining the elements of the policy mix to match new goals; displacement refers to the process in which new institutions slowly replace existing ones; disruption occurs when the current elements are replaced by new ones due to external shocks (Geels et al., 2016; Howlett and Rayner, 2013). Table 5 summarizes the main characteristics of each transition pathway as transitions unfold.

### 3.2.2 Strategic niche management[38]

The SNM framework is closely related to the MLP framework but focuses mainly on the niche level. It involves a clear governance aspect in that it suggests that strategically managing niches is 'a possible (or even necessary) strategy for governments to manage the transition process to a different regime' (Kemp et al., 1998, p. 185). A general argument is that protected spaces are required for entrepreneurs and system builders to experiment with a new technology in relation to user practices, demonstrate its viability, and attract funding, as well as to achieve the institutional adaptations needed to eventually achieve a widespread diffusion (Schot and Geels, 2008).

There are several conceptualizations of niche development, including the early work by Kemp et al. (1998) as well as later elaborations of their framework by other scholars (e.g. Geels and Raven, 2006; Schot and Geels, 2008; Smith et al., 2010), which identify three main niche development processes: learning processes, articulation of expectations and visions, and the enrolment of commitments from a growing network of actors.[39] In more recent literature, three properties of niches as protected spaces have been identified (Smith and Raven, 2012). First, *shielding* implies that niches protect the emerging innovation from selection pressures in the mainstream market or other relevant selection environments (Smith and Raven, 2012) and thus create a space for experimentation (Verhees et al., 2013). Second, *nurturing* corresponds to the three main niche development processes described above (Naber et al., 2017; Raven et al., 2016; Verhees et al., 2013). Third, *empowering* refers to different processes that improve the competitiveness of niche innovations and remove shielding, either by adapting the niche innovation to fit current selection

[38] This text has been partially reproduced from Bergek and Haddad (2021).
[39] Kemp et al. (1998) identified three aims of strategic niche management: (i) to articulate necessary technological and institutional changes and adaptations, (ii) to set learning processes in motion in relation to different technological options, (iii) to stimulate the development and diffusion of these and other complementary technologies, and (iv) to build a semi-coordinated constituency around a new technology.

environments (fit-and-conform processes) or institutionalizing shielding by making mainstream selection environments more agreeable to the niche innovation (stretch-and-transform processes) (Raven et al., 2016; Verhees et al., 2013). Based on this framework, several subsequent articles have described, operationalized, and analysed niche-level processes in more detail, which I draw on to develop my framework in the next section.

Despite its governance focus, the SNM framework primarily describes niche development as a bottom-up process, without much clear directionality. However, as mentioned above, it considers the development of a common vision among niche stakeholders to be an important part of that process. It also sheds some light on how niches can contribute to modifying transition pathways, as it highlights some of the non-technical factors that lead to changes in the regime (Schot and Geels, 2008).

### 3.2.3 The technological innovation system[40]

Together with the MLP, the technological innovation system (TIS) framework is another strand of literature that analyses the radical innovation leading to transformation processes, which is also rooted in evolutionary theory[41] (Markard and Truffer, 2008). While, initially, the TIS concept had little to do with sustainability and focused on providing policymakers with tools to promote specific technologies targeting economic growth (cf. Andersson, 2020; Carlsson, 1995), the concept also started to be applied to investigate the emergence and growth of renewable energy systems (cf. Johnson and Jacobsson, 2001). As such, TIS has 'emerged as an influential concept in academic debates on the design of policies to stimulate environmental innovations and facilitate sustainability transition' (Magnusson and Berggren, 2018, p. 217).

A technological (innovation) system can been defined as 'a network of agents interacting in a specific *economic/industrial area* under a particular *institutional infrastructure* or set of infrastructures and involved in the generation, diffusion, and utilization of technology' (Carlsson and Stankiewicz, 1991, p. 111). This implies that TISs are problem-solving knowledge networks

[40] This text has been partially reproduced from Bergek and Haddad (2021).
[41] This is because both approaches highlight aspects such as the 'importance of networks and learning processes together with the crucial role of institutions for successful innovation processes. Both acknowledge phenomena such as path-dependency, lock-in, interdependence, non-linearity and coupled dynamics' (Markard and Truffer, 2008, p. 597).

(rather than production networks) related to particular product markets (Bergek, 2019). Additionally, a TIS comprises of all the elements that influence the innovation system, and not only to the focal technology. Moreover, the TIS may also be part of a sub-system of a sectoral system, cut across different sectors, and may have a geographical dimension (Bergek et al., 2008a).

In the TIS literature, innovation outcomes have been conceptualized in both structural and functional terms. Some literature describes processes that contribute to the structural build-up of new systems, such as actor entry, network formation, and institutional adaptation (Jacobsson and Bergek, 2004; Jacobsson and Johnson, 2000).[42] Regarding functionality, seven key processes have been identified that contribute to the development, diffusion and utilization of new technologies and, thus, to changes in the socio-technical system of a sector: knowledge development and diffusion, entrepreneurial experimentation, guidance of the direction of search, market formation, legitimation, resource mobilization, and development of positive externalities (Bergek et al., 2008a). These are closely related to niche nurturing, as described in the SNM framework (Smith and Raven, 2012). Table 6, second column, details the definition of each function, while the third and fourth columns indicate typical indicators used to assess the performance of the innovation system.

Overall, in order to analyse a TIS and help policymakers in the selection and prioritization of public policies, Bergek et al. (2008a) proposed an analytical scheme composed of six main steps: (i) defining the TIS in focus; (ii) identifying the structural components of the TIS; (iii) mapping the functional pattern of the TIS; (iv) assessing the functionality of the TIS and setting process goals; (v) identifying inducing and blocking mechanisms; and (vi) specifying key policy issues.

[42] Some authors also include the accumulation of knowledge and artefacts among the structural processes (cf., e.g., Bergek et al., 2008b)

Table 6. Typical indicators to assess the TIS functions.

| Function | Description[a] | Hekkert et al. (2007) | Bergek et al. (2008a) and Bergek (2019) |
|---|---|---|---|
| Knowledge development<br><br>Knowledge diffusion | Broadening and deepening of the knowledge base of a TIS, sharing of knowledge between actors within the system and new combinations of knowledge because of these processes. | R&D projects over time<br>Patents<br>Investments in R&D<br>Number of workshops and conferences on a particular technology<br>The network size and intensity over time | Bibliometrics indicators (citations, volume of publications, orientation)<br>Learning curves<br>Subsidies for demonstrations<br>Technological collaboration, communication and dissemination<br>Learning by doing and using<br>Knowledge acquisition, absorption and accumulation<br>Learning by doing and using |
| Entrepreneurial experimentation | Problem-solving and uncertainty reduction through real-world trial-and-error experiments at different scales with new technologies, applications, and strategies. | Number of new entrants<br>Number of diversification activities<br>Number of new experiments with a new technology | The breadth of technologies used, and the nature of the complementary technologies employed<br>Number of incubators<br>Advice systems for SMEs<br>Pilot and demonstration with new technologies |
| Market formation | The opening up of a space or an arena in which goods and services can be exchanged in (semi-)structured ways between suppliers and buyers, including e.g., articulation of demand and preferences, product positioning, standard-setting, and development of rules of exchange. | Number of niche markets that have been introduced<br>Specific tax regimes for new technologies<br>New environmental standards that improve the chances for new environmental technologies | Who are the users and what they are purchasing?<br>Demand articulation<br>Market size and customer group<br>Actors' strategies, role of standards and purchasing processes |
| Influence on the direction of search | Mechanisms that influence to what opportunities, problems and solutions firms and other actors apply their resources, incentivizing and pressuring them to engage in innovative work within a particular technological field and determining what strategic choices they make within that field. | Specific targets set by governments or industries regarding the use of a specific technology<br>Number of articles in professional journals that raise expectations about new technological development | Beliefs in growth potential<br>Incentives from factor/product prices<br>The extent of the regulatory pressures<br>The articulation of interest by leading consumers |

| Function | Description[a] | Hekkert et al. (2007) | Bergek et al. (2008a) and Bergek (2019) |
|---|---|---|---|
| Resource mobilization | The system's acquisition of different types of resources for the development, diffusion and utilization of new technologies, products, and processes, most notably capital, competence and manpower, and complementary assets (e.g., infrastructure). | Funds made available for long-term R&D programmes set up by industry or government to develop specific technological knowledge<br>Funds made available to allow testing of new technologies in niche experiments<br>Perception of the actors regarding the access to sufficient resources | Rising volume of capital,<br>Increasing volume of seed and venture capital (financial resources)<br>Changing volume and quality of human resources<br>Changes in complementary assets and infrastructure<br>Public and private funding<br>Education and training<br>Development of complementary infrastructure |
| Legitimation | The process of gaining regulative, normative, and cognitive legitimacy for the new technology, its proponents and the TIS as such in the eyes of relevant stakeholders, i.e., increasingly being perceived as complying with rules and regulations, societal norms and values and cognitive frames. | Rise and growth of interest groups<br>Lobby actions | Alignment between TIS and the current legislation<br>How legitimacy influences demand, legislation, and firm behaviour<br>Technology validation and standardization<br>Changing norms and values |
| Development of positive externalities | The creation of system-level utilities (or resources), such as pooled labour markets, complementary technologies, and specialized suppliers, which are also available to system actors that did not contribute to building them up. | - | Emergence of pooled labour markets<br>Emergence of specialized intermediate goods and service providers<br>Information flows and knowledge spill-overs<br>Development of complementary technologies |

*Source: [a] Elaboration on Bergek (2019); Bergek et al. (2020) (which draw on Bergek et al. (2008)).*

### 3.2.4 Combining perspectives on socio-technical transitions[43]

The potential to combine the MLP, SNM, and TIS approaches has already been explored in earlier works from transition scholars (Kivimaa et al., 2017; Markard and Truffer, 2008; Weber and Rohracher, 2012). Some frameworks targeted the development of a system analysis in relation to individual policy programmes or more complex policy mixes, drawing on these key transition-related frameworks (cf., e.g., Janssen, 2019; Kern, 2012; Kivimaa et al., 2017; Kivimaa and Kern, 2016; Kivimaa and Virkamäki, 2014; Scordato et al., 2018). However, these frameworks have seldom addressed how to assess directionally and account for overlaps and redundancies between the different transition approaches abovementioned.

Recently, Bergek and Haddad (2021) reviewed some of the key frameworks in the sustainability transitions literature – TIS, MLP and SNM – in order to identify a non-overlapping set of key system-level change processes. The authors argue that such processes can be used as a basis for evaluating the transformative outcomes of policy programmes in relation to a targeted sectoral socio-technical configuration. In this conceptualization, transformative outcomes are analysed at the sectoral level to include several different technologies, actor networks and institutions. These transformative processes involve both structural and functional features. More specifically, the functions framework mainly contributes with knowledge on processes related to changes in the socio-technical system dimension, whereas the MLP and SNM frameworks mainly contribute with knowledge on processes resulting in changes in actor networks and institutions. Such approaches can thus be used in both summative and formative evaluation settings by assessing the elements of the targeted socio-technical system with the desired impact, and by tracing the policy intervention's influence on a few key intermediate transformative processes.

By analysing these processes at the focal sectoral socio-technical configuration (socio-technical system, actor networks and rules) as well as by employing different levels of analysis (niche and regime), analysts – or evaluators – can identify functional system weaknesses as well as the influence of policy on each process. This provides insights on the behavioural additionality of the programme. In the words of Janssen (2019, p. 79), 'policy contributions to the building of

[43] This text has been partially reproduced from Bergek and Haddad (2021). For the description of labour, see the 'List of papers' provided in the first pages of the licentiate thesis.

technological innovation systems are in fact the "bangs" [for the buck] auditors and evaluators should be looking for'.

Directionality, in turn, is captured in two ways. First, by an addition of a 'directionality filter' to each function in order to be able to capture innovation processes related to different socio-technical systems within the sectoral configuration (established as well as emerging). This enables the assessment of the innovation dynamics of different technologies and thus their relative rate of improvement, diffusion (and/or decline). Second, by explicitly considering changes in actor networks and institutions related to emerging as well as existing sub-configurations, the evaluator can assess the relative importance of new versus established actors and the type and degree of change happening in the institutional framework. Based on these directionality considerations, a preliminary assessment can be made of whether the transition seems to be unfolding, i.e., by analysing transition pathways as introduced in Section 3.2.1.1.

A more detailed discussion of how these processes were developed and how overlaps were accounted for can be found in Bergek and Haddad (2021). Below, I summarize the main elements related to the structural and functional features.

#### *3.2.4.1 Socio-technical system*

In many cases, the main goal of a TIP intervention is to induce changes in a focal socio-technical system (first element) that needs to be replaced or reconfigured in order for the targeted sector to become more sustainable (Bergek and Haddad, 2021). This requires innovation both in terms of improvements in established technologies and the development and diffusion of new technologies. As described in Section 3.2.3, this is captured well by innovation system functions (cf. Bergek, 2019; Bergek et al., 2008a).[44] These can also be applied at different system levels (sectors as well as individual technologies or groups of related technologies) (Bergek and Jacobsson, 2003; Johnson and Jacobsson, 2001) and can be used to analyse innovation processes related to both new and emerging technology fields (cf., e.g., Carlsson, 1995; Dewald and Achternbosch, 2016; Gabaldón Estevan and Hekkert, 2013).[45] The functions can thereby be analysed for all technologies

[44] It should be noted that several authors have already used the functions as a basis for assessing the effects of policy (Janssen, 2019; Kivimaa and Kern, 2016; Lazarevic et al., 2020).
[45] This contrasts with perspectives comparing TISs with (global) niches (Smith and Raven, 2012) or arguing that the functions framework is only useful for analysing emerging technologies (Markard and Truffer, 2008).

that (potentially) contribute to the overall societal function of the sector. For example, in the energy sector, the analyst would consider innovation (or lack thereof) in established technologies such as coal, nuclear, or hydro power as well as various less established technologies such as wind, solar, and marine power.

The framework departs from the list of functions presented by Bergek et al. (2008a) and further developed by Bergek (2019) and Bergek et al. (2020), as introduced in Section 3.2.3. This is complemented by niche-level shielding, nurturing, and empowering processes identified in the SNM literature, and the regime destabilization processes described in relation to the MLP framework. As described by Bergek and Haddad (2021), almost all processes that refer to change in the socio-technical system are covered by the functions (see Appendix A).[46] Similarly, most of the regime-level processes related to changes in socio-technical systems can be connected to the functions.

However, for these connections to become apparent, directionality should be explicitly accounted for in the functions in order to see whether they support emerging or established technologies, or both. In the original framework, directionality is mainly accounted for in the function 'guidance of the direction of search' (Bergek et al., 2008a). Nonetheless, this does not fully capture all aspects of directionality, as it mainly refers to supply-side actors. Therefore, a 'directionality filter' should instead be applied to each function, reflecting an understanding of directionality as an emergent property of the functional dynamics of the system (cf. Yap and Truffer, 2019) (i.e., a bottom-up perspective on directionality). For example, instead of just describing knowledge development related to a particular technology, all knowledge development processes in the focal sector could be analysed in regard to whether they support established technologies or niche technologies (and if so, which niche technologies). Similarly, market formation could include an analysis of for

[46] This contradicts previous claims that the functions underplay the importance of shielding against mainstream selection pressures and cannot explain mass-market diffusion (cf. Smith and Raven, 2012; Smith et al., 2010) – at least as far as the socio-technical system is concerned. Note also that the dynamics of market formation (incl. the importance of nursing markets) is a recurring topic in the TIS literature (cf., e.g., Andersson and Jacobsson, 2000; Bergek, 2012, 2014).

which technologies markets are formed (and how). Table 7[47] shows a summary of the main directionality aspects for each function.

Table 7. TIS functions and their main directionality aspects.

| Function | Examples of directionality aspects[b] |
| --- | --- |
| Knowledge development and diffusion | For which technologies is knowledge developed? |
| | What technological/societal problems are knowledge development efforts targeting? |
| | By and for whom is knowledge developed? |
| Entrepreneurial experimentation | Which technologies are experimented with and why? |
| | Who is experimenting with what and why? |
| | What sources of uncertainty are experiments targeting? |
| Market formation | Which segments are expanding vs declining and why? |
| | What customer needs are articulated vs ignored and by whom? |
| | Which segments and technologies do actors' market strategies target? |
| Influence on the direction of search | To which technologies are actors allocating their resources and why? |
| | To which technologies, markets, business models, etc. are actors allocating their resources and why? |
| Resource mobilization | To what extent is resource mobilization generic or technology-specific? |
| | Which technologies benefit the most by current resource endowments and why? |
| | To what extent and how can new technologies exploit existing infrastructures and complementary technologies? |
| Legitimation | Which technologies and actors are gaining vs losing legitimacy in the eyes of which stakeholders and why? |
| | Which regulations and support systems are gaining vs losing legitimacy in the eyes of which stakeholders and why? |
| Development of positive externalities | Which technologies benefit from which externalities and why? |
| | Which actors benefit from which externalities and why? |
| | Which self-reinforcing mechanisms support or hinder different technologies? |

*Source: Bergek and Haddad (2021); [b] own conceptualization.*

### *3.2.4.2 Actor networks*

Regarding actor networks, while the TIS framework covers structural dynamics, including changes in actor networks, it has mainly focused on the emergence of new systems (and then primarily in terms of entry of actors along the entire value chain). Bridging this with insights from the MLP

[47] Thus, in contrast to Hekkert et al. (2020), Bergek and Haddad (2021) do not think it is necessary to introduce an entirely new system concept. My notion of a sector-level innovation system also differs in other ways from their concept of 'mission-oriented innovation systems'. Most notably, in contrast to MIS, a sector-level TIS is not limited to innovation activities aimed at specific societal challenges but rather captures the main innovation- and transitions-related processes in a particular societal sector. It therefore captures developments in different directions (including recreating the regime) and does not require these developments to be coordinated by policymakers or other actors.

and SNM frameworks, four main transformative processes, which are relevant for both the niche and the regime level and not previously considered, can be identified (see Appendix A):[48] entry of new actors; formation of new knowledge, technology, and business networks; configuration (and de-configuration) of political networks; and development of political capacity and change advocacy (see Table 8). To account for directionality, each of these processes should be analysed from the point of view of whether they strengthen established actor networks or work towards the establishment of new or fundamentally reconfigured networks in the focal sector.

#### *3.2.4.3 Institutions*

As for actors, the TIS framework recognizes the importance of institutional change, but has not given much explicit attention to it. Again, building on the MLP and SNM frameworks, four additional transformative processes can be identified, which are also relevant for both the niche and the regime level (see Appendix A): articulation of visions and expectations; framing and redefinition of values, norms, and practices; mobilization and de-mobilization of (political support); and introduction of new regulations (see Table 9). To account for directionality, each of these processes should be analysed from the point of view of whether they strengthen established institutions or work towards the establishment of new or fundamentally reconfigured institutional frameworks.

[48] As can be seen in Appendix A, the processes I identify here are related to the functions in that they may influence them (but do not have to). It should also be noted that while 'guidance of the direction of search' covers the emergence of incentives for actors to enter a niche- or regime-level actor network, their actual entry and the subsequent formation of networks are structural rather than functional processes.

Table 8. Transformative processes (outcomes) related to actor networks (synthesis).

| Processes (outcomes) | Niche-level processes | Regime-level processes |
|---|---|---|
| Entry of new actors | Entry/involvement of powerful actors (incl. policy) to get support and allow for up-scaling (Bugge et al., 2017; Kern, 2012)<br>Generation of (and support to) new firms and businesses (Kern, 2012; Kivimaa and Kern, 2016; Raven et al., 2016; Smith and Raven, 2012) | Entry of niche actors (Ghosh and Schot, 2019; Kern, 2012; Turnheim and Geels, 2013)<br>Entry of actors from other industries and countries (Turnheim and Geels, 2013)<br>Replacement of incumbents by new actors (Kivimaa and Kern, 2016) |
| Formation of new knowledge/technology/ business networks | Forging new relationships and networks and facilitating interaction (Bugge et al., 2017)<br>Formation (and maintenance) of broad networks, i.e., networks consisting of actors from different domains (Naber et al., 2017; Verhees et al., 2013)<br>Formation (and maintenance) of deep networks, i.e., networks with high resource commitment from network members (Naber et al., 2017; Verhees et al., 2013)<br>Development of 'global' networks that support exchange and interpretation of specific lessons and experiences between niches (Smith & Raven, 2012) | New partnerships to enable business model innovation (Turnheim and Geels, 2013)<br>Emergence of new customer groups/segments (Ghosh and Schot, 2019) |
| Configuration and de-configuration of political networks | Formation of 'discourse coalitions' including (industrial, administrative and grassroots) advocates accumulating resources and political power<br>Fostering of wider societal engagement (Kern, 2012) | Balancing the power of incumbents, e.g., by inviting niche actors to advisory councils, etc. (Kivimaa and Kern, 2016; Lazarevic et al., 2020)<br>Breaking up of existing policy networks (Kivimaa and Kern, 2016; Lazarevic et al., 2020) |
| Development of political capacity and change advocacy | Development of political capacity to avoid capture by vested interests (Smith and Raven, 2012) | Development of new fora/organizations to support policy change (Kivimaa and Kern, 2016; Lazarevic et al., 2020)<br>Emergence/creation of change advocates in established (policy) organizations (Lazarevic et al., 2020) |

*Source: Bergek and Haddad (2021); own elaboration of the reviewed literature (see Appendix A).*

Table 9. Transformative processes related to institutions.

| Sub-dimensions | Niche-level processes | Regime-level processes |
|---|---|---|
| Articulation of visions and expectations | Articulation of clear, specific, and shared visions and expectations between members (Naber et al., 2017; Verhees et al., 2013) | Articulation of new visions and expectations about the future (Ghosh and Schot, 2019; Kern, 2012) |
| Framing and redefinition of values, norms, and practices | Questioning assumptions about problem definitions, function, or desirability of the technology (Kern, 2012; Naber et al., 2017; Verhees et al., 2013)<br>Articulating narratives and enacting new discourses to fit contemporary objectives and values of (powerful) stakeholders (Raven et al., 2016; Smith and Raven, 2012)<br>Framing shielding and nurturing as temporary and promoting that innovation will be competitive under conventional criteria (Verhees et al., 2013) | Raised public awareness of the need for change (Kern, 2012; Turnheim and Geels, 2013)<br>Broad cultural changes or changes in underlying values that challenge the regime (Ghosh and Schot, 2019; Turnheim and Geels, 2012)<br>Changes in industry mission, identity and confidence (Turnheim and Geels, 2013)<br>Changes in organizational practices (Lazarevic et al., 2020; Turnheim and Geels, 2013) |
| Mobilization and de-mobilization of (political) support | Lobbying to achieve explicit political support (Smith and Raven, 2012)<br>Overcoming initial reluctance (Bugge et al., 2017)<br>Arguing for temporal exemptions from existing rules and standards (Smith and Raven, 2012; Verhees et al., 2013) | Reduction or removal of subsidies, funding, and protective measures (Kivimaa and Kern, 2016; Lazarevic et al., 2020; Turnheim and Geels, 2012)<br>Changes in regulations that favour established technologies or hinder new ones (e.g., building codes or siting rules) (Kern, 2012; Lazarevic et al., 2020)<br>Lobbying, framing or public contestation against the regime (Turnheim and Geels, 2012, 2013)<br>Attempts to influence policy development and change (Kern, 2012) |
| Introduction of new regulations | Development of institutional reforms (Smith and Raven, 2012)<br>Identification and implementation of technology-specific policy instruments (Kern, 2012; Raven et al., 2016; Smith and Raven, 2012) | Restructuring of markets (e.g., liberalization or regulation) (Ghosh and Schot, 2019; Kivimaa and Kern, 2016; Lazarevic et al., 2020; Turnheim and Geels, 2012)<br>Implementation of control policies (e.g., taxes, import restrictions, emissions regulations, bans, or plans for phase-out of specific technologies) (Ghosh and Schot, 2019; Kivimaa and Kern, 2016; Lazarevic et al., 2020; Turnheim and Geels, 2012, 2013) |

*Source: Bergek and Haddad (2021); own elaboration of the reviewed literature (see Appendix A).*

## 3.3 Summary of theoretical framework

The aforementioned theoretical framework provides the basis for the development of the integrate framework for evaluating TIP and brings insights to answer the licentiate research problems. First, the overview of the two main approaches for theory-based evaluation explore how to perform theory of change and realist evaluations, highlighting their main steps and forms of representation. Additionally, I summarize the literature discussing how to combine the two approaches, which points out that ToC can bring a broader overview of the programme, while realist evaluation can help the evaluator better understand the mechanisms contributing to or hindering the programme's outcomes. Moreover, I explain how theory-based evaluation perceives causal attribution.

Second, I introduce the TIS, MLP and SNM frameworks and highlight how the latter two can inform new conceptual developments in the TIS framework. In particular, I summarize the main system-level change processes that can be used as a basis for evaluating the transformative outcomes of policy programmes. These are divided into three main clusters: (i) the socio-technical system, which encompasses the seven functions of innovation system; (ii) actor networks; and (iii) institutions.

That said, the theoretical framework brings many insights towards developing an integrated framework and answering the licentiate thesis research questions. Theory-based evaluation provides the basis to understand the theory behind a policy intervention, which can be built based on the transformative innovation policy concept. Additionally, the notion on generative causality, pushed forward by realist evaluation, can open a new path towards assessing behavioural additionality. Moreover, by defining the general goal of the programme – or, in other words, the directionality – the evaluator can also gain an initial understanding of the overall transition pathway the programme is aiming at.

Regarding the socio-technical system approach, the literature exemplifies the types of processes the evaluator should look for when assessing transformative innovation policy. As such, the traditional indicators for analysing the seven functions of innovation systems (see Table 6) provide an idea about the mechanisms that might influence the performance of the socio-technical system. They can also indicate the type of behavioural change affecting the system dynamics. Additional actor networks and institutional processes (see Table 8 and Table 9) complement the socio-technical system analysis with aspects not previously captured in the original TIS framework. The socio-technical system literature also sheds light on how to address directionality in two ways: (i) the directionality filter applied to each function reflects an emergent property of the functional dynamics of the system (see Table 7); and (ii) assessing the performance of the system in terms of these three clusters can give the evaluator an overview of how the programme is developing in terms of the targeted transition pathway it originally aimed at.

# 4 An integrated framework for evaluating TIP

Considering the insights discussed in Section 2 and Section 3, an integrated framework composed of three main components was developed. Table 10 summarizes the main components and steps and indicates how each aspect is related to the theoretical framework.

The first component, programme theory, is composed of three main steps: (i) define the transition focus, (ii) explicate the programme's theory of change, and (iii) develop CMOc hypotheses. This first component aims to understand the initiative's programme theory. While policymakers do not always develop an intervention with a clear programme theory sustained by a policy theory in mind, the evaluator still needs to understand 'the logical links between policy practice and their expected effects and to turn them into the theoretical support for a detailed evaluation study' (Molas-Gallart and Davies, 2006, p. 2). When initiating an evaluation of a transformative innovation policy programme, it is therefore important to first reconstruct the (implicit) programme theory (and policy theory) that underpins the policy intervention that is being evaluated and translate it into transformative innovation terms. As such, the first step within this component is to define the focus of the transition in terms of the focal challenge, the systems boundaries, and the targeted transition pathway. The second step is to explicate the programme's theory of change, as conceptualized in the ToC evaluation, by, for example, talking to policymakers about inputs, outputs, outcomes, and intended impact of the programme. The third step translates the programme's ToC in CMOc terms.

The second component, system analysis, follows from programme theory and includes two additional steps: (iv) analyse socio-technical change processes and (v) test and refine CMOc. The goal of this component is to understand the outcomes in transformative terms (such as the processes introduced in Section 3.2.3 and 3.2.4), i.e., assess how the programme is influencing the socio-technical system performance and promoting change, which also sheds light on the behavioural additionality at the system level. Therefore, in step four, the evaluator proceeds with a socio-technical system analysis in terms of functions, actor networks and institutions, as described in the previous section. In the fifth step, then, the evaluator tests and refines the hypothesized CMOc based on the socio-technical system analysis. As such, the evaluator looks for pieces of evidence that confirm the hypothesized CMOc and refine these CMOc based on the findings from the socio-technical system analysis.

Finally, the third component, transition pathways, is aimed at analysing the overall directionality of the programme in terms of which transition pathways can be emerging from the changes at the socio-technical system level. This third component encompasses two main steps: (vi) assess outcomes in relation to the pathways and (vii) revisit (and revise) programme theory. This latter step aims at updating programme theory informed by the findings from the previous steps and, hence, works as a learning tool for policymakers to generate lessons for further policy practices and formative evaluation.

Table 10. Summary of integrated framework for TIP evaluation.

| **Components** | **Evaluation steps** | **Specification** | **Section** |
|---|---|---|---|
| Programme theory | 1. Define the transition focus of the programme | ▪ Focal challenge or problem<br>▪ System boundaries<br>▪ Targeted transition pathway | 3.2.4.1 |
| | 2. Explicate the programme's theory of change | ▪ Expected outcomes in terms of socio-technical change processes<br>▪ Anticipated impact on the targeted transition<br>▪ Assumed additionality with respect to outcomes and impacts | 3.1.1 |
| | 3. Develop CMOc hypotheses | ▪ Hypothetical causal mechanisms, outcomes, and context | 3.1.2<br>3.1.3 |
| System analysis | 4. Analyse socio-technical change processes | ▪ Socio-technical system<br>▪ Actor networks<br>▪ Institutions | 3.2.3 and 3.2.4 |
| | 5. Test and refine the CMOc | ▪ Evidence towards confirming hypothesized CMOc + new CMOc emerging from systems analysis | 3.1.2<br>3.1.3 |
| Transition pathways | 6. Assess outcomes in relation to the pathways | ▪ Socio-technical system<br>▪ Actor network<br>▪ Institutions | 3.2.1.1 |
| | 7. Revisit (and revise) programme theory | ▪ Revise expected outcomes | 3.1.3 |

## 4.1 Component 1: Programme theory

The first component of the integrated framework is composed of three steps: (i) define the transition focus of the programme, (ii) explicate the programme's theory of change and (iii) develop CMOc hypotheses.

### 4.1.1 Step 1: Define the transition focus of the programme

The first step in the integrated framework is to define the transition focus of the programme. This would involve three key features. The first feature involves identifying the nature of the problem (e.g., a specific Grand Challenge) under scrutiny, as well as understanding its overall causes and consequences.[49] This allows the evaluator to identify the type of social challenge the programme is aiming at.

This will then allow for system delineation (second feature), i.e., the identification of the system's boundaries. Funnell and Rogers (2011) argue that while the situation of complex and wicked problems (which is the case for Grand Challenges) 'can lead to an ever-expanding boundary of what a program might usefully address, setting boundaries around the program by systematically scoping and focusing the program theory is important' (p. 163). That said, and as discussed in Section 3.2.4, the focal socio-technical configuration is defined at the sectoral level and can contain several distinct technologies, actor networks and sets of institutions. Therefore, it seems plausible to define the object of analysis, in the case of TIP programmes, around the focal socio-technical system. This would be similar to defining the TIS in focus (Bergek et al., 2008a, p. 412), in which 'different sets of actors, networks and institutions will be incorporated', but broadening the system boundaries for transformative change, i.e., by considering the socio-technical system dimension, as discussed in Section 3.2.4.1.

Finally, the third feature is related to the targeted transition pathway, which would indicate the desired direction of change and inform the development of the theory of change. This would involve identifying the kinds of changes policymakers foresee in terms of multi-level interactions, actors and social groups, technologies and socio-technical systems, and rules and institutions (as described in Table 5, Section 3.2.1.1).

### 4.1.2 Step 2: Explicate the programme's theory of change

The second step follows Rolfe's (2019) suggestion to develop the programme's overview in terms of implementation theory. The goal of this step is, thus, to reflect, via backwards mapping, and in

[49] This is similar to what Funnell and Rogers (2011) call situation analysis, which involves identifying the 'nature and extent of the problems or opportunities to be addressed by the program' (p. 151).

a collaborative manner with stakeholders, on the ultimate aim of the programme, the types of outputs and outcomes that will help achieve the aim, as well as the activities and inputs required to bring about change (Blamey and Mackenzie, 2007; Rolfe, 2019). From a TIP perspective, this would mean capturing how policymakers theorized socio-technical change processes (outcomes), determining their effects on the socio-technical transitions (impacts), and understanding how policy has contributed to both outcomes and impacts (additionality). It should be noted, however, that it can be challenging to identify links between innovation theory and policy evaluation practice, especially in the context of transformative policy. As argued by Janssen (2019), the complex nature of transformative policy makes it relatively difficult to demonstrate all the consequences of the implemented policy mix.

Nonetheless, the evaluation literature provides some guidance on how to address complex interventions. Regarding building robust theories of change to improve the process of learning in evaluating complex interventions, Mason and Barnes (2007) suggest involving both researchers and practitioners actively in the process, while also using different sources and resources of 'theory'. This would include, for example, workshops with stakeholders, project documentation, theoretical literature, and other research evidence. Whilst most traditional ToC approaches build upon theory based centrally on stakeholders' beliefs (Rogers and Weiss, 2007), when it comes to TIP theory, the role of the evaluator should also be that of a translator of practice to theory. Additionally, Funnell and Rogers (2011) advise revisiting programme theory constantly, as the intended impact might change as new actors become involved and the socio-technical systems evolve.

In terms of representing complex programme interventions, Funnell and Rogers (2011) also suggest using diagrams and concepts from systems thinking, e.g. network theory and system dynamics, as discussed in Section 3.1.1. These approaches seem more appropriate for TIP programme theory representation, given that they allow accounting for relationships between different actors and actor networks (network theory), and feedback loops (system dynamics).

#### 4.1.3 Step 3: Develop CMOc hypotheses

The third step follows the suggestions of both Blamey and Mackenzie (2007) and Rolfe (2019) to use RE as a means to analyse the micro-level aspects of the programme theories of most interest and identify how causal processes are generating change within the targeted population. More specifically, Rolfe (2019) proposes to use RE to identify mechanisms within the generic ToC model, by, rather than capturing all the possible causal pathways, instead selecting core points within the programme where a range of causal mechanisms play out. This is the starting point to understanding ‘the role of particular causal mechanisms and the contexts within which they operate to generate outcomes’ and hence finding evidence regarding causal process (Rolfe, 2019, p. 310).

There are many variations in the literature on how to use realist principles in practice (Pawson and Manzano-Santaella, 2012). Section 3.1.2.1 provides an overview of how to conceptualize CMOc and how it can be represented. In sum, it highlights that CMOc can be represented in the form of a realist matrix, in which the columns represent, separately, context, mechanism and outcomes, and each row corresponds to a hypothesis in the form of C1+M1=O1, C2+M2=O2. Additionally, this formula can be replaced by C&Ms → Oc to represent the large multi-layered and multi-faceted complex social systems, as suggested by Byrne (2018).

While there is a lack of applications of these principles in relation to innovation policy, Step 5 of the integrated framework discusses how CMOc can be refined for TIP interventions, based on findings from Step 4.

## 4.2 Component 2: Systems analysis

The second component of the integrated framework is composed of: (i) an analysis of the socio-technical system, which draws on insights from MLP, SNM and TIS literatures for identifying and assessing intermediate innovation- and transition-related processes that might be visible in early phases of development; and (ii) revisiting the hypothesized CMOc in order to refine and test them according to the findings from the socio-technical system analysis.

### 4.2.1 Step 4: Analyse socio-technical change processes

Step 4 encompasses analysing the socio-technical system performance. To make a parallel with the original TIS framework scheme of analysis (see Section 3.2.3), this step would follow the definition of the focal system. However, instead of looking at the structural and functional aspects of the TIS, the evaluator would analyse the socio-technical system, including functions with the ‘directionality filter’, as well as actor networks and institutional processes, as proposed in Section

3.2.4. As such, the purpose is to look for mechanisms and how they are playing around in the system to generate transformative outcomes, such as those specified in Table 6, Table 8 and Table 9. The directionality aspect is then presented in Table 7.

At this point, the evaluator might need to decide whether it is more appropriate to make a full systemic analysis of the programme or choose key aspects to focus on. A systems analysis can provide some evidence concerning systems processes, and the evaluator might need to opt between making a full systems analysis or selecting specific functions, or actor networks and institutional processes, according to the goal of the programme and the purpose of the evaluation. While a full systems analysis can provide a better overview of the performance and dynamics of the socio-technical system, which can also help to refine the CMOc in Step 5, this might not be feasible, due to, among other aspects, time, and budget constraints.

Either way, the evaluator might need to consider multiple sources of evidence to analyse the socio-technical system, including document analysis, interviews, workshops, surveys, etc. In analysing the performance of the TIS, scholars have used and combined different methods and data. Some performed qualitative assessments using different data sources, e.g. interviews and secondary data (e.g., Hellsmark et al., 2016; Jacobsson and Karltorp, 2013). Others combined interviews with historical event analysis (e.g., Huang et al., 2016; Negro et al., 2007), or asked experts to rate system function fulfilment based on a set of indicators (e.g., Wieczorek et al., 2015; Wieczorek et al., 2013). Still others also relied on structured interviews and network analysis (e.g., Van Alphen et al., 2010).

Overall, in transitions studies, researchers use three main approaches (Zolfagharian et al., 2019). The first approach, and the most common, is qualitative research methods, which are usually based on document analysis and involve techniques such as ground theory development, ethnography, action research, etc. The second is quantitative research methods, which includes numeric data sources and the use of methods such as econometrics and statistical analysis. The third is a mixed-methods approach, which combines both qualitative and quantitative techniques for data analysis.

That said, in order to identify mechanisms and contexts at play at the system level, a qualitative approach might be most suitable at this stage. In evaluating TIP, the system analysis thus helps to uncover why a programme works, for whom, and under which circumstances. A mixed-methods approach, however, might be useful when testing CMOc, and can 'pave the way for triangulation that can validate findings and thus provide added robustness to the results' (Sandin et al., 2019, p. 12). This is especially relevant when trying to find an alternative way to build the counterfactual, one in which additionality is built together with the theory-based approach. As discussed in Section 3.1.4, a generative view on causality does not seek to prove attribution definitively but rather to seek for plausible explanations in order to provide greater rigor over the analysis of causation and, hence, additionality (Hind, 2010). Therefore, the evaluator needs to work their way through the different 'pieces of evidence' to find what is additional due to the programme.

### 4.2.2 Step 5: Test and refine CMOc

While the socio-technical analysis provides a suitable starting point for assessing socio-technical outcomes, this next step is about testing and refining CMOc hypotheses in order to seek a plausible explanation of how, for whom and why a programme works. Although there may be many problems in evaluating causality in TIP programmes, it is still possible to gather pieces of evidence that increase our confidence on a given claim, by following a generative approach on causality. As pointed out by Byrne (2018, p. 92), even 'wicked problems can be partially explained using the methods of realism'. At this stage, the evaluator needs to identify the mechanisms and the context in which outcomes are being achieved.

Westhorp (2018) argues that, at the level of systems, one must consider alternative ways to construct the mechanisms in order to capture the process of change, including in: individual decision-making of firms, decision-making of governments, political structures and processes, power relationships, organizations' work, infrastructure, and so on. Therefore, one can conclude that developing CMOc hypotheses is also about identifying how the programme theory perceives changes in behaviour at different levels. In other words, this can work as an alternative to the 'black-box approach' to evaluation when evaluating behavioural additionality.

While a great deal of criticism has been raised in the TIP literature regarding the capacity of systemic frameworks to explain causal mechanisms (Papachristos, 2018; Sorrell, 2018; Svensson and Nikoleris, 2018), recent work provides some useful insights. In a paper by De Oliveira et al. (2020), the authors refine the TIS framework, using a mechanism-based approach to improve its analytical capacity to explain systemic malfunctioning and its implications. According to the authors, this would imply a clearer description of causes, contextual conditions, and outcomes. Causal mechanisms, or causal pathways between cause and outcomes, are represented by how systemic problems hinder the fulfilment of TIS functions, i.e., blocking mechanisms.[50] Outcomes are the patterns of system functioning, 'given by the hindrance of system processes' (De Oliveira et al., 2020, p. 25). Contextual conditions, in turn, involve factors as indicated by (Bergek et al., 2015, p. 45), e.g., TIS context structures (i.e. 'all other structures and relevant factors outside the TIS)', including technological, sectoral, geographical and political, as well as TIS-context interactions. While these mainly represent factors outside the TIS boundary, other contextual factors might also include TIS endogenous conditions, i.e., internal to the TIS boundaries (De Oliveira et al., 2020; de Oliveira and Negro, 2019). In other words, 'blocking mechanisms are the "pathways" caused by one or multiple systemic problems that yield an inadequate fulfilment of system processes under specific contextual conditions' (De Oliveira et al., 2020, p. 26).

Expanding this conceptual framework for TIP, I argue that this perspective on mechanism-based explanation can be applied for refining and testing CMOc. Figure 7 illustrates how CMOc can be refined for TIP programmes, based on these insights from TIP literature. In this case, mechanisms emerging from the fulfilment of socio-technical system processes (e.g., blocking or inducing mechanisms), would be the causal mechanisms for transformative outcomes. These mechanisms, in turn, are influenced by factors endogenous or exogenous to the socio-technical system.[51] Contexts that are exogenous could be, for example, external institutions that are independent of the system and not directly affected by it, but can still protect and stabilize the socio-technical system, as in TIS context structures (Bergek et al., 2015). They could also be 'landscape' forces (cf. Geels and Schot, 2007), i.e., the macro-level developments happening outside of the focal socio-technical system. Likewise, endogenous factors are those internal to the socio-technical

[50] This is similar to the definition of blocking mechanisms provided by the TIS literature (Bergek et al., 2008a; Wieczorek and Hekkert, 2012), in which blocking mechanisms emerge as a result of endogenous negative attributes of structural elements, e.g., lack of actor capability. However, De Oliveira et al. (2020) propose that the concept needs to be refined, first, to include exogenous negative attributes, e.g., poor infrastructure or weak regulatory alignment. Second, it needs to better explain 'how blocking mechanisms relate to systemic problems (causes), how they come up and manifest themselves and how they lead to poor system functioning' (De Oliveira et al., 2020, p. 25).

[51] De Oliveira et al. (2020) also point out that their notion of blocking mechanisms as causal mechanisms can also be applied broadly, e.g., to explain inducing mechanisms (Bergek et al., 2008a) or motors of innovation (Suurs and Hekkert, 2009).

system structure. This is also in consonance with the realist assumption, in which 'earlier' mechanisms can act as a context for 'later mechanisms' (Rolfe, 2019).

De Oliveira et al. (2020) suggest that in order to analyse causal mechanisms, the most prominent method would be process tracing (cf., e.g. Beach and Pedersen, 2016, 2018). 'Process tracing is a research method for tracing causal mechanisms using detailed, within-case empirical analysis of how a causal mechanism operated in real-world cases' (Beach and Pedersen, 2016, p. 1).[52] Moreover, in order to identify TIS contextual influences, de Oliveira and Negro (2019) recommend collecting detailed data about events and mapping their evolution in terms of actors involved, place and sector, activities, and motivations.

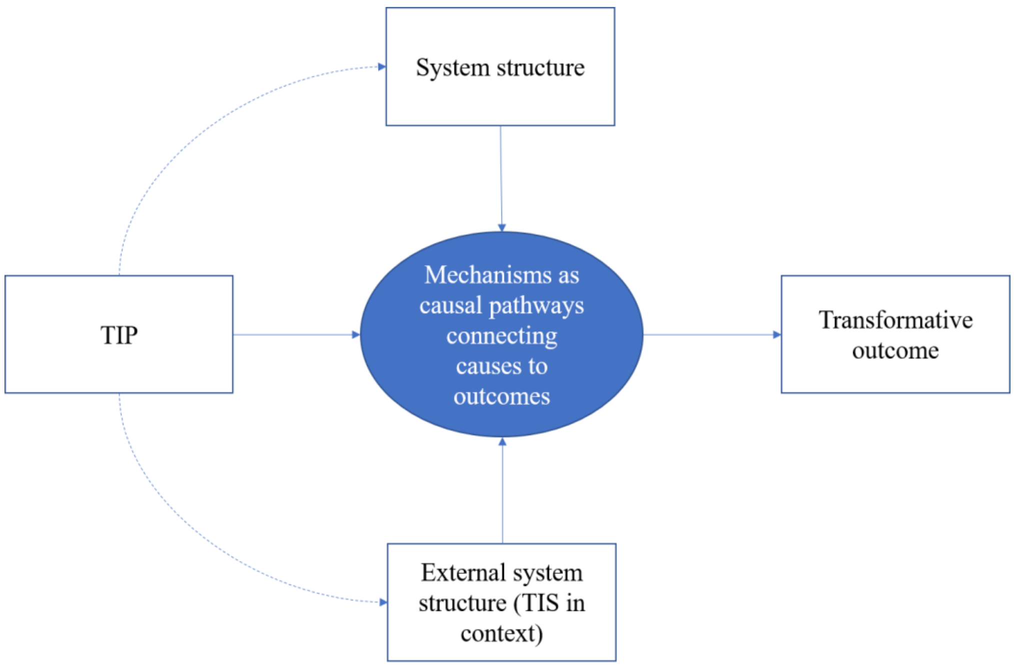



Figure 7. Refining CMOc for TIP programmes.

## 4.3 Component 3: Transition pathways

The last component of the integrated framework includes two steps: (i) assess transition pathways, which includes comparing the outcomes of the system analysis with the transition pathways characteristics in order to assess the direction that the programme is heading; and (ii) revisit

[52] Discussing process tracing is beyond the scope of this licentiate thesis. See Beach and Pedersen (2016) for a detailed description of how to define causal concepts for mechanism-based approaches. Additionally, Fontaine (2020) discusses how process tracing can be aligned with realism.

programme theory, which involves updating the programme theory according to the findings from component two.

### 4.3.1 Step 6: Assess transition pathways

In Step 1, the evaluator, together with policymakers and programme managers, defines the intended transition pathway the programme is aiming at. In Step 6, instead, the assessment of the pathways should indicate the direction of change the programme is, in fact, leaning towards, based on the findings from Step 4. As such, the analysis of the socio-technical outcomes (related to the three elements: functions, actor networks and institutions) performed in Step 4 provides a way to assess transition pathways following a socio-technical transition analysis. This is done by comparing the findings with the four elements of the pathways typology to analyse unfolding transitions (see Table 5 in Section 3.2.1.1). In addition to the socio-technical transition analysis, the literature highlights another two ways to analyse transition pathways, including quantitative system modelling and practice-based action research (cf. Hof et al., 2020; Turnheim et al., 2015). Each approach contains strengths and weaknesses and can be combined in order to provide a better picture of how the sustainability transition is unfolding (cf. Turnheim et al., 2015). The evaluator can thereby complement the assessment based on these two other ways, if deemed relevant for the evaluation process itself.

### 4.3.2 Step 7: Revisit programme theory

Finally, in the last step, the evaluator uses the evidence from theory-testing and theory-refinement (Step 5), as well as the findings regarding transition pathways, to improve the ToC model. While RE analysis can contribute to a process of learning and generate more robust ToCs (Rolfe, 2019), by analysing the direction of change via transition pathways, the evaluator can better understand if programme theory achieved its purpose. Programme managers and stakeholders can, thus, also learn about the implications of their theories of change for systems innovation. Moreover, improved ToCs can inform future policy interventions (Mason and Barnes, 2007).

# 5 An illustrative example of the BioInnovation SIP

Below, I illustrate how the integrated framework introduced in Section 4 can be applied. Section 2.4 describes the methods used to run this first attempt in order to apply it.

## 5.1 Step 1: Defining the transition focus of the programme

As described in Section 4.1.1, the definition of the transition focus of the programme involves three main features: nature of the problem, system delineation and targeted transition pathway. The first includes discussing the grand challenges or societal problems the programme is focusing on. The second defines the focal socio-technical system under analysis, in terms of actors, network, institutions and technologies. The third and last includes identifying the transition pathway the programme is aiming at.

### 5.1.1 Nature of the problem

When it comes to the nature of the problem, the BioInnovation Strategic Innovation Programme (SIP) emerges inspired by current grand challenges, such as climate change due to fossil emissions, population growth and increased consumption of natural resources (BioInnovation, 2020c). The programme is also one of 17 other initiatives (see also Section 2.1) that are of strategic importance to Sweden in creating sustainable solutions for the SDGs. The SIPs were developed under the strategic research and innovation agenda[53] that ran between 2012 and 2016 (Vinnova, 2018). More specifically, the BioInnovation SIP is a result of the combination of 9 different agendas out of 133: (1) the electronic highway from construction to clearing site; (2) welfare materials from sustainable forest resources; (3) new bio-based materials and products; (4) national mobilization of resources for new applications of forest materials; (5) biorefinery agenda/green agenda; (6) sustainable harvesting of forest raw material; (7) wood agenda; (8) made in Sweden: future textiles and paper; and (9) mobilization of resources around new processes for bio-based materials (Sweco, 2017).

That said, BioInnovation reflects on the role of a circular bioeconomy as the way forward towards achieving sustainable development and contributing to the SDGs (BioInnovation, 2020c). Within

[53] In order to set up an innovation agenda, Vinnova brought together stakeholders from several areas to define the innovation needs, while also aiming at addressing societal challenges (Vinnova, 2018).

Agenda 2030, the bioeconomy relates to all 17 SGDs, but it contributes at a higher degree to eight of them: SGD 7 *Affordable and clean energy*; SGD 8 *Decent work and economic growth*; SGD 9 *Industry, innovation and infrastructure*; SDG 11 *Sustainable cities and communities*; SDG 12 *Responsible consumption and production*; SDG 13 *Climate action*; SDG 14 *Life below water*; and SDG 15 *Life on land* (United Nations, 2015). As such, the programme's goal is to strengthen the bioeconomy in Sweden, given that it is not only strategically important, but also that the country already has strong research and innovation in the area (BioInnovation, 2020c). BioInnovation uses the definition given by Formas, which defines a bio-based economy (bioeconomy) as an economy based on:

> Sustainable production of biomass to enable a growth in use within a number of different social sectors. The objective is to reduce climate effects and the use of fossil-based raw materials.
> Increased added value for biomass materials, together with a reduction in energy consumption, and recovery of nutrients and energy from the end products. The objective is to optimize the value and contribution of ecosystem services to the economy. (Formas, 2012, p. 17)

Accordingly, it sees development as being 'dependent on the use of more renewable and bio-based raw materials, resource-efficient manufacturing processes, and that we create materials with a low environmental impact throughout their whole life cycle. It also requires changes in consumer behaviour and circular systems' (BioInnovation, 2020c, p. 3). More specifically, the programme has the vision that Sweden will have transformed into a bioeconomy by 2050 (BioInnovation, 2020f).

### 5.1.2 System delineation

As discussed in Section 3.2.4.1, TIP interventions aim to induce changes in a focal socio-technical system. In the BioInnovation SIP, the focal socio-technical system is not well defined. This makes sense, given that the bioeconomy is a cross-cutting strategy and encompasses various sectors, including agriculture, food, chemicals, forestry, etc. (European Commission, 2012). According to Jander and Grundmann (2019), a bioeconomy transition involves all sectors of an economy that are important for the transition from a fossil-based to a bio-based economy. Therefore, it not only involves sectors that are classified as 100 per cent bioeconomic, such as wood, forestry, bioenergy, food and wood, but also those that are only partially bioeconomic, e.g. textile, construction, and chemistry (BioInnovation, 2020d; Jander and Grundmann, 2019).

The document analysis indicates that BioInnovation works with three priority areas: Chemicals & Energy, Materials, and Construction & Design. This does not, however, decrease the complexity of such a transition, as these priority areas also encompass many different sectors, including construction, chemical, textile and clothing, and energy, among others (BioInnovation, 2020c). Consequently, there is not only one focal socio-technical system, but many. This indicates both a variety of technologies and a diversity of actor networks and institutions.

Table 11 exemplifies some of the technologies BioInnovation is targeting. Within the Materials sector, the programme focuses on developing solutions for packaging and textile/fashion industries, and aims at developing new bio composites, which are used in several industries. The Construction & Design area focuses mainly on the value chain of industrial timber, with a goal to increase resource-efficiency in construction and interior design. Additionally, within the Chemicals & Energy area, the programme mainly targets the development of green chemicals and fuels.

Table 11. Focus areas of BioInnovation.

| **Area** | **Products and processes** | **Example** |
|---|---|---|
| Materials | Packaging: designing of packaging materials and packaging solutions that provide both functionality and good climate and environmental performance | Packaging that is made from bio-based or recycled raw material |
| | Textiles: more resource-efficient and environmentally friendly manufacturing processes, new fibre and textile concepts, new business models, designs, and systems for a circular economy | Textiles based on cellulose |
| | Bio composites: development of composites (a combination of several materials which together form a construction material with new properties) in which at least one of the constituents is bio-based | Bio-based solutions to supplement or replace today's batteries |
| Construction & Design | The value chain of industrial timber: this encompasses the entire value chain for wood, from timber to sawn wood commodities, and finally interior design in buildings | Resource-efficient manufacturing processes for sawmills and manufacturers of wood products |
| Chemicals & Energy | Bio-based chemicals: development of green chemicals, produced from renewable biomass, as well as improving processes for separation and fractionation of constituent components | Proteins, prebiotics and active substances for cosmetics, and vanillin |
| | Fuel: development of fuel chemicals, produced from renewable biomass, as well as improving processes for separation and fractionation of constituent components | Biofuels for the aviation industry |

*Source: adapted from BioInnovation (2020f) and BioInnovation (2019).*

Regarding actor networks, the programme involves a set of different stakeholders from the business community, academia, and the public sector (BioInnovation, 2019, 2020f). BioInnovation started with approximately 50 different stakeholders. By 2019, more than 540 organizations had already participated (BioInnovation, 2020a). These include programme initiators and financers, as well as research institutes, e.g., RISE, which is a Swedish state-owned research institute; universities, e.g., KTH, Chalmers, Linköping University, Lund University, Luleå University, Stockholm University; and hospitals, e.g., Sahlgrenska University Hospital, among others. Stakeholders from the public sector include the Västra Götaland, Värmland, and Halland regional governments, as well municipalities.

Stakeholders from industry include both peripheral actors and incumbents[54] from these sectors, but also cross-sectoral actors. The list is extensive, but examples from incumbents include: Stora Enso, which is a Finnish manufacturer of packaging, biomaterials, wooden constructions and paper solutions; Preem, which is a Swedish petroleum and biofuel company; Sandviken Energi AB, which is an energy company that operates in district heating, electricity networks, sewage, etc.; Valmet, which is a Finnish company that supplies technologies, automation and services for the pulp, paper and energy industries; Sherwin-Williams, which is a US company that manufactures paint and coating products; and Nordic Paper, which is a Norwegian company from the pulp and paper industry.

Other peripheral firms include, for example Organofuel Sweden AB, which offers sustainable solutions in animal feed, cosmetics, and chemicals from forest raw materials; OrganoClick AB, which develops environmentally friendly solutions using cellulose-based materials; The Loop Factory, which offers services focusing on realizing sustainable innovation solutions from idea to commercialization; and Re:newcell, which is a Swedish textile-to-textile recycling company.

In terms of institutions, BioInnovation would encompass the role range of norms, regulations, standards, cultural aspects, etc. from all sectors under scrutiny. One common institutional aspect, however, is the programme's vision regarding the transition towards a bioeconomy.

[54] According to Geels (2014), incumbent firms are large, politically powerful, and scale-intensive actors, which possess manufacturing capability and core competencies within a given industry. Peripheral firms, in turn, are 'fringe actors or new entrants for whom it is relatively easier to deviate from regime rules' (Geels, 2014, p. 266).

### 5.1.3 Transition pathways

In relation to transition pathways, the programme does not clearly specify what its pathway might be. Although BioInnovation follows Forma's bioeconomy definition, and some general goals are set by the programme itself, questions such as 'what does a transition towards a bioeconomy encompass?' are only partially answered. On this note, previous research on the bioeconomy in Sweden has shown that, although there is a general idea of what a bioeconomy is, there is a lack of understanding about what it would really mean in practice (Ahmad, 2016). According to a report from the Stockholm Environmental Institute, a lack of consensus on the definition of a bioeconomy at the EU level has also prevented the development of parameters that can indicate whether a country is developing a bioeconomy over time (Skånberg et al., 2016). Therefore, at both the EU and Swedish levels, little is known about what kinds of parameters can be used to assess whether a country is transitioning towards a bioeconomy (Jander and Grundmann, 2019). Currently, general measures to assess the performance of the bioeconomy in Sweden include statistics such as percentage of GDP, turnover, number of employed people in industry, and value added of Swedish industries (cf. Statistics Sweden, 2018). However, this might not be enough to assess whether a transition is ongoing, especially because this barely reflects changes needed at the socio-technical system level.

Nonetheless, the document analysis shows that BioInnovation aims to create new business models by encouraging new entrants, as well as by reorienting established actors towards the use of materials with a low environmental impact (BioInnovation, 2020d). Moreover, at the technological level, it envisages the replacement of 'climate-impacting materials and chemicals with bio-based alternatives, so-called substitution' (BioInnovation, 2020c, p. 6). There is also the aspiration to use 'new bio-based processes and products in integration with existing production infrastructure, and existing processes' in order to benefit from investment and operations costs (BioInnovation, 2020c, p. 17). Little is said, however, about the intended changes at the institutional level, apart from the need to change consumer behaviour and circular systems. Externally, landscape pressures can be linked to the increasing concern regarding plastic use and pollution, as well as climate change, as mentioned in the beginning of this section. It is therefore difficult to identify a specific intended transition pathway. So far, the current programme design presents characteristics of both the substitution pathway at the technological level, and the reconfiguration pathway at the actor and social groups level (see Table 5 in Section 3.2.1.1).

### 5.1.4 Summary of findings

To sum up, BioInnovation has a clear vision that Sweden will have transformed into a bioeconomy by 2050, which involves the increased use of bio-based raw materials, as well more resource-efficient processes. Regarding its systems delineation, the programme has not defined a focal socio-technical system. While a transition towards a bioeconomy would involve all sectors of an economy, the programme focuses on three main areas: Chemicals and Energy, Construction and Design, and Materials. This also means that these SIPs involve a range of different actors from different industries, including forestry, chemicals, wood, etc. In terms of transition pathways, the programme does not clearly specify what its pathway might be. According to the programme's goals, it can be aiming either at a substitution pathway or reconfiguration.

## 5.2 Step 2: Explicating the programme's theory of change

In order to explicate the programme's theory of change, I split this section into three parts. The first part provides an overview of the official espoused effect logic as defined by programme managers. The second part reflects upon some of the problems identified within this logic. The third part shows how the espoused effect logic can be interpreted by taking the socio-science theory into account (in this case, TIP theory, as discussed in Section 3.1.4). An overview of themes used for the content analysis has already been discussed in Section 2.4.

### 5.2.1 Espoused effect logic

Annex A brings an illustration of the espoused effect logic, which is the representation of the theories of change as originally conceptualized by programme managers. Figure 8, in turn, is a modification of Annex A showing the possible causal paths, represented by dotted yellow arrows. While there is no further explanation about how the espoused effect logic was developed, I assumed that the causal path emerges in a straight line. This is because the espoused effect logic seems to follow a pipeline ToC representation, in which causality follows a straight linear process, as discussed in Section 3.1.1. Therefore, it makes sense to assume that the causal pathway is ‘conditions → efforts and activities → results goals → short-term effect goals → long-term effect goals’. In a second-round evaluation, however, this would need to be confirmed.

Regarding each linear block in Figure 8, the document analysis provides some additional information and insights (although sometimes conflicting). First, in relation to ‘conditions’, some background has already been discussed in Step 1, e.g., by specifying the agendas that gave rise to BioInnovation.[55] Second, efforts and activities include a list of activities financed and implemented by the programme. While the documents did not describe all the efforts and activities listed in the espoused effect logic, the following explanations could be found about the different kinds of project forms (BioInnovation, 2018a, 2021):

- *Innovation projects* last for several years and aim at creating the conditions in a larger area for bio-based materials, products, and services to come to market use. They focus on collaboration, knowledge sharing and systematic learning. The focus of such projects is defined by BioInnovation.
- *Hypothesis-testing projects* include projects that aim at evaluating a concept or an idea that can potentially contribute to the transition to a bio-based economy. These projects are tested for six months (hypothesis-testing Step 1). If the hypothesis is confirmed, the project can receive more funding to continue working for two more years (hypothesis-testing Step 2).
- *Thematic-call projects* aim to develop areas that need special stimulus. In those cases, BioInnovation’s programme management defines the focus of the project, while the project itself defines the challenge.
- *Cooperation projects* are carried out with separate funding from the government and can include initiatives together with other SIPs or initiatives to complement other activities within the BioInnovation programme.
- *Activity projects* involve those projects carried out at the programme level which are aimed at creating the conditions for increased collective innovation capacity and development of the programme through the study of political conditions or the creation of meeting places for markets, customers, and performers.

[55] Note that the number of agendas is not clear, as the documents provide conflicting information. While the espoused effect logic mentions 10 agendas, Sweco (2017) lists 9 (see Section 5.1.1).

- *Programme office* is responsible for managing BioInnovation by providing support, engaging in communication, and through internationalization.

There is no mention in these other documents about *cooperation processes* and *enhancing knowledge*. The former seems to represent the programme's support processes, i.e., what is developed internally to support the other programme's types of efforts and activities. The latter, in turn, seems to be focused on developing capacity at small and medium enterprises (SMEs).

Third, results goals represent what the programme has achieved during the duration of the projects. This seems close to the concept of output proposed by Belcher et al. (2020), i.e. the processes generated by project activities (see Figure 3, Section 3.1.1.1). Fourth, short-term goals represent the benefits emerging from the projects right after it ended. Finally, long-term goals are the long-term effects on organizations and society. These two latter concepts, in turn, seem to be linked to the concept of outcome, which is linked to changes in knowledge, attitudes and relationship, i.e., changes in behaviour (Belcher et al., 2020).

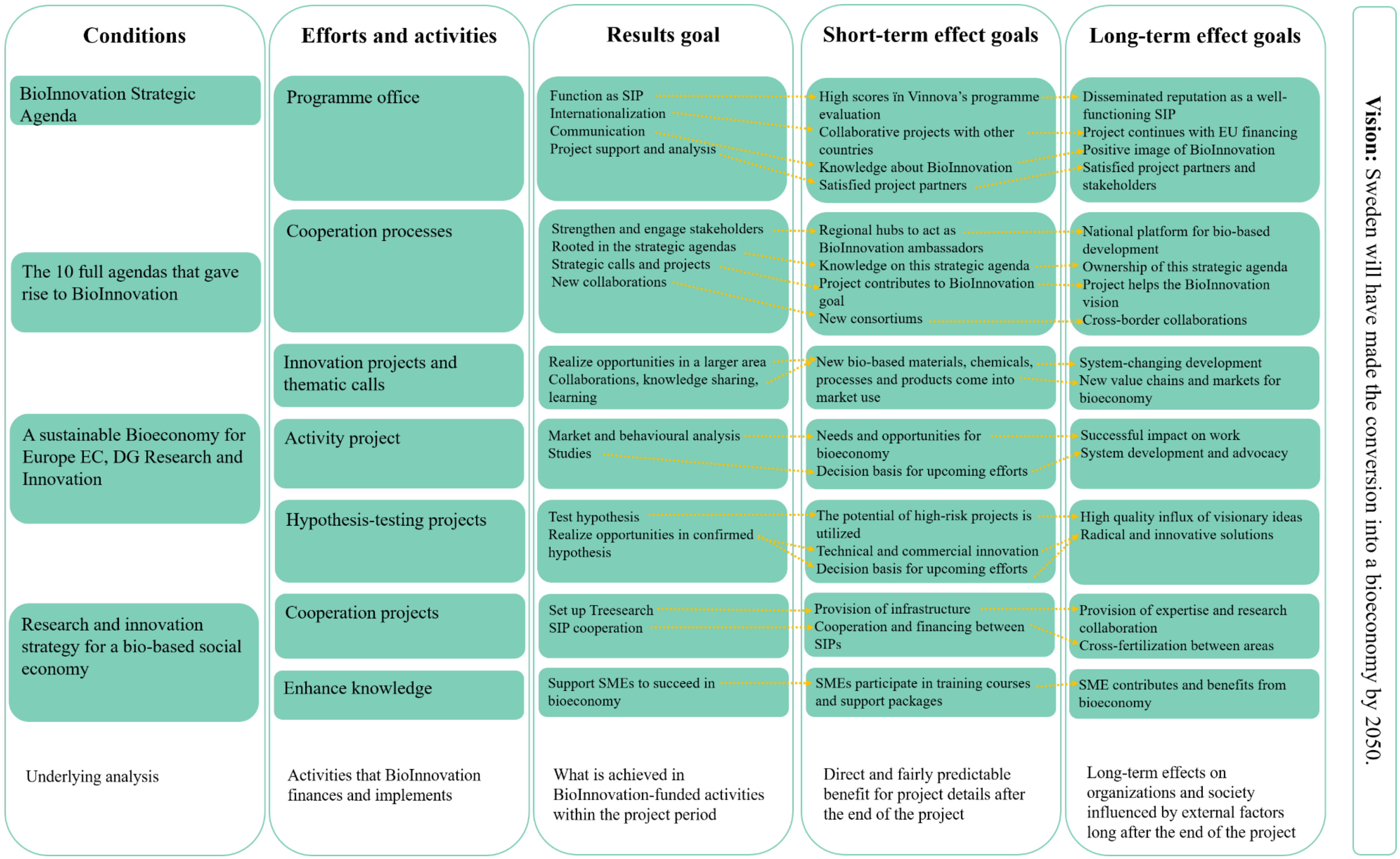



Figure 8. BioInnovation SIP-espoused effect logic.
*Source: Adapted from BioInnovation (2014, see Annex A)*

### 5.2.2 Limitations of the espoused effect logic

While this effect logic brings an initial idea about the programme's theories of change, it also shows some limitations. First, the espoused effect logic seems to mix efforts and activities that are internal to the programme, i.e., organizational support processes, with those intended to impact the socio-technical system. As such, the theories of change related to *programme office* and *cooperation processes* efforts and activities seem to be generating results and effect goals that concern how Vinnova and stakeholders perceive the programme's results. Thus, they do not directly point towards changes in the socio-technical system. An example related to *programme office* is the process 'function as SIP' results goal, which is expected to lead to 'high scores at Vinnova's programme evaluation' and 'disseminated reputation as a well-functioning SIP' (see Figure 9). An exception related to this effort and activity which can potentially impact the socio-technical system is related to the short-term effect goal 'collaborative projects with other countries' and long-term effect goal 'project continues with EU financing'.

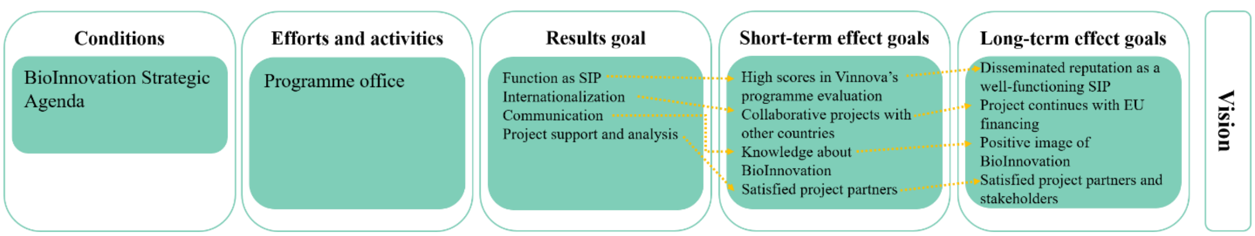



Figure 9. Excerpt of espoused effect logic related to programme office.

Another example, related to *cooperation processes*, is the results goal 'rooted in the strategic agendas', which is expected to lead to 'knowledge on this strategic agenda' in the short term, and 'ownership of this strategic agenda' in the long term. Some exceptions that can potentially impact the socio-technical system include the theories of change unfolding from the 'strengthen and engage stakeholders' and 'new collaborations' results goals (see Figure 10).

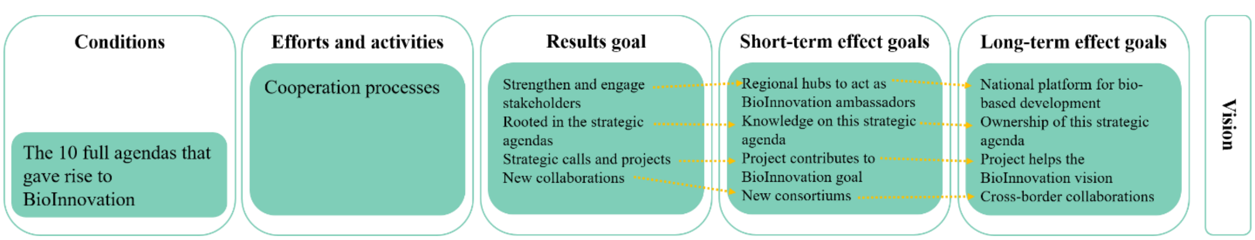



Figure 10. Excerpt of espoused effect logic related to cooperation processes.

Second, the explanatory capacity of the espoused effect logic is limited. For example, in Figure 10, it is unclear what programme managers mean by 'cross-border collaborations' or by 'regional hubs to act as BioInnovation ambassadors'. Additionally, it is unclear what the difference is between 'new collaborations' and 'new consortiums'. Another example, as illustrated in Figure 11, is related to what programme managers mean by the long-term effect goals 'system development' and 'successful impact work' and why their respective short-term effect goals and results goals would lead to these. When contrasting these theories of change with the criteria of plausibility, doability and testability, as discussed in Section 3.1.1, it is hard to say if such a pathway is plausible and doable.

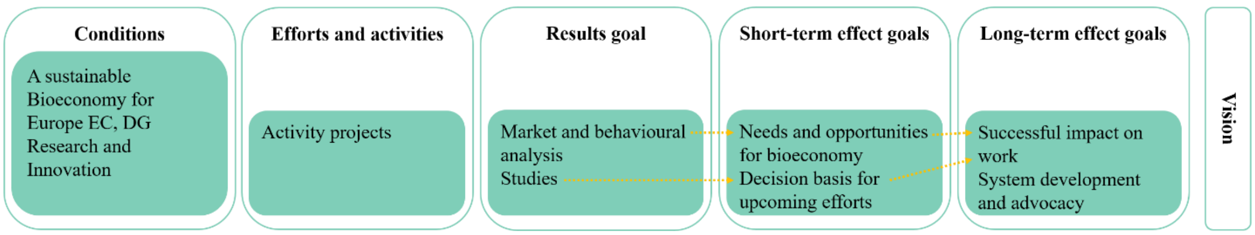



Figure 11. Excerpt of espoused effect logic related to activity projects.

Yet another example comes with the 'system-changing development' and 'new value chains and markets for bioeconomy' (long-term effect goals), which are results of new bio-based materials, chemicals, processes, and products coming into market use (short-term effect goal, see Figure 12). This, in turn, evolves from realizing opportunities in a larger area and via collaborations, knowledge sharing and learning (results goal) from innovation projects and thematic-call projects (effort and activities). While it might make it seem plausible, doable, and testable that new value chains and markets will evolve from the introduction of new bio-based products and processes into the market, it is difficult to know what programme managers mean by 'system-changing development' and what activities would lead to such effect goals.

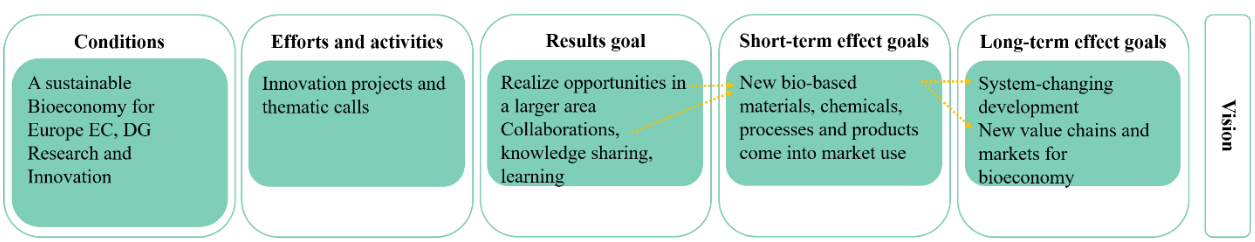



Figure 12. Excerpt of espoused effect logic related to innovation and thematic-call projects.

Third, the type of model of the espoused effect logic seems to follow a linear process, as in a pipeline model. As such, it does not account for feedback loops and it does not show the interrelations between the different efforts and activities being developed, which is common in complex programmes.

### 5.2.3 Interpreting the espoused effect logic according to policy theory

Figure 13 represents how the espoused effect logic could relate to policy theory. Note that the analysis is done in relation to short- and long-term effect goals, given that I am mainly interested in processes emerging and generating changes in behaviour in the socio-technical system. Due to the abovementioned limitations of the espoused effect logic, some processes were more ambiguous to classify in relation to a function or actor networks/institutional changes. In order to classify them, I relate to the espoused effect logic in order to see how the programme's theory of change comes about (as in Figure 8).

Additionally, some minor adaptations in relation to the processes mentioned within the effect goals were made to split terms that refer to different socio-technical processes. For example, the long-term effect goal 'new value chains and markets for bioeconomy' was split between 'new value chains for bioeconomy' and 'new markets for bioeconomy', given that they seem to relate to different processes, i.e., actor network and market formation, respectively. I also split the short-term effect goal 'cooperation and financing between SIP' between 'cooperation between SIP', which seems linked to the formation of actor networks, and 'financing between SIP', which, in turn, seems to involve the mobilization of financial resources (resource mobilization). Finally, 'provision of expertise and research collaboration' was split between 'provision of expertise' and 'research collaboration'. This is because the former seems to be related to the provision of human resources and capacity (resource mobilization), whereas the latter seems to be related to networks formed in order to collaborate on research (actor networks).

Overall, the programme seems to aim for changes in five main processes: knowledge development and diffusion, market formation, influence on the direction of search, resource mobilization, and actor networks. First, regarding knowledge development and diffusion, the espoused effect logic mentions 'the potential of high-risk projects is utilized', which seems to be related to the development of knowledge on topics that are considered to be of high risk, which is the purpose of hypothesis-testing projects. 'Cross-fertilization between areas' can be linked to knowledge diffusion between the programme's different focus areas.

Second, in relation to market formation, adding to the processes mentioned above, the programme also targets the development of 'technical and commercial innovation', which implies commercialization, and that 'new bio-based materials, chemicals, processes and products come into market use'. In the long-term, there is a goal to achieve 'radical and innovative solutions', also implying commercialization, and 'new markets for bioeconomy'.

Third, in terms of influencing the direction of search, the espoused effect logic mentions the development of a 'decision basis for upcoming efforts', which results from 'studies' or 'realizing opportunities in confirmed hypothesis-testing'. This can suggest that the programme perceives that findings from both studies and hypothesis-testing projects will influence further research. Similarly, market and behavioural analysis lead to 'needs and opportunities for bioeconomy' which, in turn, causes 'successful impact on work', which indicates that earlier results goals influence the search for short-term processes and these, in turn, influence long-term ones.

Fourth, apart from the aforementioned processes related to resource mobilization, the programme also aims at the 'provision of infrastructure' and that 'SMEs participate in training courses and support packages'. While the former relates to the mobilization of infrastructure, the latter refers to human resources in terms of capacity development.

Finally, in addition to the processes mentioned above, actor network processes include: 'collaborative projects with other countries'; 'new consortiums'; 'regional hubs to act as BioInnovation ambassadors'; 'cross-border collaborations'; 'system development and advocacy'; 'national platform for bio-based development'; and 'SME contributes and benefits from bioeconomy'.

As described in the previous section, some short- and long-term effect goals were not related to socio-technical process outcomes. As such, they were classified separately as being related to programme-internal aspects.

Figure 14 specifies what the causal links would be from efforts and activities aimed towards results goals and short- and long-term effect goals, according to the classifications shown in Figure 13, and considering the causal links as represented by the dotted yellow arrows in Figure 8. In other words, the short- and long-term goals related to the same socio-technical change process are grouped together in the dark blue and purple balloons, and their causal paths reflect the espoused effect logic. For example, activity projects are expected to develop market and behavioural analysis and studies. This would result in two short-term effect goals, which were divided between needs and opportunities for bioeconomy (knowledge development and diffusion) and decision basis for upcoming efforts (influence on the directing of search). In the long-term, the espoused effect logic anticipates that the former would lead to successful impact work (programme-internal) and the latter to system development and advocacy (actor networks). I refrain from describing all the links here, given that the processes were discussed in relation to Figure 13, and the causal links follow from the espoused effect logic. Moreover, the causal links will become clearer when discussing CMOc hypotheses in Step 3.

### 5.2.4 Summary of findings

As this section showed, BioInnovation focuses on different types of efforts and activities, such as funding for innovation projects, hypothesis-testing projects and thematic-call projects, as well as some focused on developing capacity within SMEs. However, the programme's effect logic, as designed by programme managers, presents many limitations. For example, some theories of change are unclear, leaving the evaluator without further information about some of the intended outcomes. Nonetheless, by using a transformative innovation policy lens, some outcomes can be matched with processes that can potentially have an impact at the system level. Below, these outcomes, interpreted from a transformative perspective, provide a basis for hypothesizing CMOc.

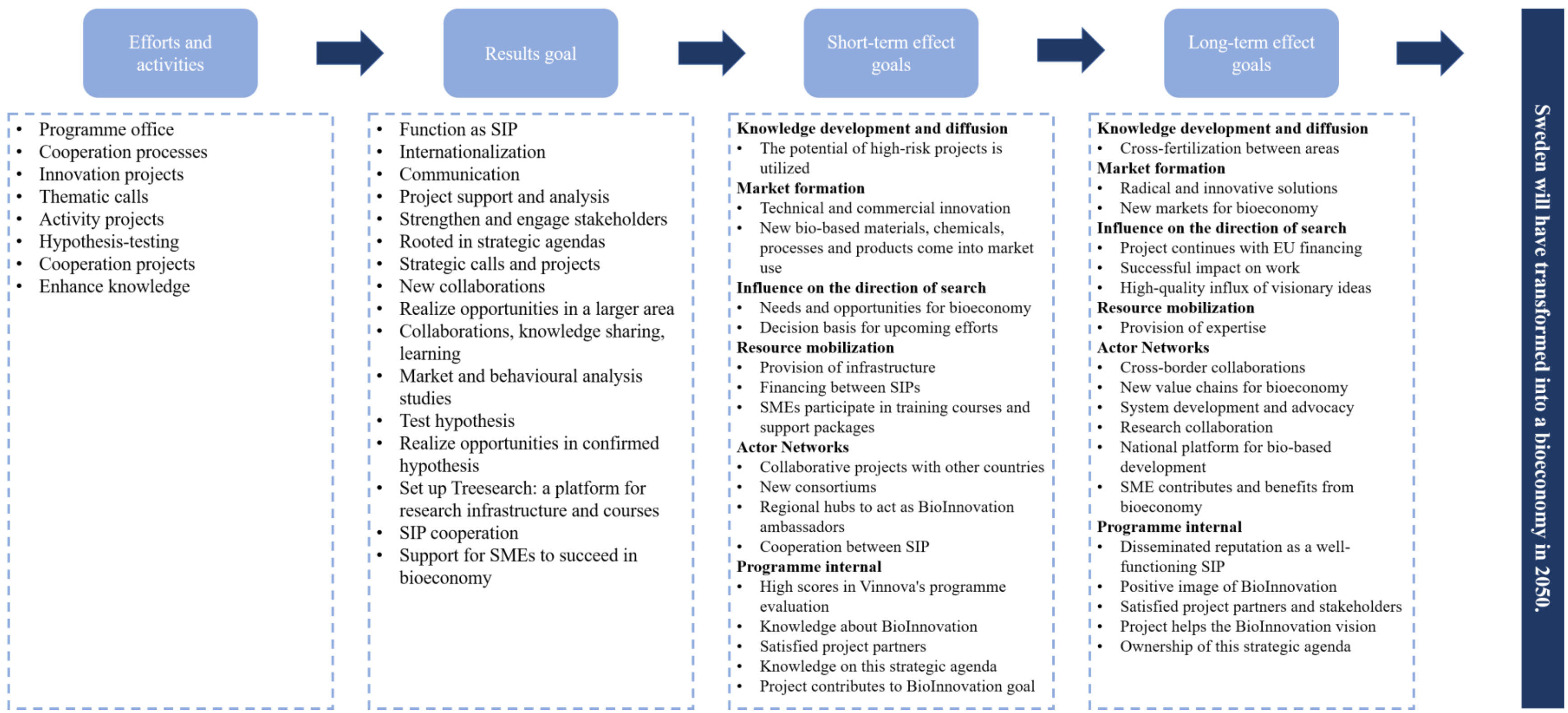



Figure 13. Effect logic reflecting policy theory themes.
*Source: adapted from BioInnovation (2014, see Annex A).*

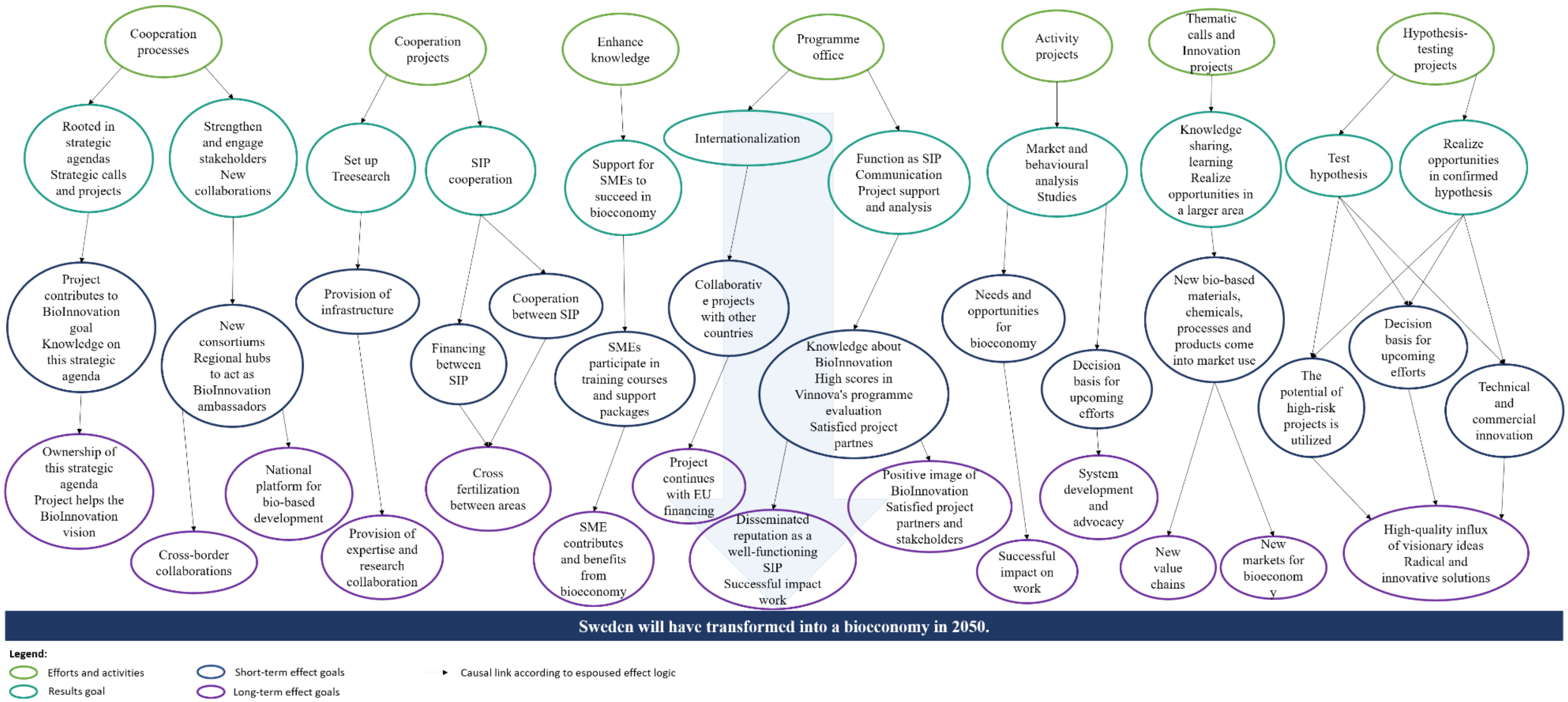



Figure 14. ToC model with causal links as outlined in the espoused effect logic.

## 5.3 Step 3: Developing CMOc hypotheses

Based on the ToC model illustrated in Figure 13 and Figure 14, Table 12 shows the realist matrix containing the list of CMOc that were identified. Each row represents a CMOc. The outcome (O) represents a short- or long-term effect goal, i.e., a socio-technical system process. The mechanism (M) is either a result goal of the espoused effect logic (see Figure 8 in Step 2), or an earlier outcome.[56] The context (C) is more difficult to identify, as the document analysis provides little information. As such, some contextual aspects are missing, as indicated in red letters. Others, in turn, can be inferred from results goals, especially those related to long-term effect goals. These, however, are not often straightforward, given that some explanatory factors regarding results goals are lacking. I point out in red, under some of the C, M or Oc, a few explanatory gaps I could identify within the CMOc construction and that need further clarification. Some of these gaps are related to the limitations of the espoused effect logic, as discussed before. Moreover, a fourth column was added to the realist matrix to provide more information about how each CMOc relates to the efforts and activities of the programme. Furthermore, I also indicated between parenthesis when a mechanism relates to another transformative process.

Within the effect logic and ToC, it was possible to identify processes related to four functions (i.e., knowledge development and diffusion, market formation, influence on the direction of search, and resource mobilization), and to actor networks. Three CMOc can be related to the knowledge development and diffusion function. One example is: *Efforts towards SIP cooperation (C) & Cooperation between SIPs (M) → Cross-fertilization between areas (O)*. This reads: the efforts towards SIP cooperation trigger/enable the cooperation between SIPs, generating cross-fertilization between areas.

Five other CMOc relate to market formation. One example is *Confirmed hypothesis & Technical and commercial innovation → Radical and innovative solutions*. As such, the programme hypothesizes that confirmed hypotheses trigger/enable technical and commercial innovation, generating radical and innovative solutions. Regarding the influence on the direction of search, five CMOc were hypothesized. For instance, the hypothesis that *Efforts towards*

[56] This follows the realist assumption that earlier outcomes or contexts can function as a 'later mechanism', as discussed in Section 3.1.2.1.

*internationalization & Collaborative projects with other countries → Project continues with EU financing*. In other words, the programme expects that efforts towards internationalization trigger/enable collaborative projects with other countries, which would thus lead to a continuation of the project with EU funding. In this case, however, the programme theory does not specify how this would come about exactly, e.g., if the programme directs participants to apply for specific funding. In terms of resource mobilization, four CMOc were hypothesized. One is structured as *Efforts towards setting up Treesearch platform & Treesearch platform provides infrastructure → Provision of expertise and research collaboration*. This indicates that the programme foresees that the efforts towards setting up the Treesearch platform will enable the provision of infrastructure, generating the provision of expertise and research collaboration for the bioeconomy.

Actor networks, in turn, shows the great number of CMOc: ten in total. An example includes the following: *New collaborations formed & New consortiums → Cross-border collaborations*. As such, the programme expects that new collaborations formed will trigger the formation of new consortiums, generating cross-border collaborations. As discussed before, the difference between new collaborations and new consortiums is not clear. It seems that consortiums are the group of actors that collaborate on a specific project, whereas collaborations are the processes actors undergo to form these consortiums. Additionally, the programme is not clear about what they mean by cross-border, i.e., whether this is, e.g., between countries or sectors.

### 5.3.1 Summary of findings

In sum, this section confirmed that the espoused effect logic presents many limitations. A number of mechanisms are left unexplained, and the document analysis provides little information about the types of contexts these mechanisms would be operating in.

Table 12. Realist matrix based on the BioInnovation SIP ToC.

| Efforts and activities | Context & | Mechanism → | Outcome configuration | Process |
|---|---|---|---|---|
| Hypothesis-testing projects | Missing | Hypothesis-testing | The potential of high-risk projects is utilized<br>What does it mean? | KDD |
| Activity projects | Missing | Market and behavioural analysis studies | Needs and opportunities for bioeconomy | KDD |
| Cooperation processes | Efforts towards SIP cooperation<br>What does it encompass? How does it trigger the mechanism? | Cooperation between SIPs (AN)<br>How does it generate the outcome? | Cross-fertilization between areas<br>How? | KDD |
| Hypothesis-testing projects | Missing | Realize opportunities in confirmed hypothesis<br>What does it mean? How does it generate the outcome? | Technical and commercial innovation | MF |
| Innovation projects and thematic calls | Missing | Collaboration, knowledge sharing and learning<br>Is it an outcome? | New bio-based materials, chemicals, processes and products come into market use | MF |
| Hypothesis-testing projects | Confirmed hypothesis | Decision basis for upcoming efforts (IDS) | Radical and innovative solutions | MF |
| Hypothesis-testing projects | Confirmed hypothesis | Technical and commercial innovation<br>Who does what? | Radical and innovative solutions | MF |
| Innovation projects and thematic calls | Collaboration, knowledge sharing and learning between project participants | New bio-based materials, chemicals, processes and products come into market use | New markets for bioeconomy | MF |
| Activity projects | Missing | Market and behavioural analysis studies | Decision basis for upcoming efforts | IDS |
| Hypothesis-testing projects | Missing | Hypothesis-testing | Decision basis for upcoming efforts | IDS |
| Programme office | Efforts towards internationalization | Collaborative projects with other countries (AN) | Project continues with EU financing<br>How does the programme influence this? | IDS |
| Activity projects | Market and behavioural analysis studies | Needs and opportunities for bioeconomy | Successful impact work<br>What does it mean? | IDS |
| Hypothesis-testing projects | Confirmed hypothesis | The potential of high-risk projects is utilized (KDD) | High-quality influx of visionary ideas<br>What does it mean? | IDS |
| Cooperation projects | Missing | Set up Treesearch platform | Provision of infrastructure | RM |
| Cooperation projects | Missing | SIP cooperation<br>How does it generate the outcome? | Financing between SIPs | RM |
| Enhance knowledge | Missing | Support for SMEs to succeed in bioeconomy | SMEs participate in training courses and support packages | RM |
| Cooperation projects | Efforts towards setting up Treesearch platform | Treesearch platform provides infrastructure | Provision of expertise and research collaboration | RM |
| Programme office | Missing | Internationalization<br>How is that a mechanism? | Collaborative projects with other countries | AN |
| Cooperation processes | Missing | New collaborations<br>How does it generate the outcome? | New consortiums | AN |
| Cooperation processes | Missing | Strengthened and engaged stakeholders | Regional hubs to act as BioInnovation ambassadors<br>What does it mean? | AN |
| Cooperation projects | Missing | SIP cooperation<br>What does it mean? How does it cause the outcome? | Cooperation between SIP | AN |
| Cooperation processes | New collaborations formed<br>What is the difference between collaborations and consortiums? | New consortiums<br>How does it generate the outcome? | Cross-border collaborations<br>What do they mean by cross-border? | AN |
| Innovation projects and thematic calls | Funding provided for thematic calls and innovation projects | New bio-based materials, chemicals, processes and products come into market use (MF)<br>How does it generate the outcome? | New value chains for bioeconomy | AN |
| Activity projects | Studies developed by the BioInnovation programme | Decision basis for upcoming efforts<br>How does it generate the outcome? | System development and advocacy<br>What does it mean? | AN |
| Cooperation projects | Efforts towards SIP cooperation | Cooperation between SIP | Research collaboration | AN |
| Cooperation processes | Strengthened and engaged stakeholders | Regional hubs to act as BioInnovation ambassadors<br>What does it mean? How does it generate the outcome? | National platform for bio-based development | AN |
| Enhance knowledge | Support provided to SMEs to succeed in bioeconomy | SME participates in training courses and support packages (RM) | SME contributes to and benefits from bioeconomy<br>What does it mean? | AN |

## 5.4 Step 4: Analysing socio-technical change processes

In this step, I turn to analysing transformative and system-level policy outcomes in relation to the targeted sectoral socio-technical configuration. This includes the functions with the 'directionality filter', as well as actor networks and institutional processes, as described in Section 3.2.4. By analysing the influence of policy in relation to each transformative process, the evaluator can capture behavioural additionality, understood here as the influence of policy on these processes.

### 5.4.1 Knowledge development and diffusion

It is hard to say what the current knowledge base level is in relation to the bioeconomy in Sweden. According to BioInnovation (2020c, p. 6), 'there is world-class research here, skilled innovators and a strong desire to invest in fossil-free alternatives. And above all, there is extensive access to biomass in Sweden'. Additionally, many of the country's global industrial companies have the capacity and competence to produce and deliver resource-efficient solutions. This has resulted in strong investments in R&D designed to support sustained growth in the bioeconomy. Within BioInnovation, R&D has been the main source of knowledge development. Substantial R&D funding has been given via the different types of projects, where actor networks in the form of consortiums have been cooperating in order to develop knowledge in all three focus areas.

Overall, the programme has a strong direction towards developing knowledge on new technologies and production processes that can potentially substitute fossil-fuel-based products and improve resource efficiency. While the types of technologies[57] and processes being developed are varied, some areas have been receiving greater attention. For example, regarding the Chemicals & Energy sector, a great portion of the R&D funding has been directed towards the development of new processes to produce fuels and chemicals from renewable lignin. Some projects have also been focusing on developing bio-based chemical components that can be used in different industrial products, e.g., painting, glue, or emulsions. In relation to the Construction & Design sector, the

[57] In order to make this assessment, I considered the following factors: funding, and number of projects focusing on a technology or group of technologies. As will be discussed in Section 5.4.5, a great portion of the funding is allocated to innovation projects, which target technologies such as new processes to produce fuels and chemicals from renewable lignin, resource efficiency in construction and renovation, and bio-based textiles. Some technologies were clustered based on their commonalities. For example, some projects were focusing on developing technologies for the healthcare industry, while others were targeting solutions for packaging. Finally, projects that did not receive a considerable amount of funding or did not fit previous clusters were classified as 'others'.

target has been how to improve resource efficiency in construction and renovation by using more wood. Additionally, some projects have been developing bio-based chemicals that are used in wood, e.g., wood surface treatment and wood impregnation chemicals. As to the Materials sector, the focus has been on developing textile fibres from forest raw materials to substitute oil-based materials and cotton fibres, as well as recycled bio-based textiles. Moreover, other R&D projects have targeted finding replacements for plastics and other fossil-based materials in packaging, and yet others have been developing bio-based solutions directed at the healthcare sector and at improving the resource efficiency of different composites (e.g., carbon fibre composite). So far, the number of projects focused on the Materials sector has been higher than the other focus areas, which can indicate a directionality towards this specific sector. Table 13 summarizes the absolute number of projects by sector for hypothesis-testing, innovation and thematic-call projects (this does not reflect the funding directed to each focus area, though, which will be discussed in more detail in relation to the resource mobilization function in Section 5.4.5).

Table 13. Absolute number of projects in each focus area and technology.

| **Type of project/Sector*** | **Chemicals and Energy** | **Construction and Design** | **Materials** |
|---|---|---|---|
| Hypothesis-testing | 14 | 8 | 33 |
| Innovation project | 1 | 1 | 1 |
| Thematic call | 1 | 0 | 6 |
| *Total* | *16* | *9* | *40* |

*As classified by Vinnova

*Note: the totals reflect finished projects in March 2021. A few ongoing projects were included, as illustrated in Appendix B.*

That said, in general, the programme seems to target the development of more disruptive technologies, which challenge current established products based on their performance attributes.[58] This is, for example, the goal of hypothesis-testing projects. When it comes to improving resource utilization, however, the projects seem to lean towards knowledge and competence enhancing,[59] as these seem to rely mainly on improving current processes. Nonetheless, this needs further research given the variety of projects being developed.

[58] This involves my own assessment based on Rosenbloom and Christensen's (1994) innovation typology, which distinguishes between disruptive and sustaining innovations, based on performance attributes. Disruptive innovations address new needs and offer new performance attributes that are not appreciated by established customers but appeal to new market segments. Sustaining innovations, in turn, are those that address the needs of established customers and improve mainstream product performance.

[59] This, in turn, is based on Tushman and Anderson's (1986) distinction between competence-enhancing and competence-destroying innovations. The first occurs when an innovation is achieved using existing skills, abilities, and knowledge, while the former refers to a developing new knowledge and competences.

Market knowledge has also been a developed as many projects have performed studies about potential markets for the technologies being developed. A few have been also trying to understand customer preferences. Additionally, the programme has performed studies about market trends of bio-based innovations (BioInnovation, 2015b), and more specifically, about the market challenge for textile fibres (Trossa, 2020). In relation to the latter, the analysis was performed in order to understand the possibilities for textile recycling, given the increasing demand for this. Institutional knowledge, in turn, has also been developed via studies about the political conditions of bio-based innovations (BioInnovation, 2015b) and on how to operationalize sustainability criteria and life cycle assessments (LCAs) for the bio-based sector in Sweden (BioInnovation, 2020e).

Knowledge has been diffused in different ways, mainly via publications and reports. Some projects' results have been presented at workshops, national and international conferences, and fairs. A few projects have also started a patenting process from their results. Additionally, the BioInnovation SIP promotes an annual conference to diffuse project results.

The setup of national research platforms such as BioLyftet and Treesearch has also been contributing to knowledge development and diffusion. The former has been developing knowledge on bio-based and recycled materials and targeting SMEs (BioInnovation, 2020b). The latter, in turn, works as a learning network between academia and industry and functions as an open research environment on new materials from the forest (Treesearch, 2020). Treesearch has also been supporting various doctoral and postdoctoral projects on developing new materials and chemicals from forest raw materials, in collaboration with companies.

Knowledge development and diffusion, however, has been weak when it comes to downstream firms. Previous research shows that there is a knowledge gap concerning bio-based products due to a lack of user-producer interactions within BioInnovation, especially at firms downstream on the value chain (Coenen et al., 2017; Grillitsch et al., 2019). This affects the collaboration among different actors and creates a mismatch regarding the understanding of bio-based materials, and also indicates a failure in directionality, since technologies are being developed by upstream firms and not for firms at the end of the value chain, which can potentially limit market formation.

Table 14 illustrates the main directionality aspects related to knowledge development and diffusion within the three focus areas. In sum, directionality has been strong as R&D projects have focused on developing technologies and processes for specific industries. While this can indicate a strong directionality aspect, it can also indicate that the programme has been quite narrow when it comes to addressing the cross-cutting parts of a transition towards a bioeconomy. Regarding the technological and societal problem being addressed, overall, it seems that BioInnovation is targeting the substitution of processes and technologies which are based on fossil-fuels or are not sustainable.

In relation to knowledge being developed and diffused 'by whom and for whom', most of the projects have targeted the consortium itself, as R&D funding comes partially from the project participants. Nonetheless, project results were also made available via reports and publications. Some patents are also underway, which limits the use of knowledge by non-participant actors. However, this has happened to a limited extent within BioInnovation. A shortcoming also related to this directionality aspect is the fact that the programme has shown that there is a knowledge gap between upstream and downstream firms in relation to the use of bio-based products. Nonetheless, ongoing projects such as BioLyftet might help to fill this gap in the long term.

Table 14. Directionality aspects of knowledge development and diffusion.

| Sector | For which technologies? | What technological/societal problem? | By and for whom? |
|---|---|---|---|
| Chemicals & Energy | New processes to produce fuels and chemicals from renewable lignin | Replace fossil-based fuels, oil-based plastics, and composites | By and for project participants |
| | Chemicals from forest raw materials | Replace unsustainable chemical components in a variety of industrial products, e.g., painting, glue, emulsions | By and for project participants |
| Construction & Design | Resource efficiency in construction and renovation by using more wood-based materials | Replace unsustainable materials with bio-based materials in construction sites | By and for project participants |
| | Chemicals used in wood, e.g., wood surface treatment and wood impregnation chemicals | Replace unsustainable chemical components in a variety of products used to protect wood-based solutions | By and for project participants |
| Materials | Bio-based textiles | Global need to produce sustainable textile materials in large volumes, and decrease resource consumption and environmental impact | By and for project participants |
| | Packaging | Need to replace plastics and other fossil-based materials in packaging | By and for project participants |
| | Bio-based innovations in healthcare | Replace fossil-based products in healthcare | By and for project participants |
| | Bio-based composites | Replace fossil-based composites by using bio-based solutions, e.g., carbon fibre composites | By and for project participants |

### 5.4.2 Entrepreneurial experimentation

Experimentation has occurred at different levels of intensity within BioInnovation. On the one hand, experimentation has been limited in short-term projects, such as *hypothesis-testing*, whose projects have six months to be completed. Those which have started experimenting with new solutions are still in an investigation phase and have only developed prototypes or demonstrators tested in a laboratory or on a small scale. These projects were aimed mainly at tackling technical and economic uncertainties. For example, some projects developed prototypes and demonstrators using different combinations of materials in order to assess their functionality in relation to commercial solutions. Others studied the economic feasibility of the production of the new materials and how this could be optimized to decrease costs. In some projects, participants have indicated a willingness to continue developing the idea after the project was over, and others have received further funding from BioInnovation. More research is needed to identify whether this was realized and which stage they are now in, as this was not possible to assess from the document analysis. Thus, it is difficult to assess, at this point, whether the programme has resulted in any changes in these participants' strategies towards, for example, the continuation of the consortium.

On the other hand, projects which can be realized over a longer period of time, such as *thematic-call projects* and *innovation projects*, have been able to perform tests and demonstrate their solutions on a larger scale. These projects have also focused on addressing technical and economic uncertainties. For instance, within the Chemical and Energy sector, pilot-scale tests have been developed to show the potential of using lignin to produce fuel under typical processes in refineries and to scale up the production of lignin-based chemicals. Regarding the Construction and Design sector, some projects have developed demonstrators to test the functionality of different wood-based materials in terms of resource utilization. Another project is testing various criteria that impact the production of tall wooden houses to show the possibility of using wood-based materials on their construction. In the Materials sector, some projects focused on the textile industry have not yet started experimenting. However, a few have been able to test products and textile waste recycling processes on a semi-industrial scale. Other projects focused on healthcare have developed real-scale demonstrators and started testing in their target industrial environment, e.g., hospitals. One specific project has also resulted in the entrance of two start-ups.

Apart from these two start-ups, BioInnovation has not been so active in terms of new entrants, either in terms of creating new bio-based firms or in diversifying established firms. Some of the participating companies already operate in industries that are considered bioeconomic, such as the pulp and paper industry. Examples include Stora Enso and Valmet. There are, however, some exceptions, such as Sherwin-Williams, which is an incumbent in the paint and coating industry and was involved in a project aimed at studying the possibility to use chemicals based on renewable raw materials.

Overall, there has been some entrepreneurial experimentation, but this function does not seem as strong as the previous one. Table 15 shows the main directionality aspects related to entrepreneurial experimentation. To summarize, experimentation has been more active in projects that have higher implementation time. These projects, however, do not necessarily involve the most disruptive technologies. This can indicate, in turn, a lack of directionality in terms of experimenting with more disruptive technologies. When it comes to 'who is experimenting and with whom', the projects have rarely tested the products with end users. This can also be linked to the lack of user-producer interactions within BioInnovation, as discussed previously in the knowledge development and diffusion section. Regarding the 'sources of uncertainty' experimentation is targeting, the focus has mainly been on addressing technical and economic aspects. Technologies that have not yet entered the experimentation phase have not been included in the table below, e.g., chemicals from forest raw materials.

Table 15. Directionality aspects of entrepreneurial experimentation.

| Sector | Which technologies are experimented with? | Who is experimenting and why? | What sources of uncertainty are experiments targeting? |
|---|---|---|---|
| Chemicals & Energy | New processes to produce fuels and chemicals from renewable lignin | Project participants are testing to show the potential of using lignin to produce fuel under typical processes in refineries and to scale up the production of lignin-based chemicals | Technical and economic |
| Construction & Design | Wood-based materials in construction and renovation | Project participants are testing wood-based materials functionality in terms of resource utilization and the possibility to use it in the production of tall wooden houses | Mainly technical |
| Materials | Bio-based textiles: Textile fibres from forest raw materials and textile waste recycling processes | Project participants are testing the commercialization viability of products and processes | Technical and economic |
| | Bio-based innovations in healthcare | Real-scale demonstrators are being experimented with in the projects' targeted industrial environment | Technical and economic |

### 5.4.3 Market formation

The bioeconomic socio-technical system seems to be in an early stage of development and most of its market is related to industries that are already classified as bioeconomic (as described in Step 1). In 2015 in Sweden, only 6% of the GDP, or an annual value of SEK 258 billion, was related to the bioeconomy. Half of this value was linked to industries classified as 100% bioeconomic, while the other half came from industries that are partially bioeconomic (Statistics Sweden, 2018).

BioInnovation has also not been so engaged in market formation. Most of the technologies and processes within the programme are still in a development or experimentation phase. Additionally, the document analysis shows that many market uncertainties remain. These include what markets to aim for, how to reach the product properties demanded by end customers, profitability potential, market capacity to absorb these innovations, and the cost of the final product. For example, some projects have reported that they need to work towards decreasing the price of their solutions, given that they are more expensive than existing commercial ones. These uncertainties match current market challenges for bio-based innovations, as identified previously in the market analysis performed by BioInnovation (2015b). The analysis indicated that issues related to product functionality, cost and quality have been some of the major factors hindering market formation. As such, in order to justify companies' investments in bio-based products, either the high costs are covered by increased revenue, or the products and/or processes themselves have to be good or better than those offered in the market. However, a survey indicates that potential customers have not expressed a willingness to pay more for bio-based alternatives. Additionally, worldwide, the demand articulation for bio-based products is still low. In the US, for example, only 5% of a survey's respondents reported to be interested in such solutions.

Another bottleneck in market formation is the fact that, for some sectors, the production side is still dominated by incumbents. For example, in the Construction and Design sector, some participants raised the issue that a great portion of the overall building volume is under the influence of traditional construction companies. Another project reported that efforts towards understanding the potential use of bio-based materials in construction was blocked due to a lack of interest from potential stakeholders, e.g., architects and house builders. Moreover, in the Materials sector, the long and segmented production chain of textiles has prevented the introduction of recycled textile fibres into the market.

Nonetheless, some processes that can potentially contribute to market formation in the future have also been initiated. For example, some projects have started to prepare their solutions for market introduction, whilst others have been developing feasibility studies in order to assess the market and economic potential of the new solutions. In the Construction and Design sector, studies were conducted in order to understand customer preferences and attitudes to wood interior environments in Europe. In addition, some efforts towards procurement procedures have been initiated. For instance, one project has developed decision support for procurement of green construction projects. Regarding the Chemicals and Energy sector, new solutions developed from lignin opened doors for different applications, e.g., using lignin as a raw material in thermoplastics or producing vanillin, which has broad applicability in the pharmaceutical industry.

A few projects have also reached the commercialization phase, mainly in the form of niche markets. These are mainly related to the Materials sector. For example, a participant of one of the projects related to the textile sector has established a partnership with H&M to launch a garment made from bio-based materials. Another example has been the two new start-ups that have started commercializing two new bio-based solutions: a disposable cup that can be used as a hazardous waste container during surgical operations and a valve that can be attached to a urinary catheter.

In yet another example, 3D-moulded cellulose-based food trays resulting from another project have been through a purchasing process in one of the Swedish region's procurement rounds.

Table 16 illustrates the main directionality aspects related to market formation. Overall, BioInnovation seems to follow a technology push strategy, which also makes sense due to the programme's strong focus on RD&D. Projects targeting end customer involvement have been less common. Some exceptions include the consultation with customers about their preferences regarding the use of wood in interior design, and the involvement of municipal projects that target public procurement, as mentioned previously. Many projects, however, have not been clear about who the targeted customer group is, and others are still looking for potential markets to aim for, which can indicate a demand articulation failure. Technologies that have not yet entered the market have not been included in the table below, e.g., chemicals from forest raw materials.

Table 16. Directionality aspects of market formation.

| **Sector** | **Which segments are expanding vs declining?** | **What consumers needs are articulated vs ignored?** | **Which segments do actors' market strategies target?** |
|---|---|---|---|
| Chemicals & Energy | New processes to produce fuels and chemicals from renewable lignin<br>It is unclear whether this is expanding | Manufacturers/refineries (articulated) vs end customer (potentially ignored) | Unclear |
| Construction & Design | Wood-based materials in construction and renovation<br>It is unclear whether this is expanding | End customers for interior design (articulated) and municipalities vs potential stakeholders (not ignored, but lack interest) | Renovation: end customers<br>Construction: municipalities |
| Materials | Bio-based textiles: textile waste and recycling<br>It is unclear whether this is expanding | Established fashion retailers (articulated) vs end customers (potentially ignored) | Fashion retailers |
| | Bio-based innovations in healthcare<br>It is unclear whether this is expanding | Public sector (articulated) vs end customers **(**potentially ignored) | Public sector |

### 5.4.4 Influence on the direction of search

Influence on the direction of search in BioInnovation can be assessed based on both external and internal factors. Externally, changes in the landscape have motivated the development of the programme as such. As discussed in Step 1, these include the need for more renewable bio-based raw materials, resource efficiency, and materials with a lower environmental impact, as well as that bio raw materials are circulated (BioInnovation, 2020c). Regulatory pressures and growth potential have also been influencing projects in all three focus sectors. For instance, the new supplementary directives on packaging and packaging waste that emphasize the reduction of landfills proposed by the EU have driven some projects in the Materials sector (BioInnovation, 2020c). In relation to the Chemical and Energy sector, the Swedish government's decision to reduce greenhouse gas emissions from petrol and diesel by 40% by 2030 has influenced the development of projects targeting biofuels. Moreover, the trend towards increasing demand for bio-based chemicals, which is expected to have an annual growth of more than 16% from 2016 to 2025, has influenced the development of projects targeting bio-based chemicals. Similarly, the increasing demand for buildings made from wooden frames, which is expected to reach 50% of the Swedish market share (of apartments buildings) by 2025, has influenced the focus on the wood industrial value chain in the Construction and Design sector (BioInnovation, 2020b).

Internally, the direction of search has been influenced by the different structures of the projects and through learning in and between projects within BioInnovation. Regarding the former, *thematic-call projects* offer partial funding for research in need of special stimulus. The direction of such projects is defined by the programme, while the actor network defines the challenge itself. For example, in 2016 the 'Bio-based innovations in publicly funded activities' targeted projects that aimed at stimulating innovation that led to new bio-based materials, products and services that can be implemented in publicly funded activities. The types of solutions, in turn, were defined by the consortium in the form of, for instance, products targeting the healthcare sector.

With respect to the latter, stepwise projects such as *hypothesis testing* offer partial funding for high-risk projects during a six-month period in Step 1. In Step 2, further funding is provided for confirmed hypotheses to promote product and process development for two more years. These projects have been targeting the development of chemicals from forest-based raw materials, chemicals used in wood, and packaging. Another example comes within *cooperation projects*, where the first phase of the 'Timber on top' project, which aimed at understanding how to use timber as an extension in construction, influenced the definition of a second stage. Yet another example is related to *innovation projects*: the focus on textile fibres from forest raw materials was identified in an 'Innovation Race', an innovation activity developed with different actors to discuss strategies for the bioeconomy (BioInnovation, 2015a).

Table 17 shows the key directionality aspects related to influence on the direction of search. Overall, it seems that a great portion (if not all) of the projects developed within BioInnovation have been influenced by either external or internal factors. This can indicate a directionality towards addressing landscape changes, regulatory pressures, and other problems identified through research and discussions with stakeholders. Additionally, actors have mainly directed their resources towards new technologies or processes or towards markets that have indicated an increasing trend. Less focus has been given, however, to developing new business models.

Table 17. Directionality aspects related to influence on the direction of search.

| **Sector** | **To which technologies are actors allocating their resources and why?** | **To which markets and business models etc. are actors allocating their resources and why?** |
|---|---|---|
| Chemicals & Energy | New processes to produce fuels and chemicals from renewable lignin | Trend towards increasing demand for bio-based chemicals |
| | Chemicals from forest raw materials | Trend towards increasing demand for bio-based chemicals |
| Construction & Design | Resource efficiency in construction and renovation by using more wood-based materials | Trend towards increasing demand for buildings made from wooden frames |
| | Chemicals used in wood, e.g., wood surface treatment and wood impregnation chemicals | Trend towards increasing demand for bio-based chemicals |
| Materials | Bio-based textiles | Unclear |
| | Packaging | Unclear |
| | Bio-based innovations in healthcare | Bio-based innovations in publicly funded activities (in healthcare) |
| | Bio-based composites | Unclear |

### 5.4.5 Resource mobilization

Within BioInnovation, a variety of resources are being mobilized. In terms of *financial resources*, the programme has been providing funding for RD&D through different project types. Figure 15 shows the total funding allocated for each sector, in Swedish crowns (SEK), for *hypothesis-testing projects* (Figure 15a), *innovation projects* (Figure 15b), and *thematic-call projects* (Figure 15c). These amounts represent the partial investment in both completed and ongoing projects by June 2021. Due to a lack of access to data, not all funding was accounted for. For example, Figure 15a does not include investments from participating partners. According the programme's rules, however, projects in hypothesis testing must be co-financed with the same amount as the grant applied for, which can be up to SEK 500,000 (BioInnovation, 2020f). Therefore, these totals may be double what is accounted for. In addition, Figure 15c does not account for investments from participating partners from Finland. As illustrated, the Materials sector holds the highest funding volume in both hypothesis-testing and thematic-call projects (and the greatest number of projects, as highlighted in relation to the knowledge development and diffusion function). As already discussed above, funds are being mobilized, among other things, to produce fuels and chemicals from lignin and other forest raw materials, to improve resource use in construction by adopting the use of wood-based materials, and to develop textile fibres made from forest raw materials.

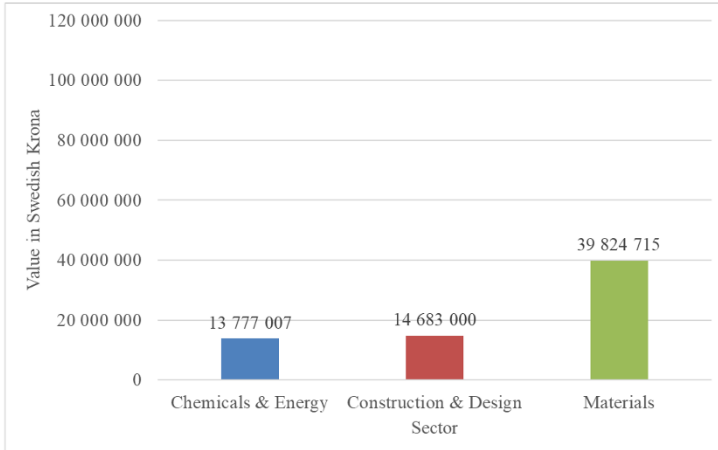
Regarding types of technologies, Figure 16 illustrates the funding provided exclusively by Vinnova for each category of technology. As previously mentioned, a great deal of the funding is directed towards innovation projects and to the solutions being developed within them, which include new processes to produce fuels and chemicals from renewable lignin, resource efficiency in construction and renovation, and bio-based textiles. Other projects that were targeting similar technologies were also accounted for in those totals. Bio-based innovations in healthcare have also received a good portion of the funding. Other technologies that were targeted include chemicals from forest raw materials and used in wood, as well as packaging and new bio-based composites. The Sankey diagram also shows funding directed to other technologies that did not receive as much funding as those previously mentioned.

Some project participants have also indicated that they would continue developing their solutions even after their participation in the programme was finished, either by applying for further funding outside BioInnovation or by using their own resources. This can indicate behavioural additionality in terms of the influence public funding has in firms' strategies, given that, in some cases, R&D is only sustained because of public funding. It is unclear, however, how many consortiums have proceeded with these efforts after their projects within BioInnovation were completed.

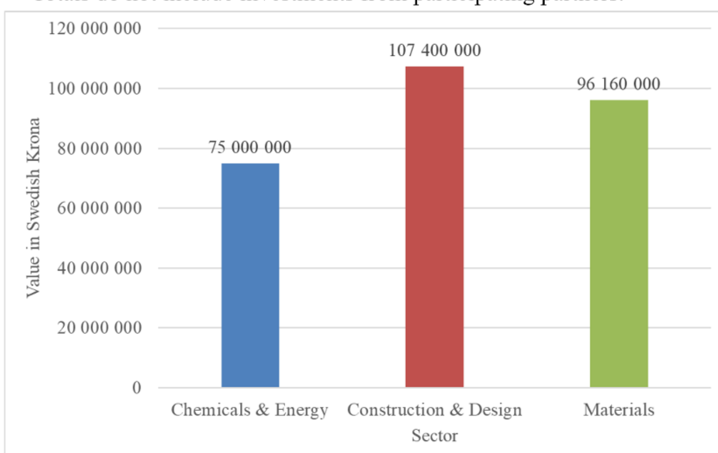
Regarding *human resources*, the programme has started two initiatives focused on capacity building: BioLyftet and Treesearch (see also knowledge development and diffusion). BioLyftet has been training SMEs in order to build capacity in the use and application of bio-based and recycled materials. In 2019, the initiative trained more than 220 participants from companies all over Sweden. It is unclear, however, whether these companies have changed their behaviour due to this initiative. Currently, many companies are hindered from developing bio-based products due to a lack of capacity (BioInnovation, 2020a). These companies are usually completely dependent on their suppliers' knowledge and range. Treesearch has also been training and supporting doctoral and postdoctoral projects on new materials and chemicals from forest raw materials (Treesearch, 2020). It is still too early to determine whether firms have absorbed human resources formed within BioInnovation and whether this has induced change.

Resources are also being mobilized in the form of *complementary assets and infrastructure*. For instance, Treesearch has been responsible for advancing an open research infrastructure on materials and chemicals (Treesearch, 2020). Interested actors can have access to different specialized laboratories around Sweden, as well as contact with various researchers. So far, more than 290 researchers have joined the platform and more than 92 projects have been registered. Additionally, participants within the different consortiums have been sharing complementary capacity and infrastructure to develop new products and processes. For instance, some participants are contributing with raw materials, e.g., nanocellulose, others with technical expertise, e.g., expertise in 3D printing, and yet others with equipment and manufacturing infrastructure, e.g., RISE Processum's mini reactor. Moreover, some projects have been studying the possibility of using existing infrastructure to produce new bio-based solutions. For example, some solutions for packaging aim at using existing industrial processes to produce new bio-based solutions.

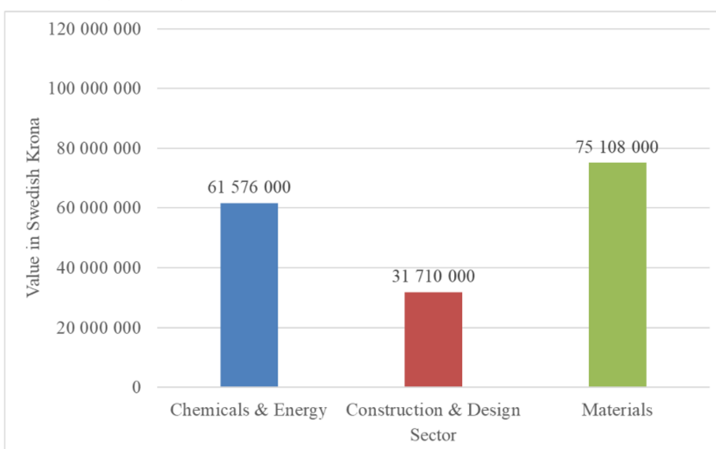
**Funding for hypothesis-testing, innovation projects and thematical calls**




a) Funding for hypothesis-testing projects from Vinnova (in SEK). Totals do not include investments from participating partners.




b) Funding for innovation projects from Vinnova and participating partners (in SEK).




c) Funding for thematic calls from Vinnova and Swedish participating partners (in SEK). Totals do not include investments from participating partners outside Sweden.

Figure 15. Funding for hypothesis-testing, innovation, and thematic-call projects.
*Source: Vinnova (2021a) and BioInnovation (2021).*

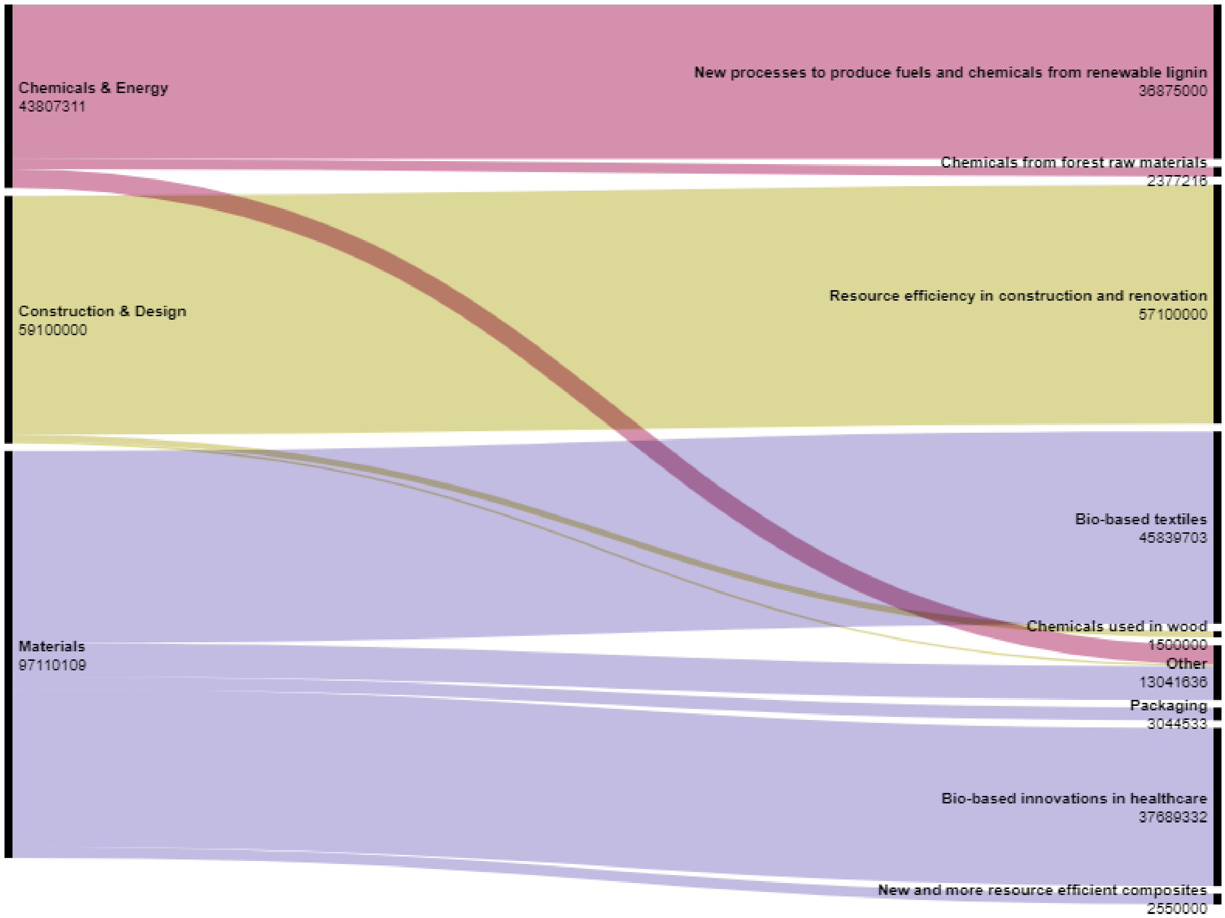



Figure 16. Sankey diagram showing the flow of funding (in Swedish Kronor) from focus area to technology. *Note: Sankey diagram developed based on the funding provided exclusively by Vinnova (funding from project partners are not accounted for).*

Table 18 shows the main directionality aspects related to resource mobilization. In sum, the technologies benefiting the most are the same as identified previously, in terms of knowledge being developed and diffused. Additionally, overall, the consortiums seem to be using the strengths of each participant, i.e., complementary human resources, and infrastructure, to develop the projects. Regarding the extent to which new technologies can explore existing infrastructure, in general, the document analysis indicates that a great number of consortiums are developing solutions that can be developed using current industrial processes and/or infrastructures, or by adapting them. Others have also been using residual streams from existing industrial operations as raw materials to develop new solutions. For other consortiums, the extent is not as clear.

Table 18. Directionality aspects related to resource mobilization.

| Sector | Which technologies benefit the most? | To what extent do actors mobilize complementary assets? | To what extent can new technologies exploit existing infrastructure and complementary technologies? |
|---|---|---|---|
| Chemicals & Energy | New processes to produce fuels and chemicals from renewable lignin | Consortiums have been exploring complementary human resources and infrastructure | Partially: some projects have aimed at producing fuels based on lignin using typical processes in refineries |
| | Chemicals from forest raw materials | Consortiums have been exploring complementary human resources and infrastructure | Partially: some have aimed at developing new solutions, whilst others have aimed at adapting existing bio-based technologies to be used as chemical components |
| Construction & Design | Resource efficiency in construction and renovation by using more wood-based materials | Consortiums have been exploring complementary human resources and infrastructure | Partially: some projects have been exploring existing manufacturing methods, while others have focused on improving resource efficiency of existing wood-based solutions |
| | Chemicals used in wood, e.g., wood surface treatment and wood impregnation chemicals | Consortiums have been exploring complementary human resources and infrastructure | Partially: some projects have been investigating the possibility of using residual streams from, e.g., the paper and pulp industry |
| Materials | Bio-based textiles | Consortiums have been exploring complementary human resources and infrastructure | Partially: some projects have aimed at using existing processes and infrastructures |
| | Packaging | Consortiums have been exploring complementary human resources and infrastructure | Partially: some projects have aimed at developing new packaging solutions, others have focused on using existing infrastructure |
| | Bio-based innovations in healthcare | Consortiums have been exploring complementary human resources and infrastructure | Partially: some have been exploring the potential of using 3D-printing, others have been developing technologies that can be used together with other technologies in healthcare |
| | Bio-based composites | Consortiums have been exploring complementary human resources and infrastructure | Partially: some of the composites that are being developed can replace current fossil-fuel based ones and have applicability to several industries |

### 5.4.6 Legitimation

Overall, BioInnovation has not engaged so actively in promoting legitimation. However, some actor and institutional change processes can potentially contribute to this function in the long term. These include, among other aspects: (i) the long-term vision that the programme has for bioeconomy; (ii) the involvement of incumbents and the public sector in some of the projects; and (iii) the development of technologies that use current processes and infrastructures or adapt to these. The document analysis, however, provides little insight into how these aspects have affected the overall performance of the system and whether this is leading to a transition.

In addition, some projects have been engaged in developing solutions that comply with current or upcoming legislation, pursuing a fit-and-conform strategy. For instance, a project from the Materials sector studied ways to develop bio-based healthcare solutions in accordance with the Swedish Public Procurement Act, which covers measures to procure supplies, services or works by Swedish authorities. Another project from the Construction and Design sector has improved resource efficiency of wood-based materials in order to comply with the new energy requirement coming up in 2021. While such strategies may not at first glance seem to fall under the category of behavioural issues, they can eventually lead to changes in behaviour of actors from the public sector once they opt for bio-based solutions instead of established ones.

A few factors hindering legitimation can also be identified. For example, many projects have reported that their resulting solution is still expensive in comparison with existing commercial products. This can indicate a normal 'liability of newness', which can be resolved when the products reach the market and start enjoying economies of scale and experience. Nonetheless, it might take time and effort to bring about institutional change. Another aspect is related to the lack of overall market formation, which can signal a lack of social acceptance and demand for new bio-based solutions.

Table 19. Directionality aspects related to legitimation.

| **Sector** | **Which technologies/actors are seeing a change in legitimacy, and in the eyes of which stakeholders?** | **Which regulations and support systems are gaining vs losing legitimacy in the eyes of which stakeholder and why?** |
|---|---|---|
| Chemicals & Energy | Potentially, chemicals and fuels developed from lignin are gaining legitimacy in the eyes, for instance, of incumbents | Unclear |
| Construction & Design | Potentially, resource efficiency in construction and renovation by adopting the use of more wood-based materials are gaining legitimacy in the eyes of municipalities | Public procurement for green construction projects is gaining legitimacy in the eyes of municipalities<br>Wood-based materials are being improved to comply with upcoming energy requirements set by the Swedish government |
| Materials | Potentially, solutions for the healthcare sector are gaining legitimacy in the eyes of the public sector | Potentially, public procurement of bio-based products for healthcare, in the eyes of the public sector |

Table 19 illustrates the directionality aspects regarding legitimation. Overall, there is little evidence that the solutions developed within BioInnovation are gaining legitimacy. This can indicate that the legitimation direction is still towards established technologies rather than bio-based ones. Institutional change processes, however, can potentially impact legitimation in the future. Due to the lack of evidence towards the legitimation of other technologies, e.g., bio-based composites and bio-based textiles, they were not included in the table below.

### 5.4.7 Development of positive externalities

The document analysis provides little information regarding the development of positive externalities. More research, especially via interviews, might provide a better overview regarding this function. Some indirect processes, however, can potentially contribute to such a function in the long term. For example, by training new SMEs, BioLyftet can potentially lead to new entrants and, hence, to the emergence of intermediate goods and service providers that benefit the bioeconomy. Treesearch, as a knowledge platform, can contribute to information flows and knowledge spill-overs, which, in turn, can strengthen knowledge development and diffusion. Additionally, companies outside BioInnovation can benefit by recruiting people who have been trained by the programme.

Given the lack of information regarding positive externalities, it is hard to assess which technology is benefiting from which externality and why, or which self-reinforcing mechanisms are supporting or hindering different technologies. Considering the example above, actors that can potentially contribute from externalities include SMEs and other firms that hire people who have been trained in the bioeconomy.

### 5.4.8 Actor networks

In terms of actor networks, BioInnovation shows mixed results. On the one hand, the programme has been engaged in trying to form new actor networks and has succeeded, at least to a certain extent. The programme has, for example, enabled the formation of various consortiums at the niche level. These consortiums consist of actors from different domains and some also involve powerful actors, e.g., incumbents and the public sector. Some projects have been able to involve the entire value chain and have reported that this has created the basis for further work in the future. This has been the case, for example, in the projects focused on the development of new chemicals and fuels from lignin. In addition, other project participants indicated that they aim to maintain the network, even without further support from the programme, to bring the resulting solutions to the market. Others will continue with support from BioInnovation, e.g., within the 56 completed *hypothesis-testing projects* (see Appendix B), at least 13 projects were approved to continue in a

Step 2. On the other hand, the programme has been less active at the regime level. An exception is the fact that some of the projects have involved actors from other countries than Sweden. For example, some ongoing thematic projects involve partners from Finland.

Some projects have also reported a few factors blocking the formation of actor networks. For example, and as mentioned before, in the Construction and Design sector, the market is still dominated by traditional construction companies at the regime level. Additionally, a project within the Materials sector reported a mismatch between participants with regard to working with innovation in terms of goals and experiences. These factors have been hindering the entrance of niche actors, as reported by some participants. Moreover, other projects, from all involved sectors, have indicated that they were not able to build an actor network involving the entire value chain. Accordingly, this has prevented changes in existing value chains and blocked some projects from reaching their final goals, e.g., reaching the commercialization stage of their solutions. Furthermore, previous research has found that there is a lack of SMEs specialized in experimentation (Grillitsch et al., 2019).

### 5.4.9 Institutions

BioInnovation has been less active in promoting institutional change, apart from a few efforts at the niche level. These include, for example, efforts targeting small institutional reform, such as the development of decision support for the procurement of green construction projects. Additionally, two *activity projects* have resulted in the introduction of common sustainability criteria and LCA methods, as mentioned before. These had the support of the Swedish Standard Institute (SIS) and had their results published in the international Environmental Product Declaration (EPD® System, 2020).

A shortcoming at the niche level has been related to overcoming initial reluctance from some incumbents, which complain about the lack of capacity to work on innovation projects that involve large constellations of actors (Grillitsch et al., 2019). The same authors have also identified that BioInnovation has been facing many challenges related to the development of its niches, including how to promote risk-taking behaviour in incumbents.

At the regime level, little has been done by the programme towards destabilization. This has also been found in previous research from (Coenen et al., 2017; Grillitsch et al., 2019). Most efforts within the programme have been directed at understanding institutional aspects related to the bioeconomy. For example, political requirements for the development of a bioeconomy (BioInnovation, 2015b), or institutional aspects that need to be considered in the textile industry (Trossa, 2020), as discussed before. An exception from the Construction and Design sector would be the development of decision support for the procurement of green construction projects, which can potentially work as a reformed policy targeting public procurement. In the Materials sector, another initiative has targeted the development of general awareness about the possibility of using forest raw materials to manufacture textile products. Project participants have been exploring the emotional connection of their end customers with the Swedish forest and framing the products' quality as similar to other established alternatives.

At both the niche and regime levels, the programme itself and its long-term vision can be contributing to the articulation of visions and expectations among the wide range of participating actors. However, how and whether this has been impacting the overall performance of the system is still unclear.

#### 5.4.10 Summary of findings

Overall, the socio-technical system analysis shows that BioInnovation has been quite active in promoting knowledge development and diffusion, and many projects have also started experimenting with new technologies and processes. Additionally, initiatives such as Treesearch and joint efforts from participants have been supporting the mobilization of resources. The programme has also been influencing the direction of search in various ways. In contrast, other functions, such as market formation, legitimation and development of positive externalities have shown weaker performance. Regarding actor networks, BioInnovation has focused mainly on the niche-level processes, and less so on changing regime-level processes. Nor has much been done towards changing institutional processes, e.g., destabilizing the current regime.

These findings indicate that, on the one hand, the programme has been successful in addressing some of its goals, such as those related to knowledge development and diffusion, influence on the direction of search, and resource mobilization, as well as actor networks. On the other hand, the programme has been less successful in promoting market formation. Nonetheless, the programme has also been contributing to other processes not previously envisaged by programme theory, such as entrepreneurial experimentation.

In sum, four results patterns unfold from the analysis. First, the analysis shows that there is some evidence towards confirming some of the hypothesized CMOc. Second, other hypothesized CMOc were not touched upon in the analysis and no claim towards confirming or refuting them can be made. This can be either because the document analysis provided little information regarding these CMOc or the programme did not implement them so far. Third, the analysis provided further information about some of the CMOc, allowing them to be refined (and even confirmed). Fourth, some additional CMOc that were not considered before can be developed based on the outcomes indicated in the analysis. Below, I further elaborate on these four patterns in order to shed light on what types of changes occurred due to programme intervention and whether the initial goals are being met.

## 5.5 Step 5: Testing and refining CMOc

Before discussing which CMOc hypotheses might have been confirmed, I would like to reiterate that more research is needed in order to increase confidence in the findings from the document analysis. Additionally, given that the purpose here is to illustrate how the framework can be applied and not to perform a full evaluation, I will not discuss all CMOc hypotheses. Instead, I use one or two examples for each pattern identified in the system analysis as follows. In 'Testing CMOc hypotheses', I discuss some of the evidence towards confirming some of the CMOc hypothesized in the programme theory and point out those for which evidence is lacking. In 'Refining CMOc hypotheses', in turn, I refine some of the CMOc according to the findings from the systems analysis. I also propose some new CMOc that emerged from the analysis. Table 20 summarizes the list of CMOs that can (potentially) be confirmed, not confirmed/not mentioned, or need further refinement.

### 5.5.1 Testing CMOc hypotheses

To start with, I discuss some of the CMOc for which evidence was found in the system analysis towards confirmation (see Table 20). Consider the following CMOc related to resource mobilization: *Efforts towards setting up Treesearch platform & Treesearch platform provides infrastructure → Provision of expertise and research collaboration*. The systems analysis (see

Section 5.4.5) showed that Treesearch has been responsible for advancing an open research infrastructure on materials and chemicals, offering access to different specialized laboratories around Sweden, as well as contact with various experts. The online platform nowadays relies on more than 290 researchers and many projects have already been developed, indicating both the provision of expertise and research collaboration. What enabled the mechanism, i.e., the context, was thus the efforts put into setting up the platform, including the staff and financial resources provided by the programme.

Another example related to actor networks is the CMOc *New collaborations formed & New consortiums → Cross-border collaborations*. As presented in Section 5.4.8, BioInnovation has allowed for the formation of various collaborations in the form of consortiums. These consortiums involve actors from different domains and incumbents from different sectors. While the type of cross-border is not specified in the programme theory, these results indicate that the programme has allowed for, at least, cross-sectoral collaboration. Some cross-country collaborations have also been reported, but to a lower extent. In this case, the collaborations stimulated by the programme itself allowed the mechanism to fire, as previously envisaged by the programme's goals.[60]

Many CMOc, however, were not confirmed (see Table 20). One example is the CMOc regarding knowledge development and diffusion: *Cooperation processes & Efforts towards SIP cooperation → Cross-fertilization between areas*. Other hypothesized CMOc were not touched upon in the document analysis, e.g., the CMOc related to actor networks: *Missing & Strengthened and engaged stakeholders → Regional hubs to act as BioInnovation ambassadors*.

[60] How exactly the programme enabled these collaborations is, however, still unclear. This feature of the context can be explained by another CMOc: *Missing & New collaborations → New consortiums*. Nonetheless, this CMOc is one of those whose information about its context is still missing, i.e., under which conditions were such collaborations formed?

Table 20. CMOc assessment according to socio-technical systems analysis.

| Status | Efforts and activities | Context & | Mechanism → | Outcome configuration | Process |
|---|---|---|---|---|---|
| Confirmed, but needs refinement | Hypothesis-testing projects | Missing | Hypothesis-testing | The potential of high-risk projects is utilized<br>What does it mean? | KDD |
| Confirmed, but needs refinement | Activity projects | Missing | Market and behavioural analysis studies | Needs and opportunities for bioeconomy | KDD |
| Not confirmed | Cooperation processes | Efforts towards SIP cooperation<br>What does it encompass? How does it trigger the mechanism? | Cooperation between SIPs (AN)<br>How does it generate the outcome? | Cross-fertilization between areas<br>How? | KDD |
| Not confirmed | Hypothesis-testing projects | Missing | Realize opportunities in confirmed hypothesis<br>What does it mean? How does it generate the outcome? | Technical and commercial innovation | MF |
| Confirmed, but needs refinement | Innovation projects and thematic calls | Missing | Collaboration, knowledge sharing and learning<br>Is it an outcome? | New bio-based materials, chemicals, processes and products come into market use | MF |
| Not confirmed | Hypothesis-testing projects | Confirmed hypothesis | Decision basis for upcoming efforts (IDS) | Radical and innovative solutions | MF |
| Not confirmed | Hypothesis-testing projects | Confirmed hypothesis | Technical and commercial innovation<br>Who does what? | Radical and innovative solutions | MF |
| Not confirmed | Innovation projects and thematic calls | Collaboration, knowledge sharing and learning between project participants | New bio-based materials, chemicals, processes and products come into market use | New markets for bioeconomy | MF |
| Confirmed, but needs refinement | Activity projects | Missing | Market and behavioural analysis studies | Decision basis for upcoming efforts | IDS |
| Confirmed, but needs refinement | Hypothesis-testing projects | Missing | Hypothesis-testing | Decision basis for upcoming efforts | IDS |
| Not confirmed | Programme office | Efforts towards internationalization | Collaborative projects with other countries (AN) | Project continues with EU financing<br>How does the programme influence this? | IDS |
| Not mentioned | Activity projects | Market and behavioural analysis studies | Needs and opportunities for bioeconomy | Successful impact work<br>What does it mean? | IDS |
| Not mentioned | Hypothesis-testing projects | Confirmed hypothesis | The potential of high-risk projects is utilized (KDD) | High-quality influx of visionary ideas<br>What does it mean? | IDS |
| Confirmed, but needs refinement | Cooperation projects | Missing | Set up Treesearch platform | Provision of infrastructure | RM |
| Not confirmed | Cooperation projects | Missing | SIP cooperation<br>How does it generate the outcome? | Financing between SIPs | RM |
| Confirmed, but needs refinement | Enhance knowledge | Missing | Support for SMEs to succeed in bioeconomy | SMEs participate in training courses and support packages | RM |
| Confirmed | Cooperation projects | Efforts towards setting up Treesearch platform | Treesearch platform provides infrastructure | Provision of expertise and research collaboration | RM |
| Confirmed, but needs refinement | Programme office | Missing | Internationalization<br>How is that a mechanism? | Collaborative projects with other countries | AN |
| Confirmed, but needs refinement | Cooperation processes | Missing | New collaborations<br>How does it generate the outcome? | New consortiums | AN |
| Not mentioned | Cooperation processes | Missing | Strengthened and engaged stakeholders | Regional hubs to act as BioInnovation ambassadors<br>What does it mean? | AN |
| Not confirmed | Cooperation projects | Missing | SIP cooperation<br>What does it mean? How does it cause the outcome? | Cooperation between SIP | AN |
| Confirmed | Cooperation processes | New collaborations formed<br>What is the difference between collaborations and consortiums? | New consortiums<br>How does it generate the outcome? | Cross-border collaborations<br>What do they mean by cross-border? | AN |
| Not confirmed | Innovation projects and thematic calls | Funding provided for thematic calls and innovation projects | New bio-based materials, chemicals, processes and products come into market use (MF)<br>How does it generate the outcome? | New value chains for bioeconomy | AN |
| Not mentioned | Activity projects | Studies developed by the BioInnovation programme | Decision basis for upcoming efforts<br>How does it generate the outcome? | System development and advocacy<br>What does it mean? | AN |
| Not confirmed | Cooperation projects | Efforts towards SIP cooperation | Cooperation between SIP | Research collaboration | AN |
| Not mentioned | Cooperation processes | Strengthened and engaged stakeholders | Regional hubs to act as BioInnovation ambassadors<br>What does it mean? How does it generate the outcome? | National platform for bio-based development | AN |
| Not confirmed | Enhance knowledge | Support provided to SMEs to succeed in bioeconomy | SME participates in training courses and support packages (RM) | SME contributes to and benefits from bioeconomy<br>What does it mean? | AN |

Legend: Confirmed, but needs refinement; Confirmed; Not confirmed/not mentioned

### 5.5.2 Refining CMOc hypotheses

Appendix C brings the list of refined CMOc hypotheses for all processes, according to the finding from the systems analysis. While some CMOc still miss information regarding context or mechanism, others were possible to refine. For example, consider the following CMOc related to the influence on the direction of search function: *Missing & Hypothesis testing → Decision basis for upcoming efforts.* The systems analysis (see Section 5.4.4) showed that some of the confirmed hypothesis-testing projects influenced the decision of which project would receive further funding for continuing the project in Step 2. While the context still needs to be confirmed with programme managers, a potential one would be high-risk ideas that would not have been tested without public support. In Section 5.4.5, further evidence shows that some project participants would continue developing their solutions even without BioInnovation support. That said, a possible refinement for such CMOc would be *Funding for R&D of high-risk ideas & Hypothesis-testing → Decision basis for upcoming efforts*. Table 21 shows the refined CMOc related to the direction of search function.

Table 21. List of refined CMOc for influence on the direction of search.

| Status | Efforts and activities | Context & | Mechanism → | Outcome configuration | Process |
|---|---|---|---|---|---|
| Confirmed, but needs refinement | Activity projects | Missing | Market and behavioural analysis studies | Decision basis for upcoming efforts | |
| Confirmed, but needs refinement | Hypothesis-testing projects | Missing | Hypothesis-testing | Decision basis for upcoming efforts | |
| Not confirmed | Programme office | Efforts towards internationalization | Collaborative projects with other countries (AN) | Project continues with EU financing How does the programme influence this? | IDS |
| Not mentioned | Activity projects | Market and behavioural analysis studies | Needs and opportunities for bioeconomy | Successful impact work What does it mean? | |
| Not mentioned | Hypothesis-testing projects | Confirmed hypothesis | The potential of high-risk projects is utilized (KDD) | High-quality influx of visionary ideas What does it mean? | |

↓

| Status | Efforts and activities | Context & | Mechanism → | Outcome configuration | Process |
|---|---|---|---|---|---|
| Confirmed/refined | Activity projects | Knowledge gap | Market and behavioural analysis studies | Decision basis for upcoming efforts | |
| Confirmed/refined | Hypothesis-testing projects | Funding for R&D of high-risk ideas | Hypothesis-testing | Decision basis for upcoming efforts | |
| Not confirmed | Programme office | Efforts towards internationalization | Collaborative projects with other countries (AN) | Project continues with EU financing How does the programme influence this? | |
| Not mentioned | Activity projects | Market and behavioural analysis studies | Needs and opportunities for bioeconomy | Successful impact work What does it mean? | IDS |
| Not mentioned | Hypothesis-testing projects | Confirmed hypothesis | The potential of high-risk projects is utilized (KDD) | High-quality influx of visionary ideas What does it mean? | |
| New | Hypothesis-testing, thematic calls and innovation projects | Missing | Increasing demand for bio-based products | Influence the direction of projects within BioInnovation | |
| New | Hypothesis-testing, thematic calls and innovation projects | Landscape pressures | Regulatory pressures (LEG) | Influence on the direction of projects within BioInnovation | |

Legend: Confirmed, but needs refinement/refined; Confirmed; Not confirmed/not mentioned; New

Another example of refined CMOc is related to resource mobilization function, as illustrated in Table 22. Consider the CMOc *Missing & Set up Treesearch platform → Provision of infrastructure*. The system analysis showed that the reason why Treesearch was set up was due to a lack of capacity within companies to work with bio-based solutions (see Section 5.4.5). Therefore, a possible refinement for this CMOc would be *Lack of capacity in bio-based and recycled materials & Set up Treesearch platform → Provision of infrastructure*

Table 22. List of refined CMOc for resource mobilization.

| Status | Efforts and activities | Context & | Mechanism → | Outcome configuration | Process |
|---|---|---|---|---|---|
| Confirmed, but needs refinement | Cooperation projects | Missing | Set up Treesearch platform | Provision of infrastructure | RM |
| Not confirmed | Cooperation projects | Missing | SIP cooperation<br>How does it generate the outcome? | Financing between SIPs | |
| Confirmed, but needs refinement | Enhance knowledge | Missing | Support for SMEs to succeed in bioeconomy | SMEs participate in training courses and support packages | |
| Confirmed | Cooperation projects | Efforts towards setting up Treesearch platform | Treesearch platform provides infrastructure | Provision of expertise and research collaboration | |

| Status | Efforts and activities | Context & | Mechanism → | Outcome configuration | Process |
|---|---|---|---|---|---|
| Confirmed/refined | Cooperation projects | Lack of capacity in bio-based and recycled materials | Set up Treesearch platform | Provision of infrastructure | RM |
| Not confirmed | Cooperation projects | Missing | SIP cooperation<br>How does it generate the outcome? | Financing between SIPs | |
| Confirmed/refined | Enhance knowledge | Lack of capacity in bio-based and recycled materials | Support for SMEs to succeed in bioeconomy | SMEs participate in training courses and support packages | |
| Confirmed | Cooperation projects | Efforts towards setting up Treesearch platform | Treesearch platform provides infrastructure | Provision of expertise and research collaboration | |
| New | Enhance knowledge and cooperation projects | Lack of capacity in bio-based and recycled materials | Support for doctoral and postdoctoral projects | Provision of human resources | |
| New | Cooperation projects | Lack of capacity in bio-based and recycled materials | Knowledge development on new technologies (KDD) | Provision of human resources | |
| New | Hypothesis-testing, thematic calls and innovation projects | Project calls | Collaboration between project participants (AN) | Mobilization of complementary assets | |

Legend: Confirmed, but needs refinement/refined; Confirmed; Not confirmed/not mentioned; New

The systems analysis also sheds light on new outcomes emerging within the programme. Taking again the example of the influence of the direction of search function, the analysis showed that regulatory pressures have been influencing the direction of some projects within BioInnovation, in all three focus areas (see Section 5.4.4). These regulatory pressures emerge mainly in response to pressures at the landscape level, where the emerging concern for climate change has been influencing the development of regulations tackling, e.g., GHG emissions and plastic use, at both the Swedish and European levels. Thus, the following new CMOc can be hypothesized: *Landscape pressures & Regulatory pressures → Influence on the direction of projects within BioInnovation* (see Table 21).

Another example related to resource mobilization is the fact that the programme has been allowing for the mobilization of complementary assets within hypothesis-testing, thematic-call, and innovation projects. As discussed in Section 5.4.5, project participants have been sharing different assets in order to develop the projects. In this case, the factor triggering such sharing would be the project calls themselves. Thus, the following new CMOc can be hypothesized: *Project calls & Collaboration between project participants → Mobilization of complementary assets* (see Table 22).

### 5.5.3 Summary of findings

In sum, the CMOc testing showed that only a few hypotheses could be tested and confirmed. Others were confirmed, but information related, for example, to the context in which the mechanism was triggered to cause the outcome, was unclear. This can indicate that the programme is achieving some of its intended goals. However, this also confirms that programme theory is limited and a large portion of the CMOc that were confirmed needed further refinement. Some additional outcomes could also be identified from the systems analysis, including both inducing and blocking mechanisms (see Appendix C for an overview).

## 5.6 Step 6: Assessing transition pathways

Overall, it is still difficult to say whether a transition is underway, as the evidence about the effects of BioInnovation in the system is still limited. This could, however, be due to the fact that the programme started in 2015 and it is too early to see all the impacts it is having in the long term. Nonetheless, by using the transition pathways analytical categories (see Section 3.2.1.1) and based on the systems analysis, some conclusions can be drawn that can shed light on some of the transitions patterns that might be emerging at the system level due to the programme.

First, in terms of actors and social groups, the analysis shows that many incumbents have been participating, together with other companies, in the consortiums formed to realize all kinds of projects. New entrants, however, are quite rare. Additionally, previous research has found that there is a shortage of SMEs specialized in the bioeconomy, which prevented SME growth (Coenen et al., 2017). Therefore, while one could argue that established actors could be re-orienting themselves (reconfiguration), little is known about whether the programme has generated any effect on the behaviour of incumbents. As such, it might be that actors are just reproducing rule structures to conform with new institutions that are emerging (reproduction), e.g., the Green New Deal and the Swedish goal to reduce GHGs emissions from petrol and diesel by 40% by 2030.

Accordingly, little has been done towards regime destabilization and the programme, overall, is pursuing to conform with current regulations rather than changing them. This could indicate, thus that the current infrastructure is reproduced (reproduction) or that there are limited institutional change (layering, as in the reconfiguration pathway). Regarding technologies and socio-technical system, the analysis shows a weak performance of market formation, as new solutions have rarely been introduced in the market. As such, niche innovations are still not well-developed, as many of the developed solutions are still in a research and development phase or have just started the experimentation or demonstration phase. Therefore, it is difficult to know how the solutions being developed within BioInnovation will impact the socio-technical system. Nonetheless, the analysis shows that many solutions are being developed to either replace non-sustainable components in existing technologies, e.g., odourless lignin has many applications as a raw material in various thermoplastics, or take over established ones, e.g., cellulose-based cultivation cloths can replace plastic cloths in agriculture. This can indicate that these technologies are either combined with existing technologies or that they can, potentially, replace established ones (reconfiguration).

Finally, in terms of multi-level interactions, landscape pressures are existent in the form of the climate change debate and Agenda 2030 that have influenced the development of the strategic agendas that resulted in BioInnovation and, hence, orient the different projects within the programme. As discussed above, it seems that both incumbents and new entrants are combining efforts towards the development of new technologies, but little can be said about the adoption of niche innovations, as these are still not well-developed. Adding to the limited institutional change (layering), these patterns could indicate a trend towards reconfiguration.

Table 23 indicates the insights the analysis provided in terms of transition pathways. The areas shaded in yellow are the characteristics found as described above. Overall, BioInnovation shows characteristics that can be linked to reproduction or reconfiguration. While one could question whether the programme is transformative, as the evidence towards a transition pathway unfolding is very limited, it might be too soon to come to conclusions. However, if the programme was considering the substitution and the development of radical innovation in the beginning, as described in Step 1, there is no evidence so far that this is happening. On the one hand, more research is needed in order to understand the impact the programme is having in the socio-technical system – for example, Turnheim et al. (2015) suggest initiative-based learning and quantitative systems modelling. On the other hand, this could also be indicating a potential need to review the intervention.

Table 23. Patterns identified within BioInnovation in relation to transition pathways.

| **Transition pathway** | **Multi-level interactions** | **Actors and social groups** | **Technologies and socio-technical system** | **Rules and institutions** |
|---|---|---|---|---|
| Reproduction | No external landscape pressure | Actors reproduce rule structures through their actions | Emerging technologies have little chance to break through | Institutional infrastructure is reproduced |
| Transformation | Outsiders criticize the regime and incumbent actors adjust regime rules | Established actors re-orient themselves | Established & emerging technologies co-exist *or* Emerging technology outcompetes established | Limited change (layering) or substantial change (conversion /displacement) |
| De-alignment and re-alignment | Changes in deep structures create strong pressure on regime; incumbents lose faith and legitimacy | New actors enter after established actors exit | Competing emerging technologies replace established | Institutions are disrupted by shocks (disruption) |
| Substitution | Newcomers develop novelties, which compete with regime technologies | New entrants outcompete established actors | Emerging technologies outcompete established | Limited change (layering) or creation of new institutions (disruption /displacement) |
| Reconfiguration | Regime actors adopt component innovations, developed by new suppliers | Established actors & new entrants form alliances | Established & emerging technologies are combined | From limited change (layering) to more substantial change (drift/conversion) |

## 5.7 Step 7: Revisiting programme theory

Developing a new ToC model based on findings from the systems analysis and refined CMOc goes beyond the scope of this licentiate thesis due to the complexities it involves. Such efforts would involve tools that are able to indicate the feedback loops that come into play. As such, a simple pipeline model would not capture all these interactions. A potential approach, thus, could be the development of a system dynamics model. As suggested by Funnell and Rogers (2011), by using system dynamics diagrams, it is possible to account for interactions and effects that might be amplified or weakened over time. Additionally, previous research showed the possibility to use such models to integrate ‘motors of innovation’ and transition pathways (cf. Walrave and Raven, 2016). Others have also explored the use of system dynamics models in socio-technical transitions research (Papachristos, 2011; Papachristos, 2019). Moreover, it would be interesting to talk to programme managers and have more data on how the programme was designed and implemented before starting to develop such complex programmes.

# 6 Concluding discussions

This licentiate thesis is part of a research project funded by Vinnova that has the general purpose of studying how transformative innovation policy can be assessed and evaluated. The first step towards addressing this purpose was the development of a literature review on transformative innovation policy. Such a review was aimed at understanding the unique characteristics of this emerging approach to innovation policy, and the main challenges associated with its policymaking process, including with policy evaluation. As a result, this study served as a basis for the definition of the research gaps which this thesis aimed to address: (i) the disconnection between innovation policy and policy evaluation literatures; (ii) the need to consider a broader notion of behavioural additionality which goes beyond the change in actors and firm behaviour to also include system-level effects; and (iii) how to capture directionality.

In order to address these gaps, I developed an integrated transformative innovation policy evaluation framework, in collaboration with Anna Bergek. A first attempt towards applying the integrated framework was by studying the BioInnovation Strategic Innovation Programme (SIP) in Sweden. Below, I highlight the main findings of such efforts, as well as the contributions reached by this licentiate thesis. Additionally, I point out some of the limitations encountered while developing the framework and applying it to an empirical case. Finally, I provide some suggestions for further research.

## 6.1 Results

The decision to move towards developing an integrated framework was made due to the fact that it attempts to bring together the policy evaluation literature with that of transformative innovation policy, which links to the first aforementioned research gap. As such, it draws on theory-based evaluation and transformative innovation policy. More specifically, in relation to the former, it builds on theories of change (ToC) and realist evaluation, two of the most known and applied theory-based approaches in the literature. Moreover, regarding the latter, it combines insights from the literature on innovation system functions and socio-technical transitions (MLP and SNM).

The resulting integrated evaluation framework is composed of three main components, which form the building blocks to develop a theory-based evaluation of transformative innovation policy. The first component addresses a need for a more structured programme theory which, in practice, has been shown to represent the accountability needs of politicians instead of focusing on a holistic and systemic view of policy evaluation (cf. Molas-Gallart and Davies, 2006). As such, the programme theory is developed based on a transformative perspective that allows, later, for the assessment of intermediate innovation- and transition-related processes and that enables the connection of change processes to different transition pathways.

The second component comprises a socio-technical system analysis, which involves analysing a set of innovation system functions that consider directionality, as well as actor networks and institutional change processes. Together, these components allow for the assessment of behavioural additionality in terms of how a policy intervention contributed to the functionality of the innovation system as well as to actor network development and institutional change. By following the notion of generative causality, I argue that additionality can be assessed by understanding the role of causal mechanisms and the contexts within which they operate to generate outcomes in TIP interventions. In order to do this, the evaluator should pursue a mixed-methods approach, which can pave the way for triangulation and increase the validity of the findings. This second component, thus, addresses the second research gap indicated in this licentiate thesis, while also providing a way to assess directionality, which relates to the third and final gap.

The third component consists of a set of transition pathways characteristics (Geels et al., 2016; Geels and Schot, 2007) and a review of the original programme theory. The former includes assessing different types of changes in technologies, actors and actor groups, and institutions, and can inform about the direction in which the transition is currently unfolding. This step provides a second way to assess directionality and, as such, also relates to the third research gap. The latter proposes a review of the original programme theory in order to allow for re-evaluation and adaptation of goals, strategies, and policy instruments and, hence, formative evaluation.

The first attempt towards applying the integrated framework shows promising results (and indicates some challenges that the evaluator should consider, which will be discussed in Section

6.3). In relation to the first component, Step 1, the application showed that the BioInnovation programme has a clear vision that Sweden will have transformed into a bioeconomy by 2050, which involves the increased use of bio-based raw materials, as well more resource-efficient processes. While not having a clear focal socio-technical system nor a defined and explicit targeted transition pathway, the programme points out three focus areas: Chemicals and Energy, Construction and Design, and Materials. Additionally, in Step 2, the analysis showed that the programme's effect logic, as designed by programme managers, presents many limitations. This also made it difficult to specify theories of change and, consequently, define the Context-Mechanism-Outcome configurations in Step 3.

Regarding the second component, Step 4 showed that BioInnovation has been quite active in promoting knowledge development and diffusion. However, functions such as market formation, legitimation and development of positive externalities have shown weaker performance. In relation to actor networks, the analysis showed that BioInnovation has focused mainly on the niche-level processes, and less so on changing regime-level processes. In Step 5, I highlighted some of the evidence that was confirming some the hypothesized CMOc.

As to the third component, Step 6 indicated that it is still too soon to know whether a transition towards a bioeconomy by 2050 is possible due to the programme. Step 7 remains to be further developed due to the complexities it involves.

## 6.2 Contributions

The integrated framework brings both conceptual and methodological contributions. Conceptually, the integrated framework contributes to widening the TIS functions framework to include actor networks and institutional change processes that were not captured previously, while also accounting for overlaps. This adds to the understanding of what kind of transformative outcomes the evaluator can look for when assessing the impact of a policy intervention. Methodologically, the framework reflects how evaluations of innovation policy programmes targeting transitions can be enhanced with the use of theory-based evaluation. In other words, while theory-based evaluation provides a key to understanding complex processes between policy design and implementation and policy outcomes, while examining causal mechanisms and contextual factors, the combination of perspectives on socio-technical systems provides the basis for identifying transformative outcomes that can potentially unleash a transition. Such an approach can also provide a way to assess behavioural additionality and directionality, which are rarely addressed in current innovation policy evaluations.

Empirically, I provide a first attempt to apply the framework, using the BioInnovation SIP example, whose vision is that Sweden will have transitioned to a bioeconomy by 2050. Preliminary results show that the integrated framework has good potential to improve the evaluation of programmes targeting system innovation. More research, however, is needed in order to assess the full applicability of the framework.

## 6.3 Limitations

Admittedly, this licentiate thesis does not come without its limitations. First, in relation to the development of the integrated framework, the research followed a more deductive approach to theory and, hence, the practical side of the policymaking process related to evaluation still needs to be reflected upon. Therefore, future adjustments might be needed according to findings from the empirical application and feedback from policymakers.

Second, regarding the application of the framework, this licentiate thesis includes a first attempt towards accomplishing this. As such, it does not include a full evaluation of the programme. Preliminary findings bring interesting insights about the performance of the programme, but it still does not reflect the whole potential and complexity of the integrated framework for evaluation. Additionally, this is the first time I am using such approach and, therefore, I am just getting acquainted with the realist evaluation literature. The definition of CMOc is quite challenging and requires experience and creativity from the evaluator. Only practice can develop such skills in the evaluator. The challenges associated with developing CMOc also comprise one of the main weaknesses of the realist evaluation. As discussed in Section 3.1.3.1, such a process is quite time- and resource-demanding, and scholars have reported that it is difficult to identify and conceptualize both CMOc and meaningful theories of how programme works (Blamey and Mackenzie, 2007; Rolfe, 2019). That said, the application also represents a learning process for me as both a researcher and evaluator.

Another limitation related to the application of framework is the definition of the focal socio-technical system and delineation. In the BioInnovation case, the broad scope of the programme made it difficult to get a full picture of all sectors involved (and industries), as well as to define actor networks and institutional aspects influencing the socio-technical system. While this might reflect the nature of 'grand challenges', it can also make it difficult to design and formulate a policy intervention targeting such a broadened scope.

Finally, with respect to data collection, the empirical application relies mainly on secondary document analysis, which provides limited insights about the transformative processes being analysed, and additional data sources are thus needed. Moreover, theory-based evaluation suggests the use of different methods for analysis, which was not possible to develop at this stage. This also limited the possibility of capturing behavioural additionality and directionality, particularly regarding the analysis of transition pathways. Additionally, basing the analysis on documents makes it difficult to capture further unintended consequences and negative externalities, which is at the core of transformative innovation policy.

## 6.4 Suggestions for further research

Some interesting aspects remain to be discussed and are thus opportunities for further research. First, as previously mentioned, the views of policy practitioners on the integrated framework remains to be addressed. Insights from the practical side can not only improve the framework but also generate learning for both sides (researcher and practitioners).

Second, in relation to the application of the framework, one empirical case is still quite limited to test the full capacity of the integrated framework for evaluating transformative innovation policy. Future empirical applications can, potentially, be considered in order to test it further. This could include, for example, other SIPs or even other programmes outside Sweden in order to compare different empirical contexts and cases. Additionally, it might be interesting to dig deeper into the mission-oriented literature in order to check if it can provide a better way to delineate the system and, hence, programme theory. For example, some authors have highlighted that the mission-oriented innovation policy can potentially help policymakers with the design and formulation of a policy intervention when it comes to specifying the 'mission' and dealing with 'grand challenges' (cf. Amanatidou et al., 2014; Hekkert et al., 2020; Mazzucato, 2018). Whilst such literature has not been the focus of this licentiate thesis, it can (potentially) bring insights concerning how to better delineate the system and define programme theory.

Third, the limitations surrounding data source and methods used to analyse the empirical case need to be improved. Different types of data sources can be explored, e.g., interviews, workshops, focus groups and surveys. It might be interesting to see how these additional sources can improve the evaluation of the BioInnovation SIP empirical application. Additionally, both quantitative and qualitative methods can be tested in order to increase the validity of the evidence found in relation to the programme evaluation. Different methods have been explored in the evaluation literature and can potentially be explored in relation to the integrated framework. For example, Funnell and Rogers (2011) suggest using system dynamics for illustrating programme theory; De Oliveira et al. (2020) and de Oliveira and Negro (2019) recommend process tracing for identifying causal mechanisms and event history analysis for mapping contextual factors for systems analysis. Additionally, econometrics can still be useful for analysing input–output additionality, if that becomes relevant for programme managers, e.g., to assess whether funding generated more R&D investments at the firm level additional to programme funding.

Finally, the discussions surrounding the counterfactual in the context of transformative innovation policy need to be explored further. While some scholars have pointed out that there is a lack of a clear counterfactual regarding transformative policy (cf. Janssen, 2019; Magro and Wilson, 2019), there is a possibility to use additionality as a way to construct the counterfactual, based on a generative view of causality. This view allows the exploration, in context, of the patterns between interventions and outcomes, and has already been applied in past innovation programmes (cf. Hind, 2010). The first attempt to apply the framework has not been able to explore the generative causality concept in depth yet, as findings have been quite limited and have not provided enough answers regarding what is working for whom under which circumstances. The application of such a framework in the context of transformative innovation policy has therefore not yet been fully explored. As such, questions such as how to approach this and how to establish causal links between policy intervention and outcomes/impacts in this context remain to be addressed. Furthermore, this approach would require a complete analysis of the entire system, but can evaluators be expected to do that within their usually limited timeframe and budget?

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# Appendix A: Niche- and regime-level processes from the reviewed literature and their relationships with TIS functions

**Table A1.** Niche-level processes.

| Configuration element | Niche protection mechanism | Operationalization/indicators or examples from empirical studies | Related function(s)[a] |
|---|---|---|---|
| Socio-technical system | Shielding | Dedicated (technology-/niche-specific) RD&D support (Kern, 2012; Raven et al., 2016; Smith and Raven, 2012) | ▪ Resource mobilization<br>▪ Entrepreneurial experimentation |
| | | Implementation of technology-specific investment subsidies, public procurement, and other niche-market protection measures (Kern, 2012; Raven et al., 2016; Smith and Raven, 2012) | ▪ Market formation |
| | | Exploitation of ‘real’ niche markets, e.g., segments willing to pay higher prices or accept lower performance or places outside the reach of existing infrastructures (Raven et al., 2016; Smith and Raven, 2012; Verhees et al., 2013) | ▪ Market formation |
| | Nurturing | (Support to) Research, development, prototyping, piloting, and demonstration of niche innovations (e.g., RD&D funding, direct co-investment, technology acceleration projects) (Kern, 2012; Verhees et al., 2013) | ▪ Knowledge development and diffusion<br>▪ Entrepreneurial experimentation<br>▪ Resource mobilization |
| | | Exchange and interpretation of specific lessons and experiences between niches (at the level of the ‘global’ niche) (Smith and Raven, 2012) | ▪ Knowledge development and diffusion |
| | | Standardization (to ensure interoperability) (Bugge et al., 2017; Verhees et al., 2013) | → *Legitimation* |
| | Empowering | Infrastructural changes (Bugge et al., 2017; Raven et al., 2016) | ▪ Resource mobilization |
| | | R&D and public support targeting or achieving price-performance improvements of niche innovations in terms of quality, functionality, production cost, etc. (Kern, 2012; Raven et al., 2016; Verhees et al., 2013) | ▪ Resource mobilization |
| Actor network | Shielding | Establishment of private technology-specific incubator units/programmes (Raven et al., 2016; Smith and Raven, 2012) | → *Entrepreneurial experimentation* |
| | | Establishment of collective buying cooperatives (Raven et al., 2016) | → *Market formation* |
| | | Support to help companies identify and exploit market opportunities (Kern, 2012) | → *Market formation* |

| Configuration element | Niche protection mechanism | Operationalization/indicators or examples from empirical studies | Related function(s)[a] |
|---|---|---|---|
| | | Involvement of strong actors (that guarantee support) (Bugge et al., 2017) | → *Legitimation* |
| | Nurturing | Formation (and maintenance) of broad networks, i.e., networks consisting of actors from different domains (Naber et al., 2017; Verhees et al., 2013) | → *Knowledge diffusion*<br>→ *Guidance of the direction of search* |
| | | Formation (and maintenance) of deep networks, i.e., networks consisting of high resource commitment from network members (Naber et al., 2017; Verhees et al., 2013) | → *Resource mobilization*<br>→ *Guidance of the direction of search* |
| | | Development of 'global' networks (that support exchange and interpretation of specific lessons and experiences between niches) (Smith and Raven, 2012) | → *Knowledge development and diffusion* |
| | | Entry of powerful actors (incl. policy) into the support network of the niche (Kern, 2012) | → *Guidance of the direction of search* |
| | | Business support to (new) companies (Kern, 2012) | |
| | | Fostering of wider societal engagement of, e.g., NGOs or academics (Kern, 2012) | → *Legitimation* |
| | Empowering | Involvement of government bodies (to allow for upscaling) (Bugge et al., 2017) | |
| | | Development of political capacity to avoid protective space becoming captured by vested interests and to ensure protection stimulates the dynamic accumulation of innovative capabilities (Smith and Raven, 2012) | → *Legitimation* |
| | | Formation of networks of (industrial, administrative and grassroots) advocates accumulating resources and political power (Smith and Raven, 2012) | → *Resource mobilization*<br>→ *Legitimation* |
| | | Creating capabilities and attracting resources that empower participation in political debates (Smith and Raven, 2012) | ▪ Resource mobilization |
| Institutions | Shielding | Re-framing the technology to fit contemporary political objectives or values of specific stakeholder groups (Smith and Raven, 2012) | ▪ Legitimation |
| | | Identification of technology-specific investment subsidies, public procurement, and other niche-market protection measures (Kern, 2012; Raven et al., 2016; Smith and Raven, 2012) | |
| | | (Arguing for) Temporal exemptions from existing rules and standards (Smith and Raven, 2012; Verhees et al., 2013) | ▪ Legitimation |

| Configuration element | Niche protection mechanism | Operationalization/indicators or examples from empirical studies | Related function(s)[a] |
| --- | --- | --- | --- |
| | | Enacting new media discourses linking technologies with high-tech values in society (Smith and Raven, 2012) | → *Legitimation* |
| | | Lobbying to achieve explicit political support (Smith and Raven, 2012) | ▪ Legitimation |
| | Nurturing | Questioning assumptions about problem definitions, function, or desirability of the technology (Kern, 2012; Naber et al., 2017; Verhees et al., 2013) | → *Guidance of the direction of search*<br>→ *Legitimation* |
| | | Standardization (to ensure interoperability) (Bugge et al., 2017; Verhees et al., 2013) | → *Legitimation* |
| | | Overcoming initial reluctance (Bugge et al., 2017) | ▪ Legitimation |
| | | Overcoming different organizational practices (Bugge et al., 2017) | ▪ Legitimation |
| | | Articulation of clear, specific, and shared expectations and visions between members (Naber et al., 2017; Verhees et al., 2013) | → *Legitimation*<br>→ *Guidance of the direction of search* |
| | Empowering | R&D and public support targeting or achieving price-performance improvements of niche innovations in terms of quality, functionality, production cost, etc. (Kern, 2012; Raven et al., 2016; Verhees et al., 2013) | ▪ Resource mobilization<br>▪ Knowledge development<br>▪ Entrepreneurial experimentation |
| | | Development of institutional reforms that transform incumbent regimes (Smith and Raven, 2012) | |
| | | Articulation of narratives in flexible ways (to attract powerful actors) (Raven et al., 2016) | → *Legitimation*<br>→ *Guidance of the direction of search* |
| | | Framing shielding and nurturing as temporary and promoting that innovation will be competitive under conventional criteria (Verhees et al., 2013) | ▪ Legitimation |
| | | Policies (environmental regulations, fiscal measures, quotas, etc.) that incentivize (regime) actors to invest in niche solutions (Smith and Raven, 2012) | ▪ Guidance of the direction of search |
| | | Arguing for and achieving public or private institutional reform (e.g., changing regulatory frameworks) or creating new (technology-specific) institutions (Kern, 2012; Raven et al., 2016; Smith and Raven, 2012; Verhees et al., 2013) | |

[a] '→ *Function*' means that the process in question might eventually contribute to the function in question but has no immediate influence on it.

**Table A2.** Regime destabilization processes.

| Configuration element | Type of change | Operationalization/indicators or examples from empirical study | Related function(s)[a] |
|---|---|---|---|
| Socio-technical system | Changes in technical systems | Changes in existing production plants and infrastructure (Kern, 2012) | ▪ Resource mobilization |
| | | Investments in new complementary infrastructure (Ghosh and Schot, 2019) | ▪ Resource mobilization |
| | Reduced resource flows to established technologies | Declining markets (export and domestic) (Turnheim and Geels, 2012, 2013) | ▪ Market formation |
| | | Shifts in investment patterns (Turnheim and Geels, 2012, 2013) | ▪ Guidance of the direction of search<br>▪ Market formation |
| | Improvements to established technologies | (Incremental) product and process innovation (Turnheim and Geels, 2012, 2013) | *Innovation output* |
| | | Efficiency improvements and modernization of existing technologies and plants (Turnheim and Geels, 2012, 2013) | *Innovation output* |
| | | Public investment support or loans for efficiency improvements (Kern, 2012) | ▪ Resource mobilization |
| | Strategic reorientation of incumbent actors with regard to technology | Build-up of new technical knowledge, competences and operations (Turnheim and Geels, 2013) | ▪ Knowledge development<br>▪ Resource mobilization |
| | | Replacement of existing skills and knowledge (Kivimaa and Kern, 2016) | ▪ Knowledge development<br>▪ Resource mobilization |
| | | Experimentation with new technologies (Kivimaa et al., 2017; Lazarevic et al., 2020) | ▪ Entrepreneurial experimentation |
| | | Diversification to new product markets (Turnheim and Geels, 2013) | ▪ Guidance of the direction of search |
| Actor networks | Entry of new actors into mainstream market | Entry of niche actors (Ghosh and Schot, 2019; Kern, 2012; Turnheim and Geels, 2013) | |

| Configuration element | Type of change | Operationalization/indicators or examples from empirical study | Related function(s)[a] |
|---|---|---|---|
| | | Entry of actors from other industries and countries (Turnheim and Geels, 2013) | |
| | | Replacement of incumbents by new actors (Kivimaa and Kern, 2016) | |
| | Development of new business networks | New partnerships to enable business model innovation (Turnheim and Geels, 2013) | |
| | | Emergence of new customer groups/segments (Ghosh and Schot, 2019) | ▪ Market formation |
| | Reconfiguration of policy networks | Balancing the power of incumbents, e.g., by inviting niche actors to advisory councils, etc. (Kivimaa and Kern, 2016; Lazarevic et al., 2020) | |
| | | Breaking-up of existing policy networks (Kivimaa and Kern, 2016; Lazarevic et al., 2020) | |
| | Emergence of change advocacy (within the regime) | Development of new fora/organizations to support policy change (Kivimaa and Kern, 2016; Lazarevic et al., 2020) | → *Legitimation* |
| | | Emergence/creation of change advocates in established (policy) organizations (Lazarevic et al., 2020) | → *Legitimation* |
| Institutions | Introduction of new regulations that weaken the established socio-technical configuration | Restructuring of markets (e.g., liberalization or regulation) (Ghosh and Schot, 2019; Kivimaa and Kern, 2016; Lazarevic et al., 2020; Turnheim and Geels, 2012) | → *Market formation* |
| | | Implementation of control policies (e.g., taxes, import restrictions, emissions regulations, bans, or plans for phase-out of specific technologies) (Ghosh and Schot, 2019; Kivimaa and Kern, 2016; Lazarevic et al., 2020; Turnheim and Geels, 2012, 2013) | → *Market formation* |
| | Withdrawal of political support to established technologies and actors | Removal of subsidies, cuts in R&D funding or changes in tax laws (Kivimaa and Kern, 2016; Lazarevic et al., 2020; Turnheim and Geels, 2012). | → *Market formation*<br>→ *Resource mobilization* |
| | | Reduction or removal of protective measures (Turnheim and Geels, 2012) | → *Market formation* |
| | Changes in existing regulations and standards | Changes in regulations that favour established technologies or hinder new ones (e.g., building codes or siting rules) (Kern, 2012; Lazarevic et al., 2020) | → *Market formation* |
| | | Attempts to influence policy development and change (Kern, 2012) | → *Legitimation* |

| Configuration element | Type of change | Operationalization/indicators or examples from empirical study | Related function(s)[a] |
|---|---|---|---|
| | | Development of new (de facto) standards and technology specifications (Ghosh and Schot, 2019; Kern, 2012) | ▪ Legitimation |
| | Changes in belief systems, societal norms, and culture | Raised public awareness of the need for change (Kern, 2012; Turnheim and Geels, 2013) | → *Legitimation* |
| | | Changes in user preferences (and buying patterns) (Ghosh and Schot, 2019; Turnheim and Geels, 2012, 2013) | ▪ Market formation |
| | | Lobbying, framing or public contestation against the regime (Turnheim and Geels, 2012, 2013) | ▪ Legitimation |
| | | Broad cultural changes or changes in underlying values that challenge the regime (Ghosh and Schot, 2019; Turnheim and Geels, 2012) | → *Legitimation* |
| | Changes in cognitive rules | Articulation of new visions and expectations about the future (Ghosh and Schot, 2019; Kern, 2012) | → *Legitimation* |
| | | Changes in problem agendas (Kern, 2012) | ▪ Guidance of the direction of search |
| | | Changes in perceptions about stakeholders and relevant performance criteria (Ghosh and Schot, 2019) | ▪ Guidance of the direction of search<br>▪ Market formation |
| | | Changes in industry mission, identity and confidence (Turnheim and Geels, 2013) | → *Guidance of the direction of search* |
| | | Changes in organizational practices (Lazarevic et al., 2020; Turnheim and Geels, 2013) | → *Guidance of the direction of search* |

[a] '→ *Function*' means that the process in question might eventually contribute to the function in question but has no immediate influence on it.

# Appendix B: List of projects

## Hypothesis-testing

| Hypothesis-testing projects* | Description | Sector | Period | Hypothesis confirmed? |
|---|---|---|---|---|
| Environmentally friendly and sustainable impregnation of wood with bio-based oil | The project aimed to pave the way for providing industrial players with an environmentally friendly and bio-based alternative to today's toxic and fossil-based wood preservatives. | Chemicals & Energy | 2019-2020 | Yes |
| Improving the efficiency of silicon-based solar cells by applying bio-based material from algae | The hypothesis tested in this project is whether it would be possible to convert more of the energy of light into electrical energy with the help of bio-based material from algae, so-called frustrations. | Chemicals & Energy | 2019 | Partially (further optimization required) |
| Pure biogas with infrasound in one step | The hypothesis for the project was that gasification of biofuel with infrasound eliminates tar and soot formation in the process, which means that a pure biogas could be produced in one step at a low cost. | Chemicals & Energy | 2019 | Partially (more tests are needed) |
| Processing of biochar in urban contaminated land | The aim of the project was to test two different biocarbon compositions by measuring their capacity to absorb polycyclic aromatic hydrocarbons (PAHs) and heavy metals. | Chemicals & Energy | 2018-2019 | Partially |
| Bio-based adhesives from bark for the manufacture of wood panels (viBRANt) | The project tested the conditions for developing a bio-based adhesive that can be used in the production of plywood. | Chemicals & Energy | 2018-2019 | Yes |
| Duck food – a water-based biomass with potential | The project investigated the potential of the plant duckweed as an environmentally and cost-sustainable biomass to produce surfactants. | Chemicals & Energy | 2018-2019 | Yes |
| Renewable base oil from bio-based raw materials | The project aimed to investigate the possibility of producing a bio-based base oil by using an existing residual stream from the paper and pulp industry. | Chemicals & Energy | 2018-2019 | Yes |
| Production and texturing process for protein-rich foods from forest industry residues | This project has evaluated and demonstrated how a new protein-rich food can be produced from fungal biomass grown on residual material from a Swedish pulp mill. | Chemicals & Energy | Unknown | Unknown |
| Production and texturing process for protein-rich foods from forest industry residues – Step 2 | The goal of the project was to produce a protein-rich food based on fungal biomass, based on previous results. | Chemicals & Energy | 2018-2020 | Partially (further research is needed) |
| Renol – The link between the forest and plastics industry | By transforming lignin, the pulp industry is linked to the plastics and chemicals industry in a value chain that aims to pick out the lignin that arises after the forest industry's pulp boil and hydrophobized this polymer into a bioplastic. | Chemicals & Energy | 2017-2018 | Yes |
| Lignin-based components in Li-ion batteries the way to green batteries? | New uses for a partially underutilized raw material. Here, lignin is tested in carbon fibre composites and Li-ion batteries. | Chemicals & Energy | 2015 | Yes |
| Swedish-made protein-rich food from forest industry residual streams | This project has evaluated and demonstrated how a new protein-rich food can be produced from fungal biomass grown on residual material from a Swedish pulp mill. | Chemicals & Energy | 2015-2016 | Yes |
| Extraction of oleosin from rapeseed meal residue; a new ingredient that | This project has investigated the possibility of extracting surfactant proteins (oleosin) from rapeseed oil residues from cold-pressed rapeseed oil. | Chemicals & Energy | 2015-2016 | Yes |

| Hypothesis-testing projects* | Description | Sector | Period | Hypothesis confirmed? |
|---|---|---|---|---|
| prevents fat oxidation and stabilizes emulsions | | | | |
| Increased use of chemicals from forest raw materials in paint & varnish | This project has tested whether a unique and unexplored chemical from forest raw materials can be used as an additive in paint and varnish. | Chemicals & Energy | 2015-2016 | Partially (project was too short to confirm hypothesis) |
| Ecohelix application with dissolving pulp production | A new technology to improve existing processes: The project has worked on applying a new technology to existing processes to extract and upgrade a useful lignin-hemicellulose product. | Chemicals & Energy | 2015 | Yes |
| Better sawing | The project aimed to assess the technical, economic, and climatic benefits and conditions for increasing the value exchange in the decomposition of timber. | Construction & Design | 2019-2020 | Yes |
| Renewable water repellents for fibreboard based on tall oil | The project aimed to prepare and test 100% renewable compounds from tall oil for efficient water repellence of wood fibre boards, as a cheaper and sustainable replacement for the wax emulsions currently used in the industry. | Construction & Design | 2019 | Yes |
| Birch bark – recycling and use as a wood impregnating agent | The project aimed to evaluate the possibility of using birch bark, an underutilized residual material from the pulp industry, to produce sustainable, bio-based environmentally friendly impregnating agents for the treatment of wood. | Construction & Design | 2019 | Partially |
| Sustainable environmentally friendly wood through tailor-made impregnation | The project aimed to facilitate wood construction and increase the use of wood, for example in apartment buildings and other buildings, by improving the properties of impregnated wood. | Construction & Design | 2018-2019 | Yes |
| Wooden foundation | The project focused on creating a base plate in wood as a competitive alternative to concrete, the environmental impact from concrete foundations could be reduced | Construction & Design | 2018-2019 | Yes |
| Quartzene as a potential fire protection agent for wood surface treatment | Development of a paint solution that protects against fire. | Construction & Design | 2017-2019 | Partially (still need to develop a paint which meets all requirements) |
| Use of technology from the steel industry for series production of wood products | This project has investigated how highly productive techniques similar to those used in the steel industry could be used to cost-effectively process and further refine wood. | Construction & Design | 2015-2016 | Yes |
| New method for producing 'maintenance-free' and 'abrasion-resistant' wood materials | The goal was to create a new wood material with a water-repellent and protective layer under the surface instead of above, in order to reduce the need for maintenance. | Construction & Design | 2015-2016 | Partially (further research is needed) |
| Innovative green graph for high-tech applications | The purpose of the project was to test the hypothesis that it is possible to create a process for continuous mass production of graphene with retained electrical properties and with biomass as a raw material. | Materials | 2019-2020 | Unknown |
| Nanocellulose Hydrogel Wounds for Burns | The project strived for a wound improvement innovation that would have beneficial effects for the Swedish bioeconomy and forestry sector, and in healthcare. | Materials | 2019-2020 | Yes |
| Disruptive system innovation for Swedish wool processing | The project intended to use so-called 'whole garment' machines to enable a local production of knitwear from Swedish materials. | Materials | 2019-2020 | Partially (quality standards not met) |
| CelluPac – a bio-based alternative to EPS for full-scale manufacturing | The goal of the project was to develop a new sustainable material based on renewable raw materials that can replace fossil-based EPS in packaging materials. | Materials | 2019 | Yes |

| Hypothesis-testing projects* | Description | Sector | Period | Hypothesis confirmed? |
|---|---|---|---|---|
| Paper-based lightweight structures with EMI protection function for vehicles (PulpFun) | The project involved developing lightweight composites based on pulp that provide the structural support needed for interior panels for shielding electromagnetic interference (EMI) in road vehicles. | Materials | 2019-2020 | Yes |
| Bio-based superabsorbent in food packaging | The project aimed to develop a bio-based superabsorbent, primarily in the food and healthcare markets, as a replacement for plastic absorbents. | Materials | 2019 | Yes |
| Fully lignin-based carbon fibre composites | The project wanted to develop the first completely lignin-based carbon fibre composite material ever. | Materials | 2018-2019 | Yes |
| PhatherTex: Bio-based and biodegradable textiles from bioplastics and feathers | The project investigated the possibility of manufacturing textile materials from feathers and biopolymers. | Materials | 2018-2019 | Yes |
| Bio-based barrier to replace aluminium | The purpose was to create a new application for Swedish forest raw materials and develop a bio-based renewable barrier material that is suitable for replacing energy-intensive aluminium foil. | Materials | 2018-2019 | Yes |
| Streamateria Virtual Gateway | The goal of the project was to produce a prototype that can produce custom-made garments from bio-based raw material. | Materials | 2018-2019 | Yes |
| BioPitch | The project investigated whether forest raw material can be used as a material in a biodegradable granulate, which is suitable as a filling material in artificial turf. | Materials | 2018-2019 | Yes |
| Functionalized expandable cellulose foams | The hypothesis was that it is possible to produce bio-based expanding foams through substances that emit gas when exposed to heat in combination with a cellulose source. | Materials | 2017-2018 | Partially (further research is needed) |
| Bio-based granules for 3D printing | The idea of the project was to develop bio-based granules adapted for 3DP manufacturing of packaging by using raw material streams that today have a low value, such as groats, sawdust, and lignin. | Materials | 2017-2018 | Yes |
| HoloNano | The project aimed to investigate whether a more environmentally friendly substrate can be used, such as bio-based films of cellulose nanofibers. | Materials | 2017-2018 | Partially (performance in relation to current oil-based products is lower) |
| Bio-based wet packaging materials | The project aimed to test whether it is possible to also manufacture wet-strength papers from mechanical and chemically mechanical pulps. | Materials | 2017-2018 | Unknown |
| Cellulose composite materials in various forms | Development of a completely new material based on a composite of two diametrically different types of cellulose material, which can be used for packaging. | Materials | 2017-2018 | Yes |
| Cuboid | The project investigated whether the right combination of bio-based materials in a new 3D forming process can provide new translucent/transparent packaging. | Materials | 2017-2018 | Unknown |
| Thermally conductive paper | The challenges in this project were to be able to produce nomography paper using relatively simple and scalable methods, and to identify markets in which such heat-conducting paper can be attractive. | Materials | 2017-2018 | Partially (thermal conductivity was not achieved to the extent desired) |
| Launch of textile product from Swedish forest | Increased general knowledge of the possibilities of manufacturing products from Swedish forest raw materials. | Materials | 2015 | No information |

| Hypothesis-testing projects* | Description | Sector | Period | Hypothesis confirmed? |
|---|---|---|---|---|
| Streaming Materials – intangible ownership of physical objects | The goal of the project was to produce a prototype that can produce custom-made garments from bio-based raw materials. | Materials | 2018-2019 | Yes |
| BioModified surfaces for digital printing look and feel | This project explored the possibility of creating surfaces modified with bio-based materials to suit digital printing and which provide both better printability and good tactile properties. | Materials | 2015-2016 | Yes |
| Concept design – customized design and resource efficient production | This project investigated how to create a method for housing construction that weighs together efficient use of resources (industrial production) and the end customer's desire for individuality (architectural design). | Materials | 2015 | Yes |
| BioBlade – Investigation of natural fibre reinforced composite for use in wind turbine blade applications | This project aimed to construct a 7.5 m bio-based turbine blade for a wind turbine. | Materials | 2015-2017 | Unknown |
| Textiles from sea raw material | The project investigated whether Swedish lakes and seas can be used to produce textile materials. | Materials | 2015-2016 | Yes |
| 3D Bioprinting of functional materials from wood, WOODINK | This project investigated the possibilities of 3D printing bio-based materials such as cellulose. | Materials | 2015 | Yes |
| EkoMini – Bio-based composites for boat builders | The EkoMini project wanted to prove that a boat can be built with a completely bio-based composite structure and still be economically competitive. | Materials | 2015-2016 | Partially (the results are better for some types of boats) |
| Bio composites of thermoplastic cellulose by melt processing | The purpose of this project was to compare bio composites from nanofibers with composites from wood, and to develop a method for degrading wood fibres to nanofibers in an industrial process. | Materials | 2015 | Yes |
| Forest raw material – a component in the protection of the car's chassis and joints | This project explored the possibility of replacing these environmentally and health-hazardous chemicals with a renewable and sustainable alternative. | Materials | 2015-2016 | Partially (best results achieved with lignin-based combination materials) |
| Bio-based coating material for optical fibres | The aim was to investigate several material properties which in certain optical fibre applications may exceed the performance of currently known polymer coatings | Materials | 2015-2016 | Partially (further research is needed) |
| Manufacture of short fibre yarn | The goal was to produce a thread with properties between untreated paper thread and a thread of recycled cellulose, without using environmentally hazardous or expensive chemicals. | Materials | 2015 | Yes |
| The recycled textile-fibre paper materials (TREeToP) | This project investigated the possibility of using paper machines to produce a new material from recycled textile fibres. | Materials | 2015 | Yes |
| Super-strong bio-composite materials of carbohydrates from pulp fibre and oats | This project investigated whether beta-glucan from oats can strengthen cellulose from forests and create a mechanically super-strong material. | Materials | 2015 | Yes |
| 3D written composite of cellulose and spider silk | The goal of the project was to 3D-print a new composite of cellulose and spider silk that has as good, or better, properties than the materials individually. | Materials | 2015-2016 | Yes |

*All hypothesis-testing projects are related to Step 1, unless otherwise indicated.

## Innovation projects

| Innovation projects | Description | Period | Sector | Sub-projects |
|---|---|---|---|---|
| BioLi2.0 - From lignin to bio-based fuels and chemicals | The project aimed at developing processes to produce fuels and chemicals based on renewable lignin. as a replacement for fossil, petroleum-based products. | 2016-2018 | Chemicals & Energy | Characterization, screening, and visualization<br>Produce fuel from lignin<br>Odourless lignin<br>Produce vanillin from lignin |
| The bio-based construction and housing of the future (FBBB) | The goals of the project were to develop new business solutions for the carpentry industry; streamline the procurement and production of multi-storey buildings; develop more efficient floors and slimmer walls/climate shells for new constructions and renovations; and develop processes for measuring and manufacturing bio-based products for renovation. | 2015-2018 | Construction & Design | Decision support for procurement of green construction projects<br>Environmental and business benefits with bio-based buildings in a life-cycle perspective<br>E-commerce<br>Customer preferences for visible wood in different markets<br>Renovation process<br>Information flows for production systems<br>Information flows in value chains<br>Thinner, more efficient flooring<br>Effective climate shells<br>Bio-based sheet material<br>High multi-storey wooden houses |
| Establish locally grown textiles in Sweden (ENTIS) | The goals of the project were to develop a knowledge platform for new cross-industry collaboration and new business models; cellulose-based high-volume products for agriculture; textile-like materials produced on paper machine; improve the value chain for textile recycling in Sweden; develop recyclable bio-based furniture; investigate and demonstrate techno-economic and environmental opportunities for sustainable viscose production in Sweden. | 2015-2018 | Materials | Knowledge platform, infrastructure and living labs<br>Agriculture high-volume products<br>Paper machine for textile-like materials<br>Recycling: creating a closed value cycle<br>Establish locally grown textiles in Sweden: Designed for Recycling<br>Sustainable Swedish Viscose |

## Cooperation projects

| Collaboration projects | Description | Period | Sector |
|---|---|---|---|
| Timber on top | Timber on Top is a collaborative project with the aim of increasing knowledge about bio-based extensions and prefabricated building systems. It also targets developing circular business models where reuse and development of existing buildings are included. | 2018-2019 (1st stage) and 2019-2021 (2nd stage) | Construction & Design |
| Treesearch | Within the Treesearch platform, industry and academia collaborate on research and competence building on materials from the forest to lay the foundation for the bioeconomy of the future. | 2017-ongoing | - |

## Thematic-call projects

| Thematic-call projects | Description | Period | Sector |
|---|---|---|---|
| New technology for sustainable and efficient recovery of nutrients from sewage sludge through incineration | The project aimed to demonstrate new sustainable technology/innovation that enables the separation of phosphorus from municipal sewage sludge while reducing the content of unwanted substances in the phosphorus product. | 2016-2018 | Chemicals & Energy |
| Bio-based containers for healthcare waste | The project's goal was to develop and evaluate a prototype for a container made of fibre composite as an alternative to plastic. | 2016-2017 | Materials |
| Bio-based and innovative materials for sound absorbers in public places | The project has contributed to a bio-based economy by finding applications for textile waste. | 2016-2019 | Materials |
| Bio-based innovations in healthcare provide effective products and solutions | The project aimed to show that it is possible to replace oil-based textiles and plastics with bio-based ones in healthcare products. | 2016-2018 | Materials |
| 3D-printed prostheses based on forest raw materials (AMPOFORM) | The project aimed to show how bio-based materials can be used in public healthcare through a concrete example – 3D-printed prostheses. | 2016-2019 | Materials |
| Onskin – 3D Biomaterial from the forest | The project developed innovative materials (so-called cellulose nanofibrils) based on environmentally friendly forest raw materials that are suitable for 3D printing of advanced dressings primarily for Swedish healthcare. | 2016-2019 | Materials |
| Renewable forms in healthcare | The project has, from a needs perspective, worked to find replacement products for plastics in the healthcare sector. | 2016-2018 | Materials |



## Activity projects

| Activity projects | Description | Period | Sector |
|---|---|---|---|
| Innovation Race | This project aimed to stimulate innovation by arranging an innovation exercise – an Innovation Race – where different stakeholders, competencies and actors from bio-based industries meet and innovate together. | 2015 | - |
| MARKPOLL | This project has examined the conditions for bio-innovations from a market perspective and a political perspective. | 2015 | - |
| Area analysis textile | This project aimed at carrying out an area analysis for the Swedish textile sector. | 2019-2020 | Materials |
| Sustainability criteria and life cycle analysis for forestry | The overall goal of the project was to strengthen the bioeconomy's opportunity and status in society by ensuring that it is possible to communicate about sustainability and life cycle analyses with increased self-confidence, which is achieved through clear and credible information and data. | 2017-2020 | Construction & Design |
| Preliminary study: Operationalization of sustainability criteria and life cycle analysis for the bio-based sector in Sweden | The aim of this feasibility study project was to formulate a project that can support BioInnovation's other projects as well as the bio-based industry in general when it comes to sustainability issues. | 2016-2017 | Construction & Design |
| BioLyftet | The BioLyftet training initiative is aimed at small and medium-sized companies that want to start practically using bio-based, recycled, and recyclable materials in their plastic and textile products. | 2019-ongoing | - |

# Appendix C: Refined CMOc

## Knowledge development and diffusion

| Status | Efforts and activities | Context & | Mechanism → | Outcome configuration | Process |
|---|---|---|---|---|---|
| Confirmed, but needs refinement | Hypothesis-testing projects | Missing | Hypothesis-testing | The potential of high-risk projects is utilized<br>What does it mean? | |
| Confirmed, but needs refinement | Activity projects | Missing | Market and behavioural analysis studies | Needs and opportunities for bioeconomy | KDD |
| Not confirmed | Cooperation processes | Efforts towards SIP cooperation<br>What does it encompass? How does it trigger the mechanism? | Cooperation between SIPs (AN)<br>How does it generate the outcome? | Cross-fertilization between areas<br>How? | |

| Status | Efforts and activities | Context & | Mechanism → | Outcome configuration | Process |
|---|---|---|---|---|---|
| Confirmed/refined | Hypothesis-testing projects | Funding for R&D of high-risk ideas | Hypothesis-testing | The potential of high-risk projects is utilized<br>What does it mean? | |
| Confirmed/refined | Activity projects | Knowledge gap | Market and behavioural analysis studies | Market knowledge | |
| Not confirmed | Cooperation processes | Efforts towards SIP cooperation<br>What does it encompass? How does it trigger the mechanism? | Cooperation between SIPs (AN)<br>How does it generate the outcome? | Cross-fertilization between areas<br>How? | |
| New | Hypothesis-testing, thematic calls and innovation projects | Calls for projects | Collaboration between project participatns (AN) | Knowledge development on new technologies | KDD |
| New | Hypothesis-testing, thematic calls and innovation projects | Knowledge development on new technologies | Dissemination of project results | Knowledge diffusion | |
| New | Cooperation projects | Calls for projects within Treesearch | Support for doctoral and postdoctoral projects (RM) | Knowledge development on new technologies | |
| New | Hypothesis-testing, thematic calls and innovation projects | Knowledge gap between collaborative actors | Lack of user-producer interaction (AN) | Lack of knowledge diffusion among downstream firms | |

Legend: Confirmed, but needs refinement/refined — Confirmed — Not confirmed/not mentioned — New

## Entrepreneurial experimentation

| Status | Efforts and activities | Context & | Mechanism → | Outcome configuration | Process |
|---|---|---|---|---|---|
| New | Hypothesis-testing, thematic calls and innovation projects | Continuation of the consortium (AN) | Missing<br>In which ways? | Increase entrepreneurial experimentation | |
| New | Innovation projects and thematic calls | Collaboration between project participatns (AN) | Tests and demonstration of new solutions | Decrease economic and technical uncertainties | EE |
| New | Hypothesis-testing projects | High-risk ideas | Limited time to complete the project | Lack of entrpreneurial experimentation | |
| New | Hypothesis-testing, thematic calls and innovation projects | Projects still in a research and development phase | Missing | Lack of new entrants or diversification of established firms | |

Legend: Confirmed, but needs refinement/refined — Confirmed — Not confirmed/not mentioned — New

# Market formation

| Status | Efforts and activities | Context & | Mechanism → | Outcome configuration | Process |
|---|---|---|---|---|---|
| Not confirmed | Hypothesis-testing projects | Missing | Realize opportunities in confirmed hypothesis<br>What does it mean? How does it generate the outcome? | Technical and commercial innovation | |
| Confirmed, but needs refinement | Innovation projects and thematic calls | Missing | Collaboration, knowledge sharing and learning<br>Is it an outcome? | New bio-based materials, chemicals, processes and products come into market use | |
| Not confirmed | Hypothesis-testing projects | Confirmed hypothesis | Decision basis for upcoming efforts (IDS) | Radical and innovative solutions | MF |
| Not confirmed | Hypothesis-testing projects | Confirmed hypothesis | Technical and commercial innovation<br>Who does what? | Radical and innovative solutions | |
| Not confirmed | Innovation projects and thematic calls | Collaboration, knowledge sharing and learning between project participants | New bio-based materials, chemicals, processes and products come into market use | New markets for bioeconomy | |

| Status | Efforts and activities | Context & | Mechanism → | Outcome configuration | Process |
|---|---|---|---|---|---|
| Not confirmed | Hypothesis-testing projects | The potential of high-risk projects is utilized (KDD) | Realize opportunities in confirmed hypothesis<br>What does it mean? How does it generate the outcome? | Technical and commercial innovation | |
| Confirmed/refined | Innovation projects and thematic calls | Project calls | Collaboration, knowledge sharing and learning<br>Is it an outcome? | New bio-based materials, chemicals, processes and products come into market use | |
| Not confirmed | Hypothesis-testing projects | Confirmed hypothesis | Decision basis for upcoming efforts (IDS) | Radical and innovative solutions | |
| Not confirmed | Hypothesis-testing projects | Confirmed hypothesis | Technical and commercial innovation<br>Who does what? | Radical and innovative solutions | MF |
| Not confirmed | Innovation projects and thematic calls | Collaboration, knowledge sharing and learning between project participants | New bio-based materials, chemicals, processes and products come into market use | New markets for bioeconomy | |
| New | Hypothesis-testing, thematic calls and innovation projects | Missing | High market uncertainty | Hinder market formation | |
| New | Hypothesis-testing, thematic calls and innovation projects | Production-side dominated by incumbents | Missing | Hinder market formation | |

Legend: Confirmed, but needs refinement/refined · Confirmed · Not confirmed/not mentioned · New

# Influence on the direction of search

| Status | Efforts and activities | Context & | Mechanism → | Outcome configuration | Process |
|---|---|---|---|---|---|
| Confirmed, but needs refinement | Activity projects | Missing | Market and behavioural analysis studies | Decision basis for upcoming efforts | |
| Confirmed, but needs refinement | Hypothesis-testing projects | Missing | Hypothesis-testing | Decision basis for upcoming efforts | |
| Not confirmed | Programme office | Efforts towards internationalization | Collaborative projects with other countries (AN) | Project continues with EU financing<br>How does the programme influence this? | IDS |
| Not mentioned | Activity projects | Market and behavioural analysis studies | Needs and opportunities for bioeconomy | Successful impact work<br>What does it mean? | |
| Not mentioned | Hypothesis-testing projects | Confirmed hypothesis | The potential of high-risk projects is utilized (KDD) | High-quality influx of visionary ideas<br>What does it mean? | |

| Status | Efforts and activities | Context & | Mechanism → | Outcome configuration | Process |
|---|---|---|---|---|---|
| Confirmed/refined | Activity projects | Knowledge gap | Market and behavioural analysis studies | Decision basis for upcoming efforts | |
| Confirmed/refined | Hypothesis-testing projects | Funding for R&D of high-risk ideas | Hypothesis-testing | Decision basis for upcoming efforts | |
| Not confirmed | Programme office | Efforts towards internationalization | Collaborative projects with other countries (AN) | Project continues with EU financing<br>How does the programme influence this? | |
| Not mentioned | Activity projects | Market and behavioural analysis studies | Needs and opportunities for bioeconomy | Successful impact work<br>What does it mean? | |
| Not mentioned | Hypothesis-testing projects | Confirmed hypothesis | The potential of high-risk projects is utilized (KDD) | High-quality influx of visionary ideas<br>What does it mean? | IDS |
| New | Hypothesis-testing, thematic calls and innovation projects | Missing | Increasing demand for bio-based products | Influence the direction of projects within BioInnovation | |
| New | Hypothesis-testing, thematic calls and innovation projects | Landscape pressures | Regulatory pressures (LEG) | Influence on the direction of projects within BioInnovation | |

Legend: Confirmed, but needs refinement/refined · Confirmed · Not confirmed/not mentioned · New

## Resource mobilization

| Status | Efforts and activities | Context & | Mechanism → | Outcome configuration | Process |
|---|---|---|---|---|---|
| Confirmed, but needs refinement | Cooperation projects | Missing | Set up Treesearch platform | Provision of infrastructure | |
| Not confirmed | Cooperation projects | Missing | SIP cooperation<br>How does it generate the outcome? | Financing between SIPs | |
| Confirmed, but needs refinement | Enhance knowledge | Missing | Support for SMEs to succeed in bioeconomy | SMEs participate in training courses and support packages | RM |
| Confirmed | Cooperation projects | Efforts towards setting up Treesearch platform | Treesearch platform provides infrastructure | Provision of expertise and research collaboration | |

| Status | Efforts and activities | Context & | Mechanism → | Outcome configuration | Process |
|---|---|---|---|---|---|
| Confirmed/refined | Cooperation projects | Lack of capacity in bio-based and recycled materials | Set up Treesearch platform | Provision of infrastructure | |
| Not confirmed | Cooperation projects | Missing | SIP cooperation<br>How does it generate the outcome? | Financing between SIPs | |
| Confirmed/refined | Enhance knowledge | Lack of capacity in bio-based and recycled materials | Support for SMEs to succeed in bioeconomy | SMEs participate in training courses and support packages | |
| Confirmed | Cooperation projects | Efforts towards setting up Treesearch platform | Treesearch platform provides infrastructure | Provision of expertise and research collaboration | RM |
| New | Enhance knowledge and cooperation projects | Lack of capacity in bio-based and recycled materials | Support for doctoral and postdoctoral projects | Provision of human resources | |
| New | Cooperation projects | Lack of capacity in bio-based and recycled materials | Knowledge development on new technologies (KDD) | Provision of human resources | |
| New | Hypothesis-testing, thematic calls and innovation projects | Project calls | Collaboration between project participants (AN) | Mobilization of complementary assets | |

Legend: Confirmed, but needs refinement/refined; Confirmed; Not confirmed/not mentioned; New

## Legitimation

| Status | Efforts and activities | Context & | Mechanism → | Outcome configuration | Process |
|---|---|---|---|---|---|
| New | Hypothesis testing, thematic calls and innovation projects | Institutional | Solutions that comply with current or upcoming legislation | Promote legitimation | |
| New | Hypothesis testing, thematic calls and innovation projects | Niche technologies underperfom | Solutions are not competitive in relation to established ones | Hinder legitimation | LEG |
| New | Hypothesis testing, thematic calls and innovation projects | Missing | Lack of social acceptance and demand (MF) | Hinder legitimation | |

Legend: Confirmed, but needs refinement/refined; Confirmed; Not confirmed/not mentioned; New

## Institutions

| Status | Efforts and activities | Context & | Mechanism → | Outcome configuration | Process |
|---|---|---|---|---|---|
| New | Activity projects | Missing | Development of decision support for public procurement | Institutional reform | |
| New | Innovation projects | Missing | Large constellations of actors within a project | Reluctance from incumbents towards change | INS |

Legend: Confirmed, but needs refinement/refined; Confirmed; Not confirmed/not mentioned; New

## Actor networks

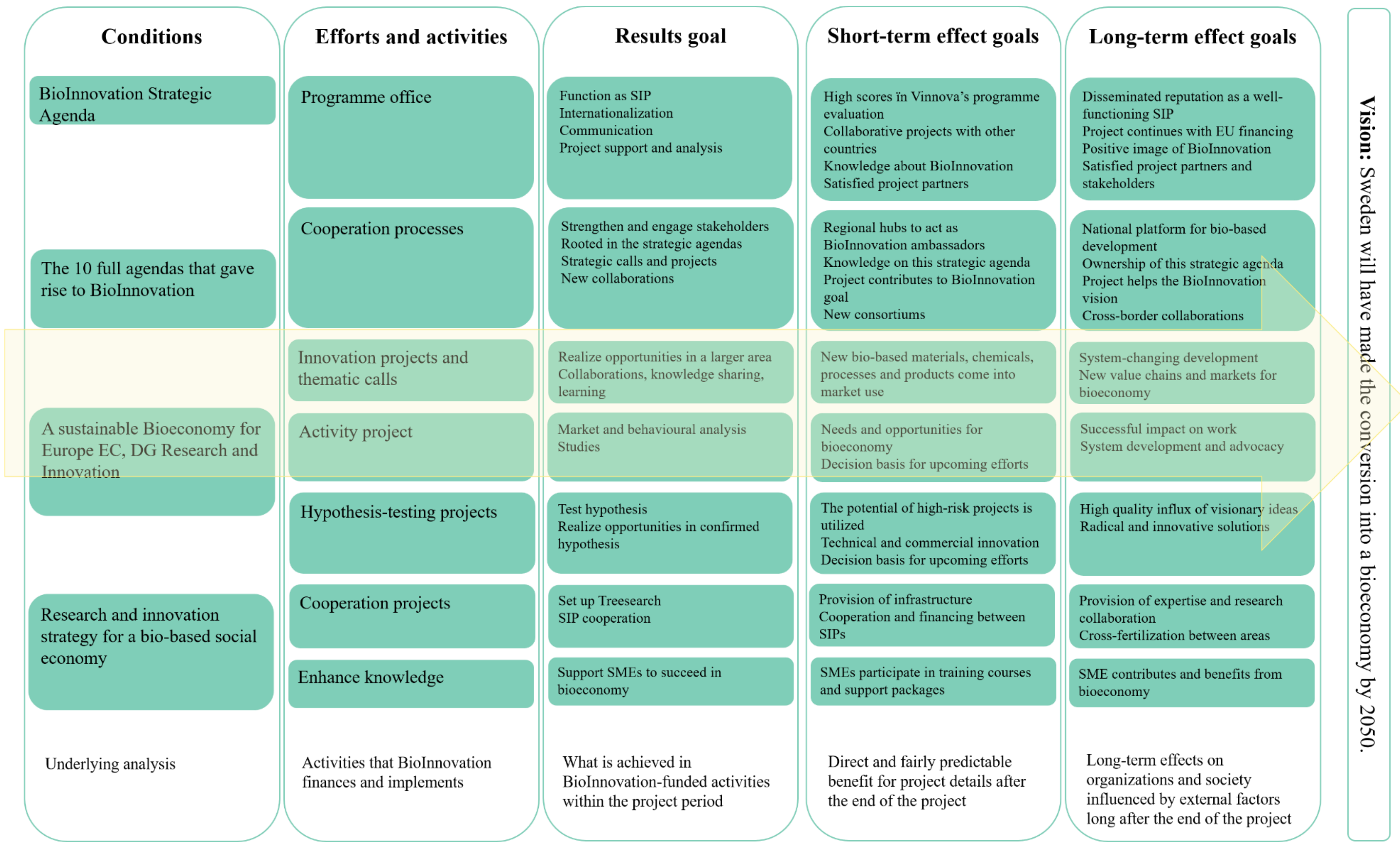
| Status | Efforts and activities | Context & | Mechanism → | Outcome configuration | Process |
|---|---|---|---|---|---|
| Confirmed, but needs refinement | Programme office | Missing | Internationalization<br>How is that a mechanism? | Collaborative projects with other countries | |
| Confirmed, but needs refinement | Cooperation processes | Missing | New collaborations<br>How does it generate the outcome? | New consortiums | |
| Not mentioned | Cooperation processes | Missing | Strengthened and engaged stakeholders | Regional hubs to act as BioInnovation ambassadors<br>What does it mean? | |
| Not confirmed | Cooperation projects | Missing | SIP cooperation<br>What does it mean? How does it cause the outcome? | Cooperation between SIP | |
| Confirmed | Cooperation processes | New collaborations formed<br>What is the difference between collaborations and consortiums? | New consortiums<br>How does it generate the outcome? | Cross-border collaborations<br>What do they mean by cross-border? | |
| Not confirmed | Innovation projects and thematic calls | Funding provided for thematic calls and innovation projects | New bio-based materials, chemicals, processes and products come into market use (MF)<br>How does it generate the outcome? | New value chains for bioeconomy | AN |
| Not mentioned | Activity projects | Studies developed by the BioInnovation programme | Decision basis for upcoming efforts<br>How does it generate the outcome? | System development and advocacy<br>What does it mean? | |
| Not confirmed | Cooperation projects | Efforts towards SIP cooperation | Cooperation between SIP | Research collaboration | |
| Not mentioned | Cooperation processes | Strengthened and engaged stakeholders | Regional hubs to act as BioInnovation ambassadors<br>What does it mean? How does it generate the outcome? | National platform for bio-based development | |
| Not confirmed | Enhance knowledge | Support provided to SMEs to succeed in bioeconomy | SME participates in training courses and support packages (RM) | SME contributes to and benefits from bioeconomy<br>What does it mean? | |

↓

| Status | Efforts and activities | Context & | Mechanism → | Outcome configuration | Process |
|---|---|---|---|---|---|
| Confirmed/refined | Programme office | Calls for projects | Internationalization<br>How is that a mechanism? | Collaborative projects with other countries | |
| Confirmed/refined | Cooperation processes | Calls for projects | New collaborations<br>How does it generate the outcome? | New consortiums | |
| Not mentioned | Cooperation processes | Missing | Strengthened and engaged stakeholders | Regional hubs to act as BioInnovation ambassadors<br>What does it mean? | |
| Not confirmed | Cooperation projects | Missing | SIP cooperation<br>What does it mean? How does it cause the outcome? | Cooperation between SIP | |
| Confirmed | Cooperation processes | New collaborations formed<br>What is the difference between collaborations and consortiums? | New consortiums<br>How does it generate the outcome? | Cross-border collaborations<br>What do they mean by cross-border? | |
| Not confirmed | Innovation projects and thematic calls | Funding provided for thematic calls and innovation projects | New bio-based materials, chemicals, processes and products come into market use (MF)<br>How does it generate the outcome? | New value chains for bioeconomy | |
| Not mentioned | Activity projects | Studies developed by the BioInnovation programme | Decision basis for upcoming efforts<br>How does it generate the outcome? | System development and advocacy<br>What does it mean? | AN |
| Not confirmed | Cooperation projects | Efforts towards SIP cooperation | Cooperation between SIP | Research collaboration | |
| Not mentioned | Cooperation processes | Strengthened and engaged stakeholders | Regional hubs to act as BioInnovation ambassadors<br>What does it mean? How does it generate the outcome? | National platform for bio-based development | |
| Not confirmed | Enhance knowledge | Support provided to SMEs to succeed in bioeconomy | SME participates in training courses and support packages (RM) | SME contributes to and benefits from bioeconomy<br>What does it mean? | |
| New | Hypothesis-testing, thematic calls and innovation projects | Market dominated by incumbents | Missing | Hinder the entrance of niche actors into the regime | |
| New | Hypothesis-testing, thematic calls and innovation projects | Mismatch between actors' goals and experiences | Missing | Hinder the entrance of niche actors into the regime | |

Legend: Confirmed, but needs refinement/refined; Confirmed; Not confirmed/not mentioned; New

# Annex A: BioInnovation-espoused effect logic




*Source: BioInnovation (2014, translated by the author).*