Co-Evolution of Business Strategies in material and construction industries and public policies

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Traditionally, gravel, cement and concrete producers focus on their role as material or resource suppliers. The higher the material turnover, the higher the economic success. Hence, the business-model is in conflict with the societal goal of increased resource efficiency. Driven by stricter regulations, some companies have recently developed new business models focusing on additional services in waste-management and logistics. From a policy perspective, such diversification strategies are very interesting because they accelerate changes in economic structures that lead to increased resource efficiency. In our project, we analyse how this development could be further encouraged. We introduce the term "co-evolution" describing a process of mutual learning between representatives of public policies and business. To this end we use system dynamic modelling in combination with integrated assessment. In our transdisciplinary research approach, we collaborate closely with stakeholders in industries and public policy using group-model-building. Data is collected in case study analysis with seven different companies producing sand, gravel, cement, concrete and services in logistics, construction and waste management. Both system dynamic and assessment model are based on Material-Flow-Analysis on different scales (company and region). It proves to be a valuable tool to ensure consistency of both models as well as data quality. First results show that different policies in waste-management, resource-management and settlement development have a strong effect on decision making in material and construction industries.

1. Introduction

Traditionally, gravel, cement and concrete producers focus on their role as material suppliers. The most important share of their value creation is situated up-stream in the production chain including excavation, crushing, production of cement, gravel and concrete and transport. Their economic success depends on material turnover and conflicts with the societal goal of increased resource efficiency.

In recent years, some companies diversified their portfolios with additional services in waste management and logistics. These innovations are driven by policies in public procurement, waste management and spatial planning. From a policy perspective, such diversification strategies are promising as they accelerate structural changes fostering resource efficiency. This relates to SDG 12 «Responsible consumption and production» and SDG 11 «Sustainable Cities and Communities».

Yet, economic structures in the material and construction sector in Switzerland start to change as construction activities decrease and markets for construction materials are saturated [1]. Whereas new business models – up to now – helped to increase market shares in growing markets, they will now be crucial for a company's economic future. As a result, many companies are reviewing and adapting

their business models (see e.g. [2]). The success of different business models will – again – be strongly influenced by public policies. This relates to SDG 9 «Industry, innovation and infrastructure».

Against this background, the research project «Co-Evolution of Business Strategies in material and construction industries and public policies» funded by the Swiss National Science Foundation investigates the co-evolution mechanisms of construction industry business models and the corresponding public policies, in view of a circular economy. Co-evolution in this context refers to the interdependent evolution of public policies (the regulatory environment) and market performance of private sector companies. Successful co-evolution occurs when economic outcomes improve in parallel with resource efficiency, which is the focus of public policy. In this paper we explain our research design and present preliminary results. In the conclusions we discuss our insights on transdisciplinary research combing system dynamic modelling and integrated assessment based on Material Flow Analysis in the context of management of material, energy and natural resources.

2. State of research

In socio-technical systems, long periods of slow change are interrupted by periods of radical change [3]. These periods are transitional shifts, governed by reinforcing feedback, where systems move from one dynamic equilibrium to another [4]. In this context, the term co-evolution is used if «the interaction between different societal subsystems influences the dynamics of an individual subsystem, leading to irreversible patterns of change» [5]. Research on co-evolution and transition research has been focused on ex-post analysis [5] empirically investigating interdependencies between different societal subsystems, e.g. environmental regulation and competitive performance [6], environ-mental taxation and resource management [7], alternative business models and mass market players [8].

In the recent decade the framework for transition management has been further developed and applied for ex-ante analyses of the processes facilitating transitions towards sustainability [4]. Methodologies for transition managements involve transdisciplinarity and typically follow multi-method approaches. Quantitative modelling is frequently used as a tool, integrating heterogeneous disciplinary knowledge as well as knowledge and values from scientific and non-scientific origin [9]. In our project, we develop simulation models for analysing and facilitating co-evolutionary transition processes for construction industries. Simulation models are increasingly developed and/or used within participatory or transdisciplinary approaches [10][11]. The integration of simulation models in transdisciplinary processes requires hybrid frameworks where multiple qualitative and quantitative methodologies are applied, making use of a combination of existing quantitative sources, case studies, and stakeholder input (for example [12]). In our project, we use the following modelling approaches:

- **Material Flow Analysis**: MFA is a method to investigate processes and their dependencies in a company or industry. In the construction industry, and especially in waste management, various studies have been carried out in recent years. An overview can be found in [13]. Many studies focus on stock-flow-models of defined regions [14].
- **Assessment models based on Material Flow Analysis**: Material flow analysis can be used in combination with environmental and economic performance indicators (see [15] for an overview). For environmental assessment, material flows in production chains are analysed and the significance of potential environmental impacts is evaluated. For economic assessment, MFA is considered as physical input-output analysis (PIOT), analogous to economic IOA, and combined with data on prices of products and production factors [16].
- **System dynamics (SD) modelling**: System dynamics is a computer-aided approach to policy analysis and design. It applies to dynamic problems arising in complex social, managerial, economic, or ecological systems — literally any dynamic system characterized by interdependence, mutual interaction, information feedback, and circular causality [17]. Co-evolutionary processes involve delays, feedback, tipping points, and path dependency. In addition, the impacts of transition policies tend to have unanticipated consequences. They thus lend themselves particularly well to

the use of dynamic, quantitative modeling approaches. System dynamics has been used successfully to support socio-technical transition management processes [18].

3. Methods and data

The main challenge in our project is to identify and understand contemporary co-evolution processes in the construction industry. The research is embedded in a transdisciplinary setting, involving stakeholders of the Swiss construction industry, with the goal to direct the transition towards realignment of societal goal of increased resource efficiency with business goals. The guiding research questions for the project as a whole are:

(i) What are the central co-evolution mechanisms driving alternative business models and regulation in the Swiss construction industry?

(ii) How can this co-evolution process be directed towards sustainability?

To answer these questions, we develop a system dynamic model and an assessment model (see subsections 3.1 and 3.2).

3.1 Assessment model

The model developed in this study combines MFA with data from LCA and prices/costs to evaluate a region and/or company ecologically and economically

To investigate the processes and inter-industrial dependencies of the companies or regions, we use Material-Flow-Analyses – as first step - which include all relevant processes and materials of the mineral building materials industry. From these MFAs, Physical-Input-Output tables (PIOT) are then generated.

The data basis for the material flows of the region is provided by an existing data base (named KAR-Model) that has been developed in many studies commissioned by cantonal administrations for nine cantons over several years including data on material flows exchanged between cantons and the neighbouring countries [1]. It allows us to analyse different case studies on regional scale – comparing regions with different characteristics such as density of settlement, etc.

In order to map the Swiss construction industry, we selected seven companies as case studies that cover all production steps in the value chain of construction minerals, ranging from material extraction, over processing virgin/recycling aggregates, producing cement and concrete, constructing building and providing services in logistics and waste management. Most companies' activities in this study focus on concrete production with a variation in the degree of vertical integration. In different workshops data was collected on material flows as well as costs/prices and validated with data from official statistics and statistic of trade associations, e.g. [19].

The assessment model combines economic and ecological assessment:

- **Economic assessment based on value added**. The value added represents factor income generated by labour and capital on regional scale and is used to indicate economic effects. It relates to SDG 11 «Sustainable Cities and Communities» as the regional economy benefits from urban development. On a company scale, factor income is analysed in the production chain by subtracting material costs from material turnover. Any upstream chains and the resulting costs outside the system boundary are not considered in the analysis. Costs and turnover are both estimated by multiplying material flows with material prices to obtain a monetary Input-Output table (MIOT). For the study, market prices of Switzerland are used, which were verified by interviews in the case studies.

- **Environmental assessment based on Global Warming Potential (GWP), Cumulative Energy Demand (CED), resource and landscape conservation.** These indicators reveal how much the industry harms the environment by pollution and resource consumption. It relates to a number of SDGs, including SDG 13 «Climate action». Yet, our focus is on consumption of natural resources on regional scale. To evaluate these environmental impacts, the obtained MIOTs are extended with

emission coefficients by linking coefficients for emissions/resource consumption from the database ecoinvent (version 3.4) and data from the MFA-model.

3.2 System dynamic model

The system dynamics models conceptualizes balancing and reinforcing feedback mechanisms that a) to stabilize the current regime and impede a transition towards circular economy; and b) accelerate the transition to a circular economy. A quantitative simulation is used to analyse and design public policies that can accelerate that transition.

We conducted a series of transdisciplinary group model building workshops with a panel including 10 experts from industry associations, public administration and environmental NGO (ongoing workshop series, 4 three hourly workshop sessions already conducted, 2 workshops remaining for designing public policies and an implementation plan). The group model building participants are the «model owners» and participate in important modelling decisions. Between the group model building sessions, information from the group model building session are synthesized into a consistent model and triangulated the information from the group model building session with other information (material flow data from MFA, data from semi-structured interviews with case study partners).

The first two workshop were dedicated to problem definition and dynamic hypothesis formulation and took place before the MFA analysis. The initial challenge was to identify adequate system boundaries of the material and construction system of Switzerland with the participants. Therefore, we conducted three standard «group model building scripts» ([20], [21]) to help eliciting the problem understanding, initiate the modelling process and data collection, based on a shared problem hypothesis.

We conducted case study interviews to validate assumptions about business policies of companies. Additionally, we used MFA data for a model region (annual MFA data from 2012 to 2017), historical and current price data and cost data to calibrate the model. We triangulated this information with the dynamic hypothesis from the first two group model building workshops. During this triangulation process, we iteratively built first drafts of a system dynamics simulation model.

The GMB workshops 3 and 4 formed a learning process, in which the group model building panel completed the model. According to [22] a model is considered valid when the model is judged as convincing by group model building participants and the assessment of the policy designs does not change as additional information was added. Model validation is based on (i) formal model testing (e.g. [23]); (ii) comparing model parameters, variables, relationships and behaviour to existing theory and empirical data hierarchically on different levels [22]; and (iii) building confidence in the model validity in a community represented by the GMB panel members ([23], [24]).

4. Results

In the first two years of our research project we analysed business models of six companies as case studies and carried out four workshops in the group model building process. We started developing a system dynamics model as well as an assessment model and used first model prototypes for case study analysis of specific material and waste management systems on regional scales. Our preliminary results are summed up in the following two subsections.

4.1 Assessment model

We used the model prototype of the assessment model to analyze individual companies (as part of the case study analyses) as well as three regions: the cantons of Argovia and Thurgovia and the upper Rhine valley in the north of canton Grisons [25].

The assessment on company level showed that

- Environmental impacts are dominated by cement production (cumulative energy demand, global warming potential), extraction of primary resources and landfilling of CDW construction and demolition waste (resource and landscape conservation). Yet, most gravel and concrete producers have no influence on cement production.
- Most value added is created in cement production and construction activities. There are two important co-production processes: (i) gravel extraction and landfilling of excavated materials as well as (ii) processing of recycling aggregates and waste management of CDW. Both co-production processes create a comparable amount of value added per output unit.
- Primary gravel is mostly substituted with excavated material (with a high gravel content) whereas recycling aggregates are of minor importance.

The assessment on regional level confirm the results on company level. There is a trade-off between economic benefits from construction activities on a regional scale and induced environmental impacts, which cannot be resolved by gravel and concrete producers alone. Their contribution to economic benefits is small and their impacts on the environment are primarily relevant on local scale. Only around 5% (cantons Thurgovia and Aargovia) of all factor income generated in the value chain of construction materials can be accounted to gravel and concrete produced within the region (including related waste management services). The remaining 95% are generated in construction activities including their supply chains from other industries. For these reasons, business models in gravel and concrete production don't have a major influence on eco-efficiency on a regional scale.

Yet, gravel and concrete producers contribute significantly to closing material cycles of construction minerals on regional scale. Their strategy aims at saving primary gravel as well as managing volumes for depositing mineral construction waste and excavated material. It also increases efficiency in transport logistics. In a case study for the upper Rhine valley we could show that the amount of virgin gravel/sand extracted per year could be decreased by 44% if all excavated material was used in gravel production.

4.2 System dynamic modelling

We identified a lock-in situation to the status quo, blocking the uptake of secondary resources. In many Swiss regions gravel producers earn more money by depositing excavated materials (in empty gravel pits) than by producing gravel. As a result, current prices for gravel are low and it is not economically beneficial to produce aggregates from mineral construction waste or excavation material. This lock-in situation was repeatedly reported by case study partners.
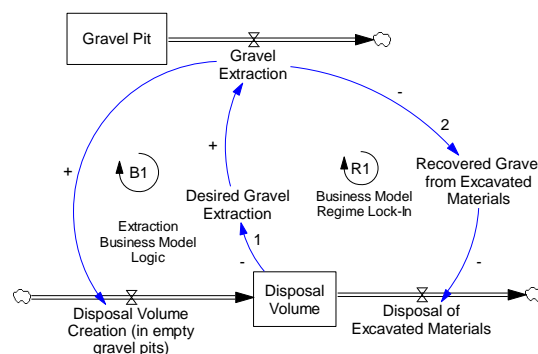

Figure 1: Stock and Flow Diagram including business policies that explain the extraction business model lock-in. Adapted from Kliem and Scheidegger (see [26]).

Figure 1 shows a stock-and-flow diagram representing an extract from a larger model [26] that visualizes the lock-in dynamics.
Firstly, the diagram shows relevant material stocks and flows (Disposal Volume, Gravel Extraction, Recovered Gravel from Excavated Material, Disposal of Excavated Material). Secondly, it includes

causal relationships representing business policies, as reported in the case studies. For example, arrow «1» reads «if the disposal volume is low, companies operating gravel pits desire extracting more gravel (in order to create new disposal volumes).» Arrow «2» reads «if gravel extraction is high, companies recover less gravel from excavated materials (because gravel prices are low).»

Connecting the physical material flows to current policy decisions, resulted in a model showing the feedback structure causing a lock-in to primary resource consumption. The feedback loop B1 represents a balancing feedback loop intended by the companies of the gravel sector: if disposal volume is low, they extract more gravel, and create thus empty space for disposal. The feedback loop R1 is reinforcing and describes the lock-in origin: the more gravel extraction, the less recovered gravel from excavated materials, the more disposal of excavated materials; this reduces the disposal volume, thus companies extract more gravel.

Combining a MFA with associated policy mechanisms sharpens the focus on a selected dynamic problem. A quantitative system dynamics model allows the analysis of policy interventions, and helps to understand the long-term effects of policies, while reducing the risk of unintended consequences. The model accounts for material flows, material stocks as well as relevant informational feedback. This perspective helps to consider important non-linear policy feedback mechanisms when analysing and designing transition policies.

5. Conclusions

MFA and SD practice starts from slightly different ontological and epistemiological positions [27]. On a continuum from a «subjective» to an «objective» approach to science, both are rather positioned on the «objective» side. However, the way SD is used in this project suggests a slightly more subjectivist perspective. The «model owners» in the GMB workshops participate in modelling decisions, and their point of view directs the modelling of the causal mechanisms explaining the dynamic problem. However, the modeller make sure that the model is consistent with basic physical laws and that model validation principles are respected. This way, SD is ideally suited to bridge from MFA – taking an ontologically realist and epistemiologically positivist position – towards a more subjectivist view required for conceptualizing and designing transition dynamics in socio-ecological systems.

From a SD perspective, MFA helps analysing the «physical backbone» of resource management systems. MFA uses a very simple modelling approach, based on mass balancing of material or substances. It is a suitable tool to develop a consistent data base for material extraction, processing, use and deposition, especially in cases of poor data availability. It aims at developing robust input-output models taking account of uncertainties and supporting data validation. This is very important in our project for case study analysis, because companies do not provide complete and consistent data sets. In this sense, MFA is an excellent tool for pre-studies in system dynamic modelling.

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In addition, MFA can reveal information on system dynamics if used to calculate time series for material flows. In our project, we could use an existing MFA data base that has been developed and applied for over a decade to analyse material flows of gravel, excavated materials and mineral construction waste over time. It proves to be a very valuable data source to model system behaviour.

The MFA-based assessment model reveals which processes or sub-systems are most relevant in transition towards a more sustainable economy - with respect to goals defined by the «model owners».

From this starting point, SD-modelling can focus on a specific puzzling dynamic problem. In our research project, we identified extraction of gravel and deposition of CDW as key issues. We, therefore, decided to focus on co-production of virgin gravel and deposition of excavated materials.

From a MFA perspective, SD-modelling helps identifying and describing dynamics of resource management systems. MFA models can be either time depended (if time series data is given for exogenously defined parameters) or driven by dynamics of material stocks (e.g. stocks of buildings). Yet, they cannot capture dynamics caused by feedback loops within the system or include knowledge about the reaction of processes to economic incentives or changes in the regulatory system. SD-modelling can fill this gap. In our project, we reveal that relative prices of virgin gravel and recycling aggregates are influenced by co-production of virgin gravel and deposition of excavated materials. If excavated materials can be used to refill empty gravel pits, prices for virgin gravel will fall. As a result, there are little economic incentives to use recycling aggregate as substitute for virgin gravel.

This research approach can be transferred to other regions outside Switzerland. Yet, it requires a very good MFA data base as well as a relationship of trust between research groups and industries.

6. Outlook

The results obtained in this project can directly transferred into practice, as they provide the basis for:
- **Recommendations** for actors from politics and administration for the development of measures and instruments for a recycling economy in the construction industry and for the promotion of an efficient use of mineral raw materials (effectiveness analysis of policies). In the final year of our project we will evaluate different public policies such as (i) taxation of gravel extraction or imports and (ii) policies to grant permissions for gravel extraction or deposition of excavated materials.
- **Improved decision bases** for companies in the construction industry to further develop their business models towards sustainable development. In the final year of our project we will evaluate how different business models perform with respect to goals of sustainable economic development represented by our indicator set (factor income, Global Warming Potential (GWP), Cumulative Energy Demand (CED), resource and landscape conservation).

To these aims, both models will be used together for scenario analyses, combing scenarios for (i) development of parameters outside the system focusing on alternative future developments of the built environment and (ii) parameters influences by alternative public policies.

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