FISSAC

FOSTERING INDUSTRIAL SYMBIOSIS FOR A SUSTAINABLE RESOURCE INTENSIVE INDUSTRY ACROSS THE EXTENDED CONSTRUCTION VALUE CHAIN

A process for the transition from linear to circular business models for industrial symbiosis

D 7.4: A process for the transition from linear to circular business models for industrial symbiosis
WP 7, T 7.2

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1. Summary

The main objective of WP7 “Industrial Symbiosis replicability and social issues” is to demonstrate the replicability of a FISSAC model. An important part of the model is the transition from linear to circular business models in the field of industrial symbiosis. Within the FISSAC project the approach used to create a foundation for this transition has been performing analyses of the Technological Innovation System, TIS. The TIS framework allows for the identification of innovation and change suppressors and promotors. Important for the success of the FISSAC model has been the inclusion of different stakeholders in a life like context in order to facilitate an open and collaborative innovation process.

The TIS framework has had great practical impact as a tool for mapping and guiding innovation processes. It was also in part developed in collaboration with policy makers to aid with their need for advice on appropriate governance measures and used as a practical method for designing technology development strategies, e.g. in the Netherlands and in Sweden.

Within the FISSAC project the TIS framework has been used to perform a case study, presented in this report, and was found to be very helpful in identifying the important intersection between complicated technological issues and complex social issues, making it clear to the participating stakeholders where they needed to come together and co-create in order to make industrial symbiosis opportunities possible, from legal, technological, social and economic perspectives. In this way the use of the TIS framework ties it closely to the work performed within the FISSAC model living labs (LL) as the opportunities for industrial symbiosis solutions identified with the TIS framework and the transition from linear to circular business models can be developed and tested within the LL structures and then used for the implementation of new business models, new legislation and new technologies.

As with the national LLs associated with the FISSAC model, the TIS analyses must reflect the priorities of the stakeholders in the different countries. This means that different value chains and challenges, barriers and drivers related to each country will be investigated. For each TIS analysis there will be a separate starting point with its own development goals and its own barrier to overcome in order to create industrial symbiosis and moving towards a circular economy. For some this might result in the need to establish a network for knowledge sharing whereas for others it may be a need to reach a more “co-creation”. This is still too early in the process to know. Nevertheless, the challenges and opportunities present in each country can be identified using the TIS framework.

From this publication regarding the transition from a linear to a circular business model for industrial symbiosis can be stated that there is not one over-all goal to align the TIS analyses in the sense that they should all work with the same barriers and opportunities. A comparison between the TIS analyses must only be made in order to share experiences and knowledge on how to overcome barriers and to find inspiration through experiences made by the other teams working with TIS as part of the LLs or otherwise. Working in accordance with the FISSAC model will create long term competitiveness and profitability for the stakeholders and a more sustainable construction sector. The European industry is facing a huge challenge in becoming part of a circular economy. Cooperation in the format of LLs and the use of the TIS framework can be one important tool in this and using the FISSAC model where design practices, analytical methodologies, and financial viabilities are combined should further aid in this work.

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Abbreviations and acronyms

LL, Living Lab
TIS, Technological Innovation System
IS, Industrial Symbiosis

2. WP 7 - Industrial Symbiosis replicability and social issues

The main objective of WP7 "Industrial Symbiosis replicability and social issues" is to demonstrate the replicability of FISSAC model. In particular, technical and non-technical aspects that could affect an Industrial Symbiosis are analyzed in this WP and the necessary steps to change from linear to circular business models are defined for the most representatives EC countries and FISSAC related industries. At this purpose, several concepts and instruments are applied such as LLs, interviews and Technological Innovation System (TIS) analysis. The WP7 activities are divided in three main tasks, whose objectives are shown in the following figure.

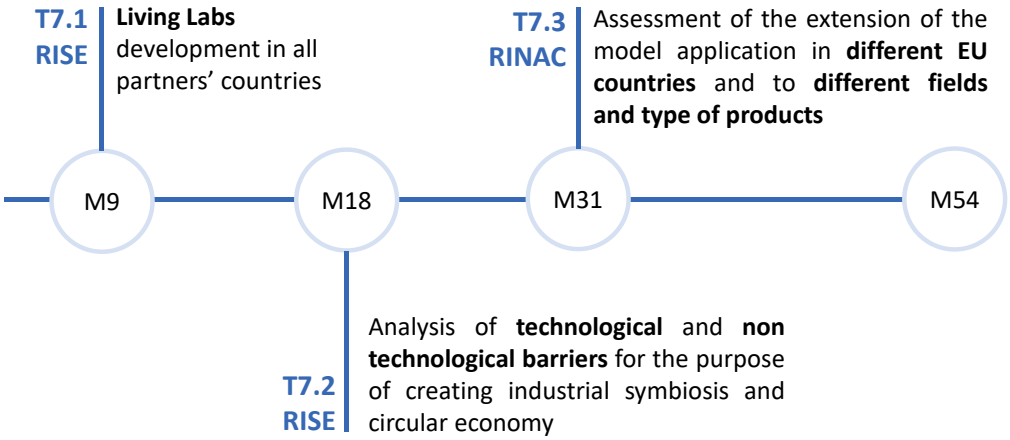

Figure 1: WP 7 Tasks and objectives

3. Task 7.2: Analysis of the condition of the various represented industries to detect technological and non-technological drivers and barriers for the purpose of creating industrial symbiosis and circular economy

The TIS framework has been shown to have great practical impact in the innovation process as it identifies barriers and opportunities for change and innovation. It can also identify how the different aspects of the innovation system can work in tandem to bolster positive forces for change and innovation as well as how they can work in tandem to hinder development and innovation. This is the main reason for including the TIS Framework in the FISSAC model.

The TIS analysis, used correctly, should reflect the priorities of stakeholders in the different countries; investigate relevant aspects to include in the FISSAC model; and bring valuable inputs to solve problems and explore pathways within the project and in some cases beyond. Including the TIS analysis work in the LLs active within the FISSAC project provides a model very suitable for analyzing technological and non-technological drivers and barriers of innovation for industrial symbiosis and circular business models. Using the TIS framework to analyze where opportunities and barriers are situated in the technological innovation system and then implementing this knowledge in the work performed by the LLs, allows a focus on the right issues. What the right issues are will vary from country to country, from sector to sector and from context to context. Knowing the boundaries and opportunities as identified by using the TIS framework then allows the LLs to prioritize what issue to tackle first and to allocate adequate resources to where they are most needed.

As will be shown in the case study presented below, it will be clear that by using TIS as a model for analyzing the current situation, a technological or business sector can be made aware of what each sector actor can contribute with, knowledge, resources and networks, in order to be part in transitioning the entire sector towards better use of IS and towards a more circular approach to economy and production.

4. Living Labs – The FISSAC Way

Within the FISSAC project, a broad definition of what an LL can consist of is used, leaving every partner free to design and manage a lab that suits their industrial and stakeholder context.

The organization of the LLs in Sweden started in advance, in order to generate some first insights about methodology and process that might be relevant to the efforts to come in other regions.

After the First Swedish LL, a survey about methodology and process was shared with the other partners, in order to collect important topics to discuss and to include in the guiding documents, presentation and reports for the project.

On the basis on the experiences gained working with the Swedish LL, of the results of the survey and of the outcomes of discussions during the general assemblies, a document called Living Labs Guidelines has been prepared by RISE and shared with the relevant partners. It can be found in the deliverable report for task 7.1.

5. The Technological Innovation System (TIS) Analysis in FISSAC

The EU project FISSAC includes an analysis with the technological innovation system (TIS) framework of an industrial symbiosis. This section presents the framework and how it is applied within FISSAC. In the LL set up in Sweden, gypsum is studied as case of material where there are possibilities to create industrial symbiosis. Consequently, the innovation system for recycling of gypsum is chosen as the case of the TIS analysis and is used as an example throughout this report to how the TIS framework can be applied and used in an LL setting.

6. The TIS Framework

The technology innovation system (TIS) framework is anchored in the academic literature. It has been used to analyze the development of a series of innovations, mainly energy-related technologies, with the aim to increase sustainable development (Markard, Raven & Truffer 2012). The framework has had great practical impact as a tool for mapping and guiding innovation processes. It has partly been developed in collaboration with policy makers in need for advice on appropriate governance measures (Sharif 2006) and has been used in practice for developing technology development strategies, in for example the Netherlands and in Sweden.

The TIS literature has identified particular system structure characteristics and related innovation processes as key for the development and market uptake of innovations. Based on these findings, an analytical approach is offered to analyze a particular innovation trajectory, identify its barriers and opportunities for development and potential ways forward. The first step in the approach analyses the innovation system structure, that includes a delineation of the technology innovation and its value chain, the actors and network driving its development by supporting different elements of the value chain and the institutions, which are the regulations, norms and values supporting or hindering the development of the innovation system (fig. 1). This analysis gives an indication of the development phase of the innovation system, i.e. concept, demonstration, niche market, commercial or mature, and what lies ahead (Bergek, Jacobsson, Carlsson, Lindmark, & Rickne, 2008).

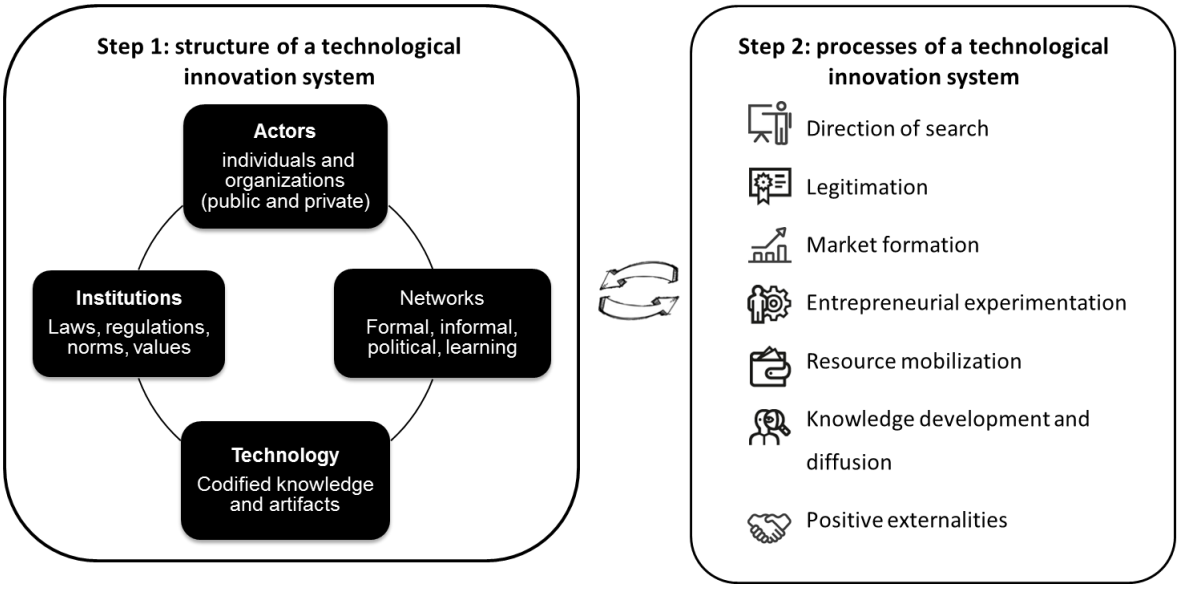

Figure 2 The two steps that can be included in the TIS analysis. In FISSAC the analysis is focused on the first step – the structure of the TIS. Source: Presentation by Perez Vico, E. 2016.

In a second step of analysis, seven key innovation processes (also known as functions) can be analyzed to understand the dynamics and development potential of the system. These activities include knowledge development and diffusion; influence of the direction of search; entrepreneurial experimentation; market formation; legitimation; resource mobilization; and positive externalities (Bergek, Jacobsson, Carlsson, Lindmark, & Rickne, 2008). However, for the analysis in the FISSAC project no particular technology or innovation that can increase recycling is in focus therefore the analysis is focused on the first step – the innovation system structure.

In addition, in FISSAC the analysis includes a prospective twist to the TIS analysis. This implies that the structural analysis will include a mapping of prospective actors next that possibly would need to be involved in order to strengthen the innovation system. In order to capture contextual factors that may influence the development of the innovation system in a positive or a negative way "Exogeneous factors", such as related incumbent innovation systems with which the system competes or structural societal changes are integrated in the analysis (Hillman & Sandén 2008; Markard & Truffer 2008).

7. How to Apply the TIS Framework in FISSAC

The first step of this analysis regards the current state and implies analyzing the following structural elements: actors, networks, institutions and knowledge. In this step, the questions outlined below could be used to guide the analysis. A generic version of the below questionnaires can be found in appendix A.

Structural element	Questions about the current innovation system
Actors and value chain	What are the actors in the value chains for productions and recycling of gypsum in Sweden? What vision and plan does each actor have (that affects recycling of gypsum)? Is the vision and plan the same for the whole organization? What would increased recycling of gypsum mean for each actor (in general and in terms of cost and income)? In what way are the activities, visions and plans of the actors hindering increased recycling of gypsum? In what way are the activities, visions and plans of the actors motivating increased recycling of gypsum?
Networks	In what networks are these actors involved? What are the purposes of each network?

	In what way are the actions of the networks hindering increased recycling of gypsum? In what way are the actions of the networks motivating increased recycling of gypsum?
Institution	What laws, policies and standards are affecting the production and recycling of gypsum? Are there cultural aspects that affect the possibilities for increased recycling of gypsum? In what way are laws, policies, standards and cultural aspects hindering increased recycling of gypsum? In what way are laws, policies, standards and cultural aspects motivating increased recycling of gypsum?
Knowledge and technology	Is there enough knowledge about how gypsum could be recycled? Or is there a need for more knowledge and technological development? (i.e. lack of knowledge is a hinder for recycling of gypsum)

The next step of the analysis regards the prospective TIS, i.e. what actors or activities would be needed to strengthen the innovation system for recycling of gypsum. Questions that could guide the analysis are outlined below.

Structural element	**Questions about the prospective innovation system**
Actors and value chain	In addition to the actors involved in current value chains for gypsum what actors would need to be involved in order to increase recycling of gypsum in Sweden? Which industrial sectors do these actors represent? Is it likely that actors from this industry would be interested to be involved in the activities needed for increased recycling of gypsum?
Networks	What actors would be needed to be involved in a network (additional to the current ones) to increase the possibilities for recycling of gypsum? What would be the purpose of this network? (e.g. lobbying, increasing public support, exchanging experiences).
Institution	-
Knowledge and technology	-

In the following section, an example of a TIS analysis workshop showing barriers and opportunities for increased recycling of gypsum is described. In the section after a detailed TIS analysis based on the workshop and other FISSAC LLs activities is performed.

8. TIS Analysis Workshop

As part of the work within the Swedish FISSAC LL the possibilities for increased recycling of gypsum has been studied. The material gypsum was chosen jointly by the participants in the LL, with the rational that it is a common material that is suitable for (material) recycling, but the recovery rate is low today. Increased recycling of gypsum can be achieved in several ways. The TIS analysis workshop focuses on how to increase recycling during deconstruction of buildings.

8.1. Background

Gypsum plasterboard has been produced in Europe since the early 20th century. The first factory in the Nordic region was built in 1957 and was located in Varberg, Sweden. Building with plasterboard is so-called lightweight construction, which means that wood chambers are combined with plasterboard. It is a common construction method, especially in the Nordic countries, the US and Canada.

Virgin material for plasterboard production, are imported to Sweden from Spain. Production of plasterboard slabs takes place with two players in Sweden. In the production of plasterboard discs, it is common to mix about 20-30% recycled material. Plasterboard is sold directly to construction companies and via wholesalers, which in turn sell to private

individuals and construction companies. Producers of plasterboards can cooperate with construction companies so that sorted gypsum can be returned directly to the manufacturer. Waste management on the construction project is decided on a case-by-case basis.

When decommissioning buildings, it may be harder to separate different materials and gypsum is often added as a fraction of landfills. However, this type of handling does not always result in the plasterboard being deposited on a landfill. The container labelled "landfill" is likely to be sorted (mechanically) at the recycling company, where as much recycling as possible is done. One recycling firm report that they recycle plaster as soil improver. It has thus been found that the marking of the container does not always correspond to the actual handling of the waste, which probably contributes to misunderstandings and perhaps also an excessive perception of the amount of gypsum actually deposited on landfills, see figure below.

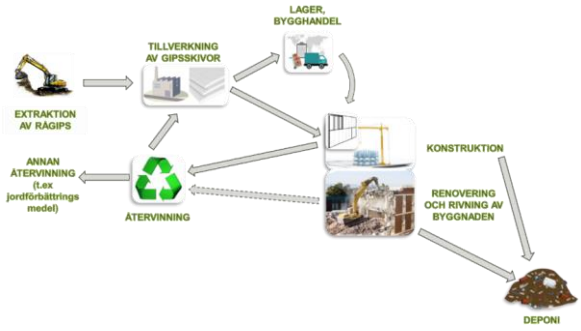

Figure 3 Gypsum value chain steps investigated during the FISSAC Living Lab "Gypsum Journey"

It has proven to be difficult to get clear figure of how much gypsum that is recycled and how they are recycled, and how much amounts are deposited or accompany the combustible fraction at a recycling plant. Today, there is considerable uncertainty in the statistics, which seems to be due to insufficient monitoring of waste and handling. This makes it difficult to assess the real potential for increased recycling of plaster.

8.2. Method – Conducting a Workshop to Collect Data for TIS analysis

In order to learn more about possibilities and barriers for increased recycling of gypsum at deconstruction the LL organized a workshop with representatives from gypsum producers, the construction firms, firms working with waste management and recycling as well as firms working with deconstruction of buildings. The framework was used to discuss possibilities and barriers for the a TIS where a large share of the gypsum is recycled at deconstruction of buildings. For the workshop, a target was set: 50% of the gypsum from demolition material would be recycled (this does not include recovery as land improvement). However, what 50% would mean in volume is very uncertain, as it is difficult to get figures on how this material is handled today. Stull, the participants at the workshop had the impression that the current figure was significantly lower. This means that there is a great potential to increase this the recycling rate relatively easy.

The workshop was carried out in two parts:

1. The first part aimed at identifying major barriers for recycling gypsum to the extent that the target image is achieved. An electronic survey was carried out, where the participants answered questions (see below) and immediately saw the results of the poll on screen.
   Questions for the survey:
   Technology: Is technology and knowledge sufficient to reach the target?
   Actors: Are the current actors sufficient to reach the target?
   Network: Are there sufficient networks between actors to reach the target?
   Institutions: Does current laws and regulations provide prerequisites to reach the target?
   Following each answered question, the group discussed the outcome of the vote and identified barriers for reaching the target.

2. During the second part the participants were divided into smaller groups and discuss possible solutions to achieve the target.

8.3. Result of the TIS Analysis Workshop

The results are presented below, and similar results could be expected when the framework is applied to other use cases and in other contexts. It is important to note that the recorded barriers and possibilities are taken from the answers given by the participating group of actors and not suggested by external experts or consultants. Relying on the expertise of the participating actors is in keeping with the LL model, staying as close to the reality and business of the case context as possible.

8.3.1. Technology and Knowledge

This part of the analysis refers to knowledge, both in terms of experiences of different actors who shape the current innovation system around material recycling of gypsum during demolition. But also, artefacts (technology) as well as in drawings and patents.

The assessment in the group is that there is a lot of knowledge available to the construction industry, demolition and recycling companies on how to increase the recycling of plaster when demolished. There are also many technical solutions that could be used to increase material recycling at demolition.

The barriers and possibilities for technology and knowledge is summarized below.	
Barriers	**Possibilities**
The raw material is relatively cheap, which expose methods that can increase recycling rates to great competition on price.	Material development could increase recycling by designed plasterboards that are made to be recycled.
If a gypsum board manufacturer is to receive return gaps, demands are often made of a relatively high degree of purification, which is not always possible at the primary recycling facility. There are market players who specialize in gypsum recycling and have technology to achieve high levels of purification. However, these players are few, which means that the waste can be transported long distances for material recycling. This is difficult to motivate for both cost and environmental reasons.	A mobile recycling solution could overcome the challenge with few players who recycle gypsum scattered at long distances. The technology is available today, but the use does not appear to be widespread.
There also seems to be some myths about the plasterboard. One example is that in the construction industry there seems to be an idea of the state of gypsum to be able to recycle. For example, that wet plasterboard cannot be recycled. This is not true. Gypsum has good conditions for recycling as material, though become wet However, the waste detector usually must pay a higher cost to the recycling company if material has become wet, since it simply weighs more, and the payment model is based on the price per kg of waste left. It could explain that such a myth survives.	Better follow-up of operational waste would strengthen knowledge of the amounts that occur annually.
Another challenge is the lack of data about how much gypsum is recycled today and what happens to the gypsum that is not recycled.	

8.3.2. Actors

Actors refers to individuals or different types of organizations that contribute to the realization of the studied TIS. Different cases will have different actor configurations. In the Swedish gypsum case, the actor configuration is found below.

The assessment in the group is that there are fairly good conditions on the players side. The actors and roles that are, or may be, involved in the production, use and recycling of plaster in Sweden are stated. The companies mentioned participate in the FISSAC LL or have been repeatedly mentioned in discussions in this group.

- Plasterboard producers: Gyproc in Bålstad
- Construction company / Entrepreneur: NCC
- Demolition company: Lotus AB
- Recycling company: Suez, Renova
- Recycling specialist gypsum: Gyro
- Builder: Future Building Development
- Industry organizations: The Swedish Construction Federation, The Swedish Recycling Industries' Association
- Construction market wholesalers
- Carpenter
- Architects
- Consultants
- Universities

The barriers and possibilities for actors is summarized below	
Barriers	**Possibilities**
As mentioned above (see the section on technology), one of the challenges with actors is that there are few recycling companies specializing in gypsum.	It would be good if higher demands were made for renovation and comparing established environmental certification systems for new production. These systems have been developed to be considered a business opportunity as they strengthen the value of the property. However, the most common environmental certification systems in Sweden do not include demolition and renovation, but should the systems evolve in that direction, there is a possibility that recycling of materials will be more in focus.
In addition to this, the group's impression was that there were probably no players missing, but the challenges were rather in pricing, costs and conditions on the market. Nobody is perceived as willing to pay what it would cost to increase the recycling of plaster. And a challenge in itself is that focus is on just the cost and not on the potential of recycling.	There is a need for new business models to increase the incentive to recycle gypsum. By valuing and demanding the skills of the demolition contractor more recycling can be increased. A concrete example would be that instead of discussing the number of tonnes at demolition, you can discuss the number of fractions.
Current agreements and orders to a demolition contractor consolidate the traditional linear role in waste management. Very few customers ask for something else and often the waste management is not followed either.	The group also found that if the client / builder starts to set higher demands for reporting and the work is clearer with the follow-up of the control plan for the demolition, the question is raised to a higher level, and possibly there are better conditions for discussing the waste as a material resource. This could eventually contribute to a more comprehensive vision of increased recycling of gypsum (see further on the need for vision / objectives under the heading institutions).
	There are examples of environmental certification systems that today include demolition and renovation; BREEAM Excellent and BREEAM In Use. Experience from demolition according to criteria in BREEAM Excellent indicates that it takes 2-3 times as long as traditional demolition. If requirements for applying

	these criteria are increased, working methods will also be developed.

8.3.3. Network

Networks involve different types of formal and informal contacts between different actors who intend to contribute to the realization of the current development path.

The assessment in the group is that the networks to increase the recycling of gypsum plaster during demolition are limited today. The meetings of FISSAC LL have, to a certain extent, been able to function as a neutral meeting place for players associated with gypsum production, use and recycling, and demonstrated the need for this kind of meeting place/network.

The barriers and possibilities for networks is summarized below	
Barriers	**Possibilities**
Some networks and partnerships exist, but more coordination is needed on the solutions for increased recycling.	Create networks or utilize existing networks (e.g. The Swedish Recycling Industries' Association and the Swedish Waste Management Association) better, for increased communication, coordination and more collaboration for increased recycling of gypsum during demolition.
Networking and joint development work takes place in project form but is not integrated into the business.	Increased communication about how to dismantle demolition materials and why. A clearer labelling of the disposal containers may help to better communicate how the waste is handled.
	Demolition companies may also request more information from recycling companies on how the waste has been handled.

Enhanced networking and more collaboration provide better opportunities for the industry to work together in the same direction and dare to be transparent and open to each other.

8.3.4. Institutions

In this regard, institutions supervise the rules for the different actors, they define what is desirable and legitimate, and affects the expectations that the development path toward more gypsum recycling will be realized. It's all about laws and regulations, but also norms, values and performances.

The group's assessment is that the institutions for increased recycling of gypsum during demolition are weak.

The barriers and possibilities for institutions is summarized below	
Barriers	**Possibilities**
The requirements regarding recycling for demolition today are too low. The law does not require a follow-up on how the waste disposal is being handled.	Builders could impose higher requirements on how to handle the waste at demolition sites and request reporting from the demolition contractor. It would create a chain of reporting and the demolition company would request information from the recycling company. With better follow-up, one gradually acquires a better knowledge of the gypsum recycling requirement level that is reasonable.
The customer does not normally ask for waste disposal follow-up.	

It is a challenge to replace virgin gypsum with recycled gypsum and achieve the same characteristics and quality as well as costs.	
For the demolition of buildings owned by municipal and state actors, public procurement law applies. Although there is the possibility of making specific demands regarding waste handling on this kind of procurement, current cases often seem to have requirements that, for example, environmental management systems should exist, rather than the recycling systems being effective and applied in a good way. This means that the deciding factor for who is given the demolition contract is, in principle, the cheapest price. Actors who work seriously and actively with recycling can be disadvantaged by the fact that only the price is crucial for the outcome.	

9. Detailed TIS Analysis – Increase Recycling of Gypsum in Sweden

The purpose of the TIS analyze of gypsum recycling is to better understand the possibilities and barriers for increased recycling of gypsum in Sweden. The analysis focuses particularly on recycling of gypsum from deconstruction of buildings and is based on the TIS analysis workshop seen above and other FISSAC LLs documents and meetings regarding gypsum recycling.

10. System Boundaries: the Swedish Gypsum Recycling Case

The technology in focus is the recycling of gypsum from construction site. The time scope covers about a decade from today. The geographical boundary is Sweden. Constructions firms and inhabitants are viewed as suppliers outside the system boundary, since building design and construction as well as use are rather independent from the gypsum recycling system considered. For a similar reason material producers, such as the cement, gypsum & concrete industry, are also considered external to the system, but on the demand side (they use recycled gypsum). In this gypsum recycling value chain, the gypsum producers are on the demand side and not on the supply side as they are usually in typical construction sector value chains. The construction sector is a supplier of recyclable gypsum. This TIS analysis tries to describe and explain the structure of the Swedish gypsum recycling value chain.

The gypsum recycling value chain is composed of two main activities, separation/dismantling of gypsum containing waste from new construction site or dismantling of old building and gypsum waste recycling. Both activities contribute to gypsum recycling, separating/dismantling by reducing the wastes coming from construction site and the building sector and increasing system efficiency and quality of recycled gypsum output. Gypsum waste is supplied from construction sites and building companies.

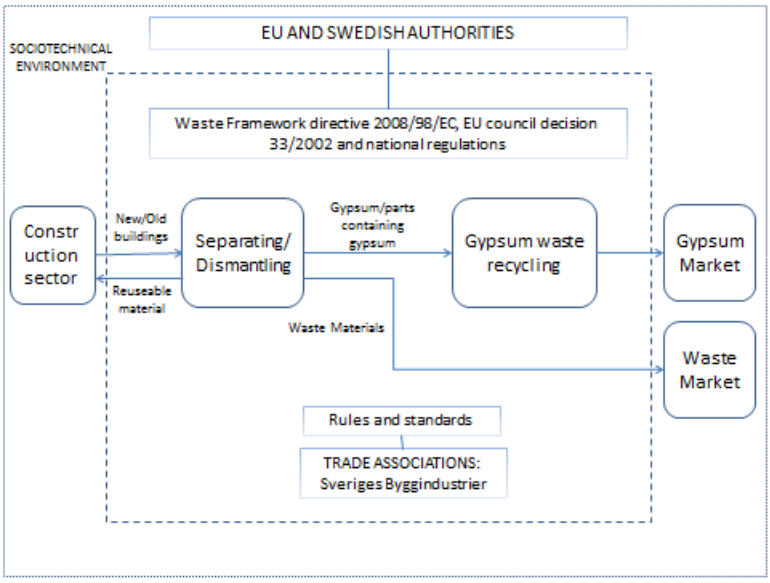

Figure 4 Model used for studying TIS of gypsum recycling in Sweden. The focal technology is analytically delineated around the capability of recovering and transforming gypsum waste from old building into recycled gypsum for the gypsum market.

Details about the gypsum value chain were also gathered during the TIS workshop.

11. Method

We are following the basic steps of a TIS analysis (Perez Vico, 2016).
First, we analyze the structure of the innovation system for recycling gypsum. These are the actors and rules that make up the system.

The main actors in the value chain for production and recycling of gypsum in Sweden can be divided in sub-groups related to the gypsum value chain:

- Gypsum plasterboard producers (ex: Gyproc, Knauf)
- Construction companies (ex: NCC, PEAB, Skanska)
- Demolition companies (ex: Lotus AB)
- Recycling companies (ex: Suez Environment, Renova)
- Recycling specialists (ex: Gyro)
- Building Developer (ex: Framtiden Byggutveckling)
- Trade organization (ex: Sveriges Byggindustrier, Återvinningsindustrierna)
- Construction market wholesalers
- Carpenters/Joiners
- Architects
- Consultant (ex: Hifab)
- Universities and Research Institutes (ex: Chalmers, RISE, IVL[2])

Every actor of the gypsum recycling value chain has a vision and a plan that affect differently the recycling of gypsum. Some may have very similar vision and plans like for instance Construction Trade Organizations and Construction companies, Research Institutes and consulting firms. Indeed NCC vision is “to renew their industry and to provide superior sustainable solutions”[3], Sverige Byggindustrier vision is “using economically and ecologically sound methods that are

[2] http://www.ivl.se/download/18.4a88670a1596305e782dc/1484131244520/B2269.pdf

[3] https://www.ncc.group/about-ncc/about-the-group/

socially sustainable, and that have among the lowest life cycle costs in the world"[4], Hifab vision is to "offer project management consultancy for a sustainable development" and RISE vision is to "ensure the competitiveness of the Swedish business community on an international level and contribute to a sustainable society" hence all being quite focused on sustainability in the building sector.

For the gypsum recycling companies, like Suez and Renova, the vision is to minimize gypsum waste and go up the gypsum waste "pyramid" with customers.

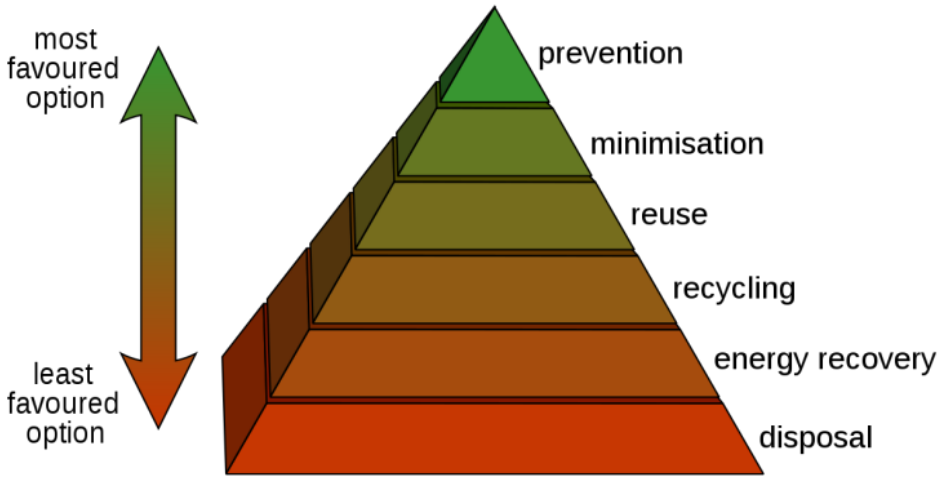

Figure 5 The waste pyramid (Source: Suez)

Others may have a very deterministic vision of their role in the gypsum value chain because of their historical role in the gypsum value chain. For instance the carpenter/joiners on construction sites think that the roles they have along the gypsum value chain are quite fixed and that the system is optimized for building and mounting gypsum plasterboard and that a "joiner" is not supposed to "de-join" things but on the contrary the joiner should ensure that parts are joined together forever.

Visions and plans are not the same for the whole gypsum vale chain and even within construction site management not everyone can have a system analysis perspective. Indeed, it is only natural that the carpenters and the joiners or the construction site manager only have today a "gate-to-gate" vision and plan for gypsum, limiting their role to what Swedish industry standards recommend, i.e. putting the right construction waste material in the right recycling container when feasible.

An increase in gypsum recycling would mean very different things for the different actors. Most of them see a high potential for gypsum recycling. Indeed, for waste handling companies like Suez it will obviously be a source of additional incomes.

For construction companies like NCC, a higher gypsum recycling would mean and increase in their operational costs and a decrease in their lifecycle costs.
For consulting firms like Hifab, an increase in gypsum recycling would mean new consultancy possibilities.
For research organizations like RISE or IVL, an increase in gypsum recycling would mean new research projects and incomes.

For building sector trade organizations like Sveriges Byggindustrier, an increase in gypsum recycling would mean a better positioning on the regional/international scene.
For construction site personal like the joiners/carpenters, an increase in gypsum recycling would mean a new way of thinking about the building and its end-of-life. This could mean extra work and routines related to gypsum waste

[4] https://publikationer.sverigesbyggindustrier.se/Userfiles/Info/468/Maalboken_sidor.pdf

management as well as extra competences to learn these routines. This would also imply extra incomes related to these special skills.

So, the increase of gypsum recycling should add some operational cost for some actors but also increase the efficiency of the value chain and should generates more incomes from a system perspective. However, whereas the goal of having 50 % gypsum from recycled construction material by 2020 is suitable and a good indicator of what could be achieved, in some of their own way the activities, visions and plans of the gypsum value chain actors are hindering an increase in gypsum recycling.

For construction companies like NCC, selective demolition of gypsum-base material is sometimes hard to carry out, which results in a large fraction of mixed waste – containing gypsum – that cannot be recycled properly. Without specific demolition standards in place it is harder/costlier to increase the recycling of gypsum. In addition, there is today no real incentive to optimize/reduce the waste from a construction site.

For waste management/gypsum recycling companies like Suez Environment companies: Gypsum construction waste consists typically of cut off pieces of plaster and boards as well as boards damaged during e.g. transport to the building site. However, contamination with other materials (e.g. paint, fastenings, screws, nails, wood and insulation materials) can make recycling of gypsum waste difficult. Indeed, when deconstructing or recycling buildings/building materials, plaster often sticks to bricks, which makes the recycling of gypsum difficult. The cost or developing new gypsum recycling/separation techniques must be justified by new regulations and several cost benefit analysis. In addition, the specifications for gypsum recycling are sometimes not only technical related but also concurrence oriented and some recycling companies prefer to handle gypsum from known customers/gypsum waste sources. This type of anti-competitive behavior can hinder the increase of gypsum recycling.

For construction site personal like joiners or carpenter, increasing gypsum recycling does not seem today as part of their job and whereas they are not reluctant to help, they simply do not have the knowledge/routines to help increase the recycling of gypsum.

For standard institutions/documentation systems like SIS, the construction standards should be developed for higher recycle rates of gypsum. This is not yet the case. In addition, the way to handle and manage standards and documents related to gypsum recycling could be improved. It is today very time consuming and not user's friendly (a "Google way" of managing documents is maybe a missing function here).

There is a consensus that activities, visions and plans among the actors in the gypsum value chain could motivate an increased recycling of gypsum. Indeed, all the actors, from the carpenter to the recycling facility managers agree that gypsum is a material that is easy to handle and to work with, and that when handled properly, could be completely recycled and lead to better cost efficiency.
This could be done by strengthening some of the existing networks in the gypsum recycling technology innovation system. These networks are groups of actors of the gypsum value chain and could be grouped in 3 main networks:

- National Research/Standards and Best Practices development network with actors like RISE, IVL, SIS, Naturvårdsverket, the Swedish Green Building Council (which operates the Building Research Establishment Environmental Assessment Method aka BREEAM - the world's longest established method of assessing, rating, and certifying the sustainability of buildings - in Sweden).
- Construction network via for instance Sveriges Byggindustrier with companies like NCC, PEAB, Skanska
- Recycling network: Suez Environment, Gips Recycling AB, Renova or Gyro

The purposes of each of these networks vary and can be summarized in the lines below.
For the Construction network on of the main purposes is to build long-lasting building with a reasonable profit margin.
For the Research/Standards network, one of the main purposes could be to develop new standards and best practices for gypsum recycling technology for a sustainable future.
For the recycling network, the main purpose is to decrease the amount of gypsum waste and recycling cost as well as increase the recycling rate.

The actions of some of the gypsum technology innovation system networks could hinder an increase in recycling of gypsum in some ways. Indeed, the construction network priorities may not be directly related to recycling of gypsum and the implementation of pilot/demonstration projects may need the help of research/standard network actors.

On the other hand, in some ways the actions of the networks can motivate an increase in recycling of gypsum. For instance, research networks are helping the construction industry to be aware of the latest technologies available enabling an increase of the recycling of gypsum. Recycling networks and consultancy networks can also promote the potential savings and benefits of gypsum recycling. The implementation at national level of EU network directives/regulation[5] can also motivate the increase of recycling of gypsum.

The mapping of the gypsum recycling TIS structures comes also through the identification of the relevant institutions related to the regulations and standards of gypsum recycling. Some national as well as EU laws, policies and standards are indeed affecting the production and recycling of gypsum. Indeed, because of the full implementation of EU Council Decision 33/2002 in April 2012, there are now only two legal ways to dispose of gypsum waste in Sweden. Number one is gypsum recycling and number tow is landfilling in a special mono-cells only accepting gypsum waste and inert waste.

Consequently, the following applies to gypsum waste in Sweden:
• Gypsum waste must be segregated from mixed waste, if it contains organic materials
• Mixed waste containing organic materials and gypsum waste, may no longer be accepted at Swedish landfills no matter how large the amount is
• Only landfills with special mono-cells for gypsum waste may accept segregated gypsum waste for disposal
• Gypsum waste may not be used as cover materials for landfills
• Gypsum waste may not be used for construction purposes at landfills

In addition to the mapping of institutions or organizations responsible for the development and standard compliance of gypsum recycling (ex: the Swedish Green Building Council which operate BREEAM in Sweden), to understand the gypsum TIS structure it is also important to understand some of the cultural aspects involved in the geographical area under study. Indeed, there are cultural aspects that affect the possibilities for increased recycling of gypsum in Sweden. As highlighted by (Bröchner, 2010) “Construction in a cold country on the periphery of Europe is affected by the merger of traditions of craftsmanship and military engineering. Centralized state control and weak professional identities have been influential. However, social and cultural traits reflected in a national management style (based on low power distance, loose control and low uncertainty avoidance) can be traced in the development of specific quality and collaboration practices in Swedish construction. Egalitarian distrust of both elitism and strong professions, expressed as a tendency for two parties to settle disputes without referring to neutral third parties, has also been identified.”[6] Adapting Sweden's construction culture of quality management and dispute resolution to a larger international/EU framework may be needed when it comes to succeeding in the implementation of International/EU gypsum recycling quality standards.

All these laws, policies, standards and cultural aspects could in some way hinder an increase in gypsum recycling. For instance, the implementation of EU directives/norms at a Swedish national level may make less relevant the development of new and more stringent national standards. Swedish culture and distrust of elitism may lead to a national and parallel recycling market which may not be compatible with recycling loops of construction companies operating globally or between EU countries. However new laws and incentives to recycle gypsum should be developed since it is still much cheaper today to not recycle - by opting for landfilling for instance - than to recycle gypsum from construction sites.

All laws, policies, standards and cultural aspects are not hindering the recycling of gypsum and some are in some way motivating an increase in gypsum recycling. For instance, the implementation of EU standards at national level may lead to synergies and new possibilities between construction companies working within the EU with intra-EU recycling loops and more circular economy within Europe. The EU council[7], the EU Commission[8] as well as Naturvårdsverket[9] are examples of institutions affecting the gypsum recycling TIS.

[5] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32003D0033&from=HR (section 2.2.3)

[6] http://www.tandfonline.com/doi/abs/10.1080/09613210210159866?journalCode=rbri20

[7] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32003D0033&from=HR

[8] https://ec.europa.eu/environment/efe/themes/waste/putting-plasterboard-waste-good-use_en

[9] http://www.gipsrecycling.se/SiteConnect/Customers/Gypsum%20Recycling%20Int/Archive/238/Brochure%20Sverige%20Nya%20bestemmelser%20om%20gipsavfall%20A5.pdf

For the structural analysis of the gypsum recycling TIS, once the actors, the institutions and the networks have been identified, it is also important to identify the knowledge and technological factors related to the TIS.
One of the conclusions from the different interviews and feedbacks from the FISAC LL is that there seem to be enough knowledge about the techniques involved in how gypsum could be recycled. The main issue preventing more recycling is mostly and organizational/management one since buildings are today demolished when they should be dismantled instead.
There may be a need for more knowledge and technological development surrounding some of the parts of the gypsum recycling value chain, namely:

- Better building dismantling technologies
- Better waste separation on construction/dismantling sites
- Better collection and de-contamination of building waste

In addition, more knowledge about how to recycle contaminated gypsum - from paint and other contaminants - is something that has also been highlighted and could be needed.

The next step of the analysis is related to the prospective TIS or what actors or activities would be needed to strengthen the innovation system for recycling of gypsum. In addition to the actors involved in current value chains for gypsum recycling, some other actors could indeed be included in order to increase the recycling of gypsum from the building sector. These actors could be:

- The virgin gypsum producer to compare the quality of raw material with recycled gypsum (though they are somehow included via the virgin gypsum used in the manufacturing of plasterboards)
- Some specialized/innovative building dismantler companies[10]
- Some gypsum/waste logistic companies to increase the number of recycling "points"

Most of these actors represent the edges of the construction sector network and hence are easy not to include since they may not be 100% dedicated to the gypsum recycling value chain and somehow not directly dependent on the gypsum market.

Indeed, the gypsum producers should be interested in seeing the progress in quality of recycled gypsum (cf. analysis of the competition) as well as the impact of a more circular gypsum economy on the finite gypsum reserves as well as raw gypsum price. In addition, the building dismantling technology developers could be interested to see how gypsum components could optimally be included in the building so that the dismantling process goes smoothly for better gypsum recycling.

To increase the recycling of gypsum some actors may be needed to be involved in some specific networks. This can be the case of specific demolition companies operating in Sweden; they may need to be included in the construction network, so the network could include the dismantling views in order to increase a better construction waste recycling, including gypsum. Including a building "dismantling" network could help the exchanges and experiences within the construction network and help the spreading of best practices on how to best recycled gypsum from buildings.

The structure of the gypsum recycling innovation system consists of the innovation system components identified above. To summarize, the four types of components are:

1. Actors: the actors involve organizations contributing to gypsum recycling, as a developer or adopter, or indirectly as a regulator or financer. The actors of the gypsum recycling TIS generate, diffuse and utilize gypsum recycling technologies through the choices they make. There is a large variety of relevant actors in the gypsum recycling TIS, ranging from private actors to public actors and from recycling technology developers to recycled gypsum adopters. The development of the gypsum recycling TIS will depend on the relations between all these actors. The gypsum recycling TIS actors can be divided into 5 categories:
    a. Knowledge Institutes (e.g. RISE, IVL, or other national and international research institutes)
    b. Education organizations: (e.g. Chalmers, or other universities)
    c. Industry (e.g. NCC, PEAB, Skanska, or other industry actors and companies)
    d. Market actors (e.g. Sveriges Byggindustrier)

[10] Taise Tecorep technology https://www.youtube.com/watch?v=_scBjJn9gqQ

e. Government bodies and Supportive organizations

2. Institutions: they are at the core of the gypsum recycling TIS. They are the formal institutions which ensure the rules related to gypsum recycling are enforced and that the policies are in place.
3. Networks: actors are usually gathered in networks. Mapping such networks is essential to understand the TIS.
4. Technology structures: they consist of the gypsum recycling facilities and infrastructures.

In the figure below, the actors and institutions of the gypsum recycling TIS which have a role in the development, diffusion and implementation of gypsum recycling technology are represented.

The different actors interact with each other in networks that develop or diffuse gypsum recycling technology, but these interactions are not shown in the pictures. The Actors, Networks, Institutions and Technology form the structural components of the TIS (see figure above).

12. Gypsum Recycling TIS Structure

Specific question can be answered to help map the TIS components and create a better understanding of the TIS structure.

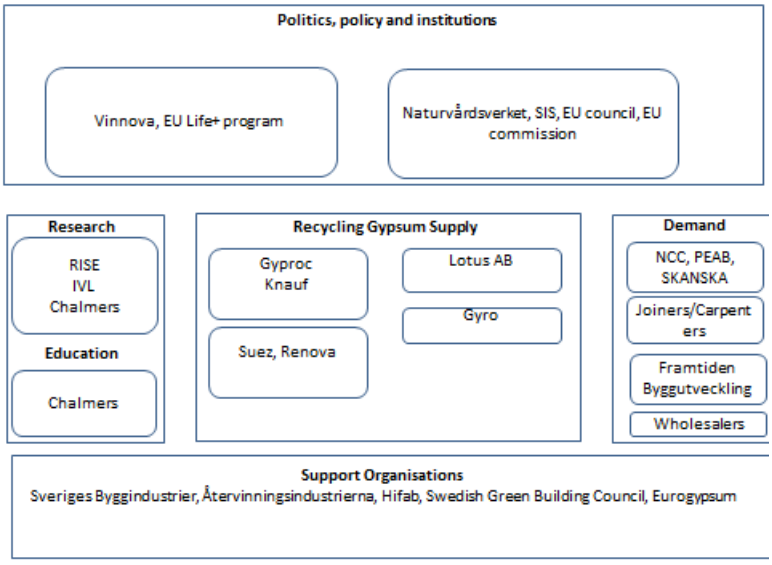

Figure 6 : Example of TIS structure for gypsum recycling (Based on Kuhlman and Arnold, 2001)

What are the technology trends? The technology trajectories/trends which involve techniques, cost, safety, reliability etc. are crucial to understand the feedback mechanisms between technological change and institutional change (Hekkert et al. 2011). Some recognizable trends in gypsum recycling technology are:

- Improved de-contamination of gypsum waste
- Complete separation of paper and gypsum powder
- Mobile gypsum recycling facilities (trailer mounted)

These are having an impact on institutions showing that circularity with gypsum is technically and economically feasible.

Who are the actors of the gypsum recycling value chain? Value Chain Analysis of the gypsum recycling industry technology trends can help relate the different organizations involved to an analysis of their respective competitive strengths. The added value brought by each organization gives crucial information about the TIS structure.

What is the state of the research related to gypsum recycling? The identification of the parties developing gypsum recycling knowledge as well as how is this knowledge growing is central in understanding innovation patterns. A list of universities, companies and government involved in gypsum recycling research is a good start.

Is there a match between gypsum recycling industry needs and the education system? Basically, the number of graduates from universities able to match the need of the gypsum recycling industry can shade and important light on the functioning of the innovation system (Hekkert, 2011).

What does the market demand look like? A driving force to an innovation system is a well-articulated demand (Pol 2006). The difference between private demand and governmental demand on gypsum recycling can also give an idea about the TIS structure.

What are the policies related to the gypsum recycling TIS? The gypsum recycling policy goals as well as the policy instruments in place are an important aspect in understanding the functioning of the TIS.
Who are the gypsum recycling facilitators? Between Universities, Industries and Governments involved in the gypsum recycling TIS there are facilitators who engage collaboration between parties. Identifying these facilitators helps understanding the TIS structure.

What does the gypsum recycling network look like? Building a graph-based structure of the gypsum recycling TIS can be very complex but it can help understand who the central players in the TIS are.

13. Conclusion

A TIS analysis of gypsum recycling in Sweden has been started to analyze gypsum recycling innovation trajectories, identify its barriers and opportunities for development and potential ways forward. The first step in the TIS analysis looked at the gypsum recycling system structure, that included a delineation of the gypsum recycling technology innovation and its value chain, the actors and network driving its development by supporting different elements of the value chain and the institutions, which are the regulations, norms and values supporting or hindering the development of the gypsum recycling innovation system. This analysis gave an indication of the gypsum recycling development phase in Sweden, i.e. concept, demonstration, niche market, commercial or mature, and what lies ahead.

As a part of the FISAC model the TIS analysis used as described in this report has proved to be useful in identifying barriers and possibilities where a combined approach of multiple actors have been necessary in order to overcome barriers and to properly utilize the full potential of the possibilities. For the Swedish example, the LL partners and stakeholders identified regulatory gaps as well as e.g. competence gaps that prevented an increase of the recycling of materials in the construction sector. As the LL allowed for discussions and knowledge sharing between multiple actors within the construction value chain, the LL could utilize the full force of the value chain. In other settings individual issues are tackled, but in the LL setting there is a way of connecting the individual issues to the greater context of the entire value chain. There is also the possibility to work with social, legislative and technological issues, barriers and possibilities in conjunction, in a way that more closely resembles real world settings where these different aspect cannot be easily decoupled and must be solved together in order to reach a stage where implementation can be seen throughout society and where innovation is reached.

14. Appendix A

Structural element	Questions about the current innovation system
Actors and value chain	What are the actors in the value chains for productions and recycling? What vision and plan does each actor have (that affects recycling)? Is the vision and plan the same for the whole organization? What would increasing the proportion of your materials mean for each actor (in general and in terms of cost and income)? In what way are the activities, visions and plans of the actors hindering increased recycling of the material? In what way are the activities, visions and plans of the actors motivating increased recycling of your material?
Networks	In what networks are these actors involved? What are the purposes of each network? In what way are the actions of the networks hindering increased recycling of the material? In what way are the actions of the networks motivating increased recycling of the material?
Institution	What laws, policies and standards are affecting the production and recycling of the material? Are there cultural aspects that affect the possibilities for increased recycling of the material? In what way are laws, policies, standards and cultural aspects hindering increased recycling of the material? In what way are laws, policies, standards and cultural aspects motivating increased recycling of the material?
Knowledge and technology	Is there enough knowledge about how the material could be recycled? Or is there a need for more knowledge and technological development? (i.e. lack of knowledge is a hinder for recycling of the material)

Structural element	Questions about the prospective innovation system
Actors and value chain	In addition to the actors involved in current value chains for the material what actors would need to be involved in order to increase recycling of the material in your region? Which industrial sectors do these actors represent? Is it likely that actors from this industry would be interested to be involved in the activities needed for increased recycling of the material?
Networks	What actors would be needed to be involved in a network (additional to the current ones) to increase the possibilities for recycling of the material? What would be the purpose of this network? (e.g. lobbying, increasing public support, exchanging experiences).
Institution	-
Knowledge and technology	-

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