

The co-evolution of business models and public policies in transitions - A system dynamics perspective

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Abstract. The role of the construction and building sector as parts of national metabolism is prominent in national sustainability agendas. Growing building stocks require continuous input of concrete, containing natural resources, such as gravel and cement. The output of construction demolition waste and excavation materials constitutes a major material flow that is either recovered or disposed. This study simulates the dynamic interactions between the gravel sector and its governing public policies. We find that public policies and business strategies co-evolve towards lock-ins, creating barriers in the mineral construction material industry towards sustainable production and consumption practices. We find that the low-price elasticity of mineral construction materials requires nation-wide policy interventions to reduce the demand for land and improve material efficiency. Thereby, a significant contribution to SDG 11 and SDG 12 is possible.

1. Introduction

The construction industry accounts for around 42% of Europe's energy consumption and is responsible for more than 50% of the European material extraction [1]. The inflow of resources into the European building stock significantly exceeds the discarded volumes, resulting in continuous stock growth [2], highlighting the importance of a transition towards a circular economy, but more importantly the responsible management of primary resources. Primary aggregates for the built environment, in loose form or concrete³ are the second most consumed material after water, being fundamental to societies infrastructure [3]. To reduce the environmental burden of construction materials, saving primary resources and recycling of construction and demolition waste (CDW) and excavation material are key to impact the most significant mass flows [1,4]. The associated environmental and social impacts differ during the life cycle stages of the built environment. To improve the social and environmental sustainability of the industry sectors, public policies are a prominent enforcing mechanism. The European commission's research on policy and framework conditions focusses on landfill restriction, regulations of waste management, enforcement of regulation, public procurement, recycling facilities, public sector involvement and public perception, awareness and acceptance [5]. This study investigates how public policies can help accelerate an industries sector transition towards sustainable resource management in a circular economy.

2. Literature

Policies for systemic transitions are complex issues that require economic, social, ecological and political change [6]. Policies that attempt to direct these transitions need to account for the social reality and agency of embedded actors [7]. The social reality of organizations defines which phenomena is considered relevant, and agency defines the impact of potential interventions. These policy interventions are a governance response to an observed phenomenon and a perceived problem, aiming at improving certain conditions. This implies, that public policies respond to the output of the industry, to improve the systems performance. Depending on the systems response in relation to

higher system goals, the policy is remains or is adapted to the new conditions. This process indicates a dynamic relationship between the industry sector and public policies, evolving towards more sustainable modes of production and consumption. Such interdependent developments among subsystem, have been defined as co-evolutionary developments of socio-technical systems [8,9]. While these co-evolutions aim at improving sustainability performances, socio-technical systems often appear to be in a state of lock-in to current practices [10]. We take a co-evolutionary perspective to understand how public policies can unlock transition dynamics within the mineral construction material industry. The focus of this study is sustainable resource management of excavation material.

3. Methodology

A quantitative System Dynamics (SD) model is developed to overcome the limitations of a static MFA model, driven by exogenous parameters. In three stage process, an endogenous perspective on the system is built. First, we understand the perceived problems of governing actors, by identifying dynamics of major Material-Flows and their relation to the goal of the organization. Secondly, we connect the relevant decision-making rules of public policies and construction material companies to problematic material flows. Thereby we identify current policies that explain the observed behavior of the systems from an endogenous perspective [11]. Existing Material flow data [4,12] are used to formulate causal relations regarding the co-evolution of the policy and industry sector. The causal hypotheses are gathered in group model building workshops with relevant policy actors that govern the industry sectors We apply traditional SD stakeholder-based design according to [13,14], engaging the participants in the process of building a simulation model. This process requires (1) a problem articulation, (2) the development of a dynamic hypothesis, (3) formulation of simulation model, (4) testing and validation of the model and (5) the formulation of potential strategies and evaluation. While this traditional setting is focused on the input of the experts, this study triangulates the causal explanations behind observed phenomena with additional data. This data is required to evaluate the articulated problems of the experts, and to present the perspective of the companies in the construction material industry. To test the policy goal of improving resource efficiency, this study uses Material-Flow-Analysis (MFA) to evaluate the articulated problems, and case studies with companies to identify relevant reactions to changes in the policy environment. This process is designed to provide an endogenous perspective on the perceived reality of both policy and industry actors. Using material flow analysis to assess the perceived problems and workshops with companies to understand their reaction to policy induced changes in their environment, will provide the empirical basis for the quantitative simulation. Ultimately, the participants in the group model building workshops design policies towards initially agreed upon goals, such as reduced consumption of primary raw materials and security of supply and waste disposal.

4. Case study

Urbanization, higher environmental regulation regarding groundwater protection and the Not-in-my backyard (NIMBY) phenomena are among the reasons why access to gravel reserves in Switzerland is shrinking [15]. The shortage of accessible gravel quarries is accompanied with an surplus of excavation material from construction sites [4], which is usually disposed in gravel quarries after the end of mining activities. To contest the disparity between gravel demand and available landfill volume, public policies for a transition towards a circular economy are discussed on various political levels [15]. While circular economy policies are considered necessary by the mineral construction material industry sector and public policy actors, existing policies face policy resistance [7,15]. To understand the drivers and barriers to circular economy practices, this case study focuses on a canton (ZH) with the following characteristics: Construction activity is high, excavation material volumes exceed primary gravel extraction volumes, potential gravel quarries are scarce and material transport distances are high. Recent data shows that construction activity in canton ZH is on its highest level

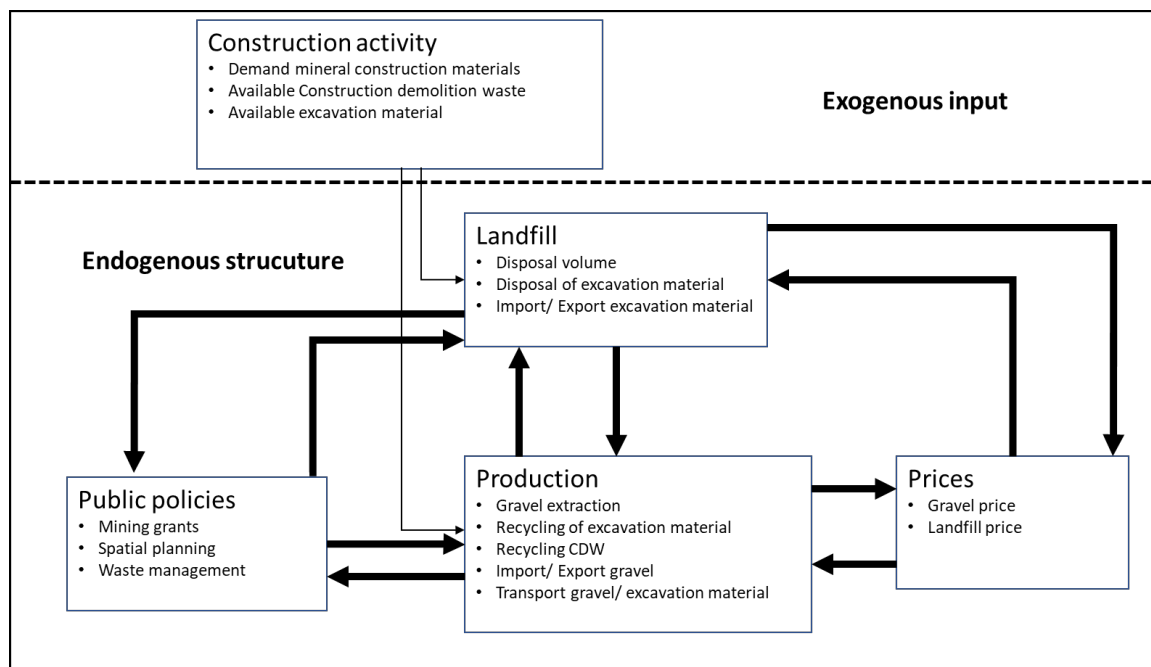


Figure 1 - Sectoral diagram

since 1954 [16], excavation material volumes exceed primary gravel extraction volumes by 12%/year [4], potential gravel quarries are scarce and material transport distances are high (15-30 km) [17].

Figure 1 provides a sectoral overview on the relevant system structures. Each sector is causally linked to other sectors, an aggregated causality is represented by the bold arrows. The model assumes an exogenous construction activity that drives the demand for materials and determines the output of construction and demolition waste and excavation material. The material outputs are either disposed in landfill or recovered with existing production capacities. Gravel extraction supplies the local gravel market and results in available landfill volumes. Mining grants can be extended beyond the granted time period of mining, instead enforcing the closure of gravel quarries. Thereby the extraction rates can be adjusted to changes in demand. A shortage of gravel or landfill volume increases the respective prices for gravel or landfilling or excavation material. Depending on these prices, the profitability of gravel extraction, recycling and landfilling is determined within the canton ZH. A finding of the model building process is the insignificant price elasticity of gravel. We identified no Feedback of the price to the demand for gravel, hence making the demand an exogenous variable. The material costs on construction projects are negligible, hence a change in gravel price does not reduce the demand. Regarding the production costs of gravel, the model assumes an operative cost advantage for extraction in relation to recycling. While extraction activities have high fixed costs, (due to high initial investments in licenses), the variable costs are comparably low. Recycling activities on the other hand are subject to rather low fixed costs, but variable costs are higher (due to a higher land use and capacity requirements to produce recovered gravel). If the price difference to neighboring cantons increases, import and export of gravel and excavation material is possible. Public policies in Switzerland are enacted on a local level and follow national guidelines. Relevant public policies are concerned with the (1) uptake of alternative building materials (2) licensing of mining grants and (3) market-based tax instruments. In an iterative process, we used System Dynamics tools and techniques to simulate dynamic regional material flows with attached relevant decision-making rules. The resulting quantitative simulation model uses causal structures to explain system behavior under different policies.

Based on this model conceptualization, the behavior of canton ZH under three different scenarios is analyzed. These scenarios are based on perceptions regarding policy interventions, which have been elicited from the group model building workshops. The exogenous inputs for primary gravel demand, available excavation material and available CDW remain constant in the following scenarios (except gravel demand in scenario 1). All policy interventions are introduced in year 5 out of 50.

Scenario 1 assumes a reduction of the demand for primary gravel due to the usage of alternative construction materials. By changing civil engineering practices, it is assumed that a reduction of the gravel demand is possible. The scenario tests if recovered gravel covers a larger share of the demand.

Scenario 2 analyses the industry sectors response to a change in mining and spatial policies. It is argued that reducing the access to land for mining will lead to an increase in recycling activities. By simulating a ban on further mining licenses, the validity of this argument is simulated.

Scenario 3 analyses market-based intervention, such as the introduction of a levy on mining. It is studied, whether the attractiveness of recycling activities increases by an increase in costs for mining.

Table 1 - Scenario overview

| Scenario | Argument | Model variable | Input |
|----------|---|-----------------------------|----------|
| 1 | “Reducing the material demand reduces demand for land” | Primary gravel demand | - 50% |
| 2 | “Reducing the access to natural resources stimulates recycling” | Licensed gravel quarries | 0 t/year |
| 3 | “Introducing a levy on extraction makes recycling financially attractive” | Costs for gravel extraction | +10% |

4.1.1. Scenario 1- Supply of recovered gravel

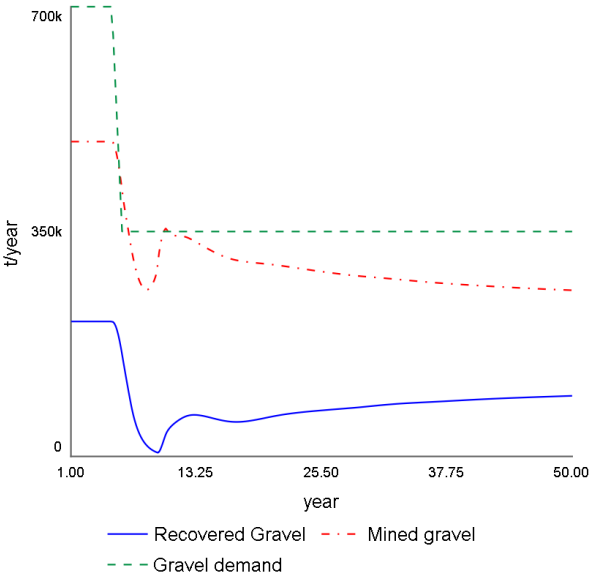


Figure 2 - Simulation scenario 1

The model is initialized in a steady state, in which 30% of the gravel demand is covered by recovered gravel from excavation material. This estimate is deducted from regional Material Flow analysis [12] and indicates that companies already recycle excavation material, such that has a high gravel content.

The simulation of the aggregated industry sector shows that a reduction of the gravel demand by 50% leads to a reduction of the relative share of recovered aggregates in the short-term. Figure 2 shows that the recovered gravel from excavation material approaches almost zero and oscillates for 10 years. These oscillations are due to the time delay until the available mining licenses approach are reduced to desirable levels, relative to the market demand. The scenario highlights that the licensed volumes for extraction in relation to the demand for gravel play a significant role

in the company’s decision of whether to increase the recycling of excavation material or not. Despite the public policy of extending extraction licenses beyond initially permitted periods, companies have an incentive to cover the demand for gravel by extraction rather than recycling. This incentive is driven by the profitability of the created disposal volumes. These landfill volumes generate more profit, in times of structural oversupply, than a company could generate with recovering the gravel from disposed excavation materials.

4.1.2. Scenario 2: Restricting the access to gravel quarries

A central problem for communities is the shortage of landfill volume, expressed as landfill coverage (Available landfill volume/Excavation material). The structural misbalance between available landfill volume and extraction of gravel is expected to continue[4]. To reduce the shortage of landfill volume, a prominent claim is to increase the share of recycling of excavation material by introducing stricter spatial planning and waste management policies. These policies could be restricting the access to primary gravel resources and thereby increase the pressure on companies to recover secondary resources. The following scenario tests this claim (starting year 5). Figure 3 shows that the reduction in mined gravel

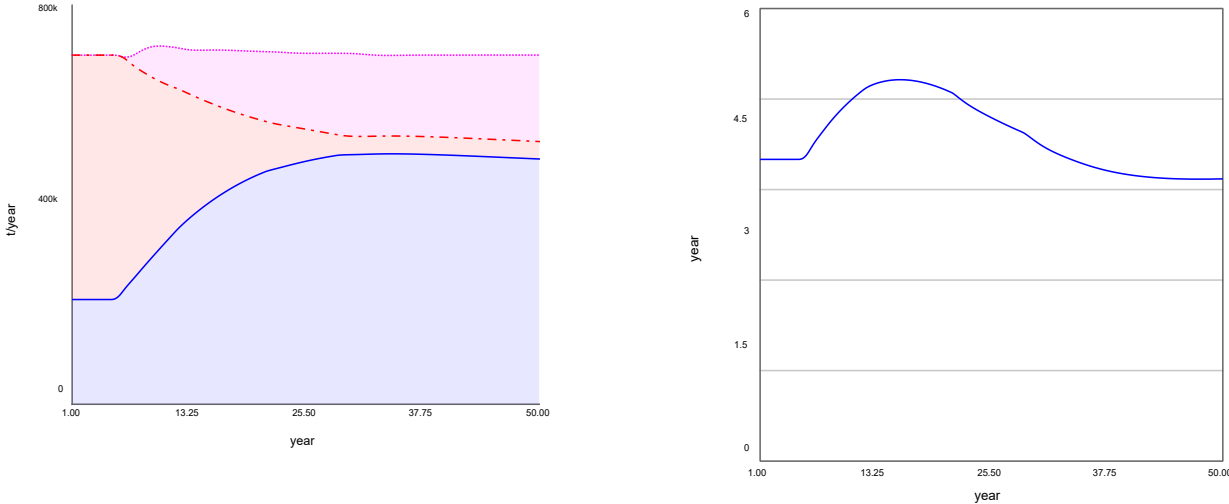


Figure 3 - Simulation scenario 2

is substituted by recovered gravel from excavation material and gravel imports. Despite the positive effect on the share of recovered material, the impact on the landfill coverage is accompanied by an increase of gravel imports. The lack of local gravel quarries and growing gravel imports increase the pressure on the local landfill volumes Imports of gravel contribute to the lack of landfill volumes, as they are not locally mined and thereby do not create local landfill volume. While the policy succeeded at improving the amount of recovered material, it did not create a long-term solution for improving the landfill coverage. If the local supply of recovered aggregates increases, the mined gravel volumes and consequently the created landfill volumes are proportionally reduced to avoid an oversupply of the local gravel market. Hence the landfill coverage cannot significantly be improved by increasing recycling quotas, due to the proportional reduction of gravel mining and an increased gravel imports. While the local material efficiency can be increased, the reduced local demand for land is potentially re-emerging in the importing region. Maintaining a desired landfill coverage while reducing the demand for land are central units of measurement in spatial planning and waste management policies, the simulation has shown that there are potential goal conflicts.

4.1.3. Scenario 3 – “Market-based” Intervention

To increase the incentives for recycling of these aggregates, Levies on the extraction of primary gravel have been part of the public discourse for years in Switzerland [18]. Such levies were successfully implemented in various countries, most notably in the UK in the 2000’s [19]. Local levies on primary gravel extraction reduce the relative profitability of mining and increase the attractiveness of excavation recycling. It is assumed that the levy will be passed on to the consumer via price increases. This scenario adds a levy of 20% of the gravel price to costs for mining in the region.

The simulation considers the federal structure of Switzerland, assuming that only the canton of interest introduces this levy, while the neighboring cantons remain without the levy. As a result, the

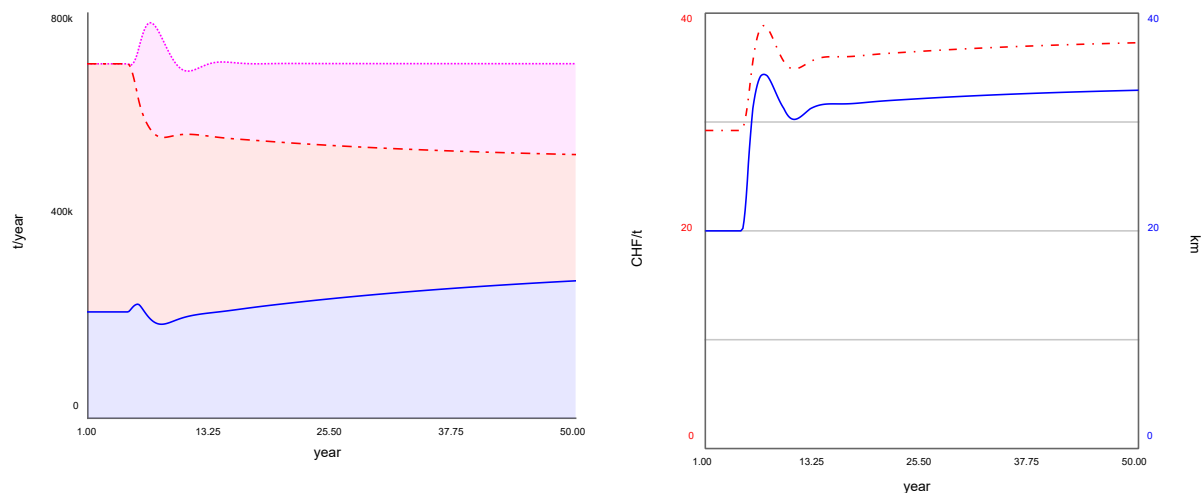


Figure 4 - Simulation scenario 3

regional gravel price rises above gravel prices in neighboring cantons. Consequently, gravel imports are profitable as long as transport costs do not exceed the price delta. Figure 4 shows that with the introduction of the 20% price surge, the maximum feasible transport distance increases by more than 50%. [17] came to comparable conclusion, concluding that transport costs of high volume and low value products increase non-linear with increasing transport distances. The rule of thumb for gravel is a doubling of transport costs for every 30 km transported by truck. This simulation demonstrates the negative impact on the region economy, by increasing competition from neighboring cantons and the associated rise in transport emissions. This scenario shows the relevance for cantonal policies to consider the framework conditions in neighboring regions. During the Group model building workshop, the discussion on levies was welcomed by public policy designers and industry representatives, since current financial flow and benefits for local communities are untransparent. The implication for the introduction are further discussed in the following chapter.

5. Discussion

The case study on the gravel and landfill sector in Switzerland has shed light on the decision-making processes that drive the dynamic interaction between the gravel industry sector and governing public policies. The results indicate that legislation regarding the management of natural resources, especially spatial planning, waste management and environmental protection influence the decision-making of companies in the industry sector twofold: (1) Access to natural resources, as without access to gravel the recycling business model was naturally more prominent, (2) Prices for gravel and costs for

extraction and recycling. In contrast, the governing public policy sector focused their decision-making on (1) Resource coverages, such as self-sufficient supply of gravel and landfill volume, (2) Environmental impacts of mining activities, such as loss of biodiversity, ground water protection and noise pollution, (3) Resistance of local communities. By understanding the basis for these decision-making processes, we argue that it is possible to improve the performance of the system. Significant sustainability performance improvements of the mineral construction material industry are limited to (1) land use and (2) transport. Resulting from the simulation model, we conclude that in a market-based system, public policies need to introduce a levy on the extraction of natural resources.

- Levies must benefit the local communities, to reduce the resistance against local mining activities. Financial compensation increases the engagement with the governance process and weakens the NIMBY effect. From a participative governance perspective, the financial compensation of communities can improve the strategic planning competence of the companies and local authorities. Companies benefit from the increased likelihood of permitted license as intervention of local citizens decreases, and the duration of the permit process can be reduced. Local authorities gain leverage in the planning process regarding local raw material management by being able to offer transparent financial compensation to the communities.
- Levies must be introduced across country and be accounted for when importing gravel exporting excavation material. A nation-wide levy on the extraction increases the feasibility of recovering gravel from excavation material, and thereby changing the local metabolism. If not; imports across regions will be initiated until transport cost to the next region without levies consumes the price difference. If the introduction of the levy is within the cantonal responsibility, it is assumed that conflicting goals of cantons form barriers to a coordinated policy implementation. Some regions were naturally subject to a lack of primary gravel while others face an abundance. Those differences naturally result in the emergence of different business models, hence different compositions of material flows, and consequently different policy foci. The levy could level the playing field between extracting and recovering gravel, regardless of the local resource situation.

While the introduction of a levy contributes to a more efficient usage of local mineral materials, the benefits towards a sustainable economy must be understood critically. Most significantly, evidence of environmental offsets has been identified. While mining bans reduce the direct negative environmental impact on local land, the simulation shows that local price surges increase gravel imports. This results in negative environmental consequences, due to increasing transport emissions. A participative governance is required to increase systemic understanding of stakeholders and create acceptable policy interventions without shifting the burden of land-use to other regions.

Ultimately, the recovery rates of gravel from excavation material are limited to the gravel content of the material. The non-gravel content of excavation material must be disposed in landfill, hence the demand for landfill volume cannot even approach zero in a best-case scenario. A circular economy is not possible without (1) large-scale construction materials from excavation material and/or (2) sufficient recycled aggregates from CDW to cover the demand for aggregates. Hence, a demand for landfill volume will even persist in a circular economy without drastic changes in the built environment.

6. Conclusion

We could show that the contribution of the mineral construction industry towards large scale landscape trends is limited. Relevant potential lies in the reduced consumption of land and little transport distances, both being rather local measures. Without changing the scale of construction

activities, the dependence on primary raw material persists. Increasing the building stock is impossible without the input of primary raw materials, hence recycling of CDW and recovering gravel from excavation material can only remedy the local demand for land (SDG 11). A system dynamics approach helped to understand the drivers and barriers of the industry, by identifying drivers of the lock in to the usage of primary materials, slow diffusion of recovered materials and inefficient management of demolition and excavation material. To improve the sector's modes of production and consumption (SDG 12), a systemic perspective on the co-evolutionary dynamics at the intersection of policy and industry is required. Without such a systemic perspective, policies are prone to unexpected side effects and shift the burden to other regions, while increasing transport emissions. This study has shown that the introduction of a levy on the extraction of primary resources can potentially overcome the barriers, that result from the decision-making rules of current industry and policy actors.

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