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VALUMICS
Food Systems Dynamics

Modelling food supply networks

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The core objective of VALUMICS www.valumics.eu is to develop approaches and tools to analyse the structure, dynamics, resilience and impact of food chains on food security, economic development and the environment.

This article presents the work done by VALUMICS during its first year on system dynamics causality-based modelling framework analysis, which has been facilitated through iterative workshops (WS) and group model building.

The framework consists of flow charts and causal loop diagrams (CLDs) for supply, value-, and decision- chains for several food supply chains and systems. These are salmon to fillets; beef cattle to steak; dairy cows to milk; wheat to bread and tomatoes to canned tomatoes.

The framework will now be further refined with stakeholders from the food value chains, so as to form a consensus vision of the overall system.

System modelling

The basic steps of system modelling are illustrated in Figure 1. These steps have been followed in the project to ensure a successful modelling process based on traditional system dynamics research design (Sterman, 2000). The first step involves clearly defining the problematic or rather undesirable behaviour of the system that is to be addressed and specify its boundaries. The next step, the system conceptualization, entails analysing the underlying feedback structure of the system in an effort to formulate a dynamic hypothesis concerning the system's behaviour. This causal theory of how behaviour is generated in the system is presented as a mental model in the form of a Causal Loop Diagram (CLD).

Throughout the modelling process this dynamic hypothesis serves as a working theory of how the problematic behaviour in the system arises. The system conceptualization is induced through system analysis and the resulting dynamic hypothesis is then used to recreate the dynamics of the system using a mathematical simulation model or system dynamics.

A Systemic approach for case studies

Case studies are enablers of the overall development work and they are designed around the modelling process. The case studies have been selected based on their potential to support the goals of the VALUMICS project to explore fairness, resilience, sustainability and integrity of food supply chains and systems. The case studies that have been selected for the VALUMICS project are the following:

1. Salmon to fillets
2. Beef cattle to steak
3. Dairy cows to milk
4. Wheat to bread
5. Tomatoes to canned tomatoes

Sub-studies (such as insects, grain and protein crops for feed) of interest for future scenarios may also be included.

Figure 2 (next page) is an overview flowchart of the food supply chains and systems selected as case studies in the VALUMICS project. The input and output stocks of food raw material and products flowing through the different stages of production, harvesting, processing, distribution and sale to consumers are depicted. The analyses in the case studies through the work in VALUMICS are highlighted in the horizontal lines at the bottom. The different analyses will underpin the development of a suite of tools for policy makers and stakeholders to explore how different foresight scenarios may influence fairness, integrity, sustainability, and resilience of food value chains.

To achieve the overall objective of VALUMICS - to develop approaches and tools to analyse the structure, dynamics, resilience and impact of food chains on food security, economic development and the environment – we have based our approach on four phases. These are: 1) development phase, 2) integration phase, 3) exploration phase and 4) implementation phase, which are driven by the system modelling framework. The five steps of the modelling process already described are integrated into these operational phases of the project to ensure adherence to the systematic approach in the case study work.

In *Phase 1: Development phase – Fundamental groundwork*, the analysis of the food system and supply chains is enabled by case studies with the

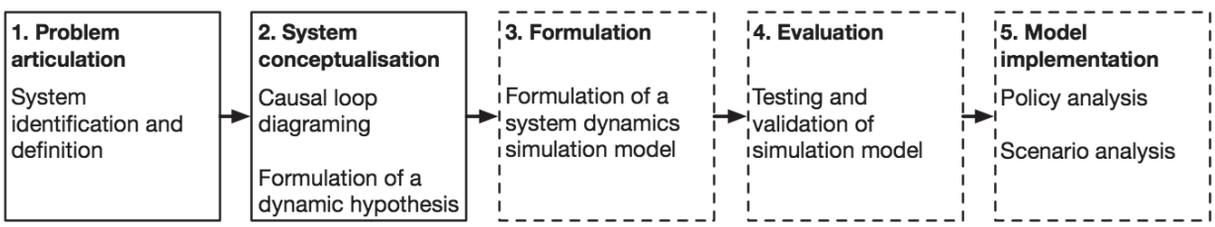

Figure 1. The formal steps of modelling

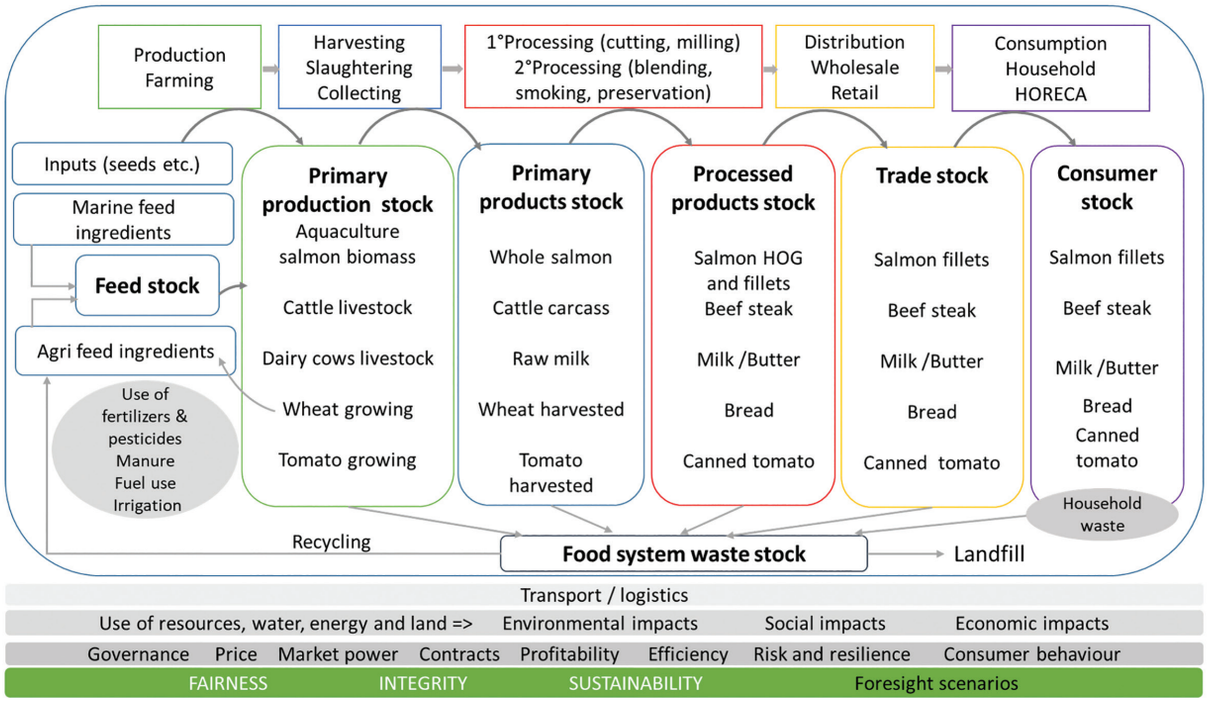

Figure 2 An overview of the CASE STUDIES and the value chain analysis in VALUMICS

objective to develop an overarching causality based conceptual model framework to analyse the structure, dynamics and governance of selected food value chains. The aim is to apply specific tools to analyse quantitatively and qualitatively the functioning of food value chains and assess their impact. For this purpose, relevant key indicators/determinants and metrics are prioritised based on their capacity to explain influences on resilience, and impacts on governance, food security and sustainable development, including economic, environmental and social dimensions. The development phase and groundwork thus integrates the initial modelling steps as follows.

Step 1 - Problem articulation involves describing the food systems to be addressed, including e.g. product functional unit, spatial scale, temporal scale, key mechanisms and transformations inside the system, system boundaries and timeframes and identification of key stakeholders in the systems. Goals are defined and problems to be addressed identified based on historical behavior and potential future behavior.

Step 2 - System conceptualization starts with mapping product and information flow using EPC (event driven process) methodology. Then the system is mapped using CLD's and flow charts. The drivers of change in terms of the problematic system behavior (e.g. resilience, sustainability, integrity issues, unfair trading practices) will be identified and the data is identified for the simulation model (for parametrisation and evaluation). This is sorted into data for starting conditions, boundary conditions, parameter settings for different processes and mechanisms, and data on system state. The system states are not used to initialize the model, but rather to evaluate the performance of the model and identify scenarios for testing and for establishing potential policy implementations.

This is part of *Phase 2: Integration phase of the project* where data gathering in case studies and primary and secondary analysis are performed to analyse the suitability of selected indicators to capture the evolution of resilience, the sustainability and the integrity of the food supply chains assessed in the case studies, and their transformative capacity. Furthermore, relationships, value and risk distribution, power asymmetries including perceptions of fairness and information exchange along food chains are explored and examples identified of best practice in actor relationships leading to greater equity. Further mapping of supply chain dynamics including material and energy flows, environmental impacts, cost structures and price transmission, as well as assessment of collaborative governance forms and consumer relations, drawing on innovative good practice is the basis for the simulation model formulation in the following step.

Step 3 - Simulation model formulation is based on collecting the relevant data and formulate an integrated simulation model based on the groundwork in the case studies.

In *Phase 3: Exploration phase – Integrated quantitative model leading to future studies,* the objective is to develop an integrated modelling approach and use for the analysis of external and internal drivers influencing the performance of food value chains and demonstrate options for improved business strategies. Explore also the impact of public regulations (quotas, subsidies, public procurement policies etc.) and private initiatives (certification, Corporate Social Responsibility, marketing, retailer standards, fair trade etc.), which have shaped these food chains to assess the conditions under which these interventions enhance or not resilience, integrity and sustainability.

Step 4 - Model evaluation focuses on determining if the model is useful and convincing in terms of how the system works and the results of the scenario testing.

In the last *Phase 4: Policy and use phase – Fit for purpose tests and scenarios,* the objective is to build foresight scenarios to reflect on the possible evolution of those food chains and on the kind of public, private and civil society instruments that would enable enhancing their desirable outcomes or counteract their negative impacts. This phase of the project integrates the last step in the modelling work.

Step 5 - Model implementation will focus on testing scenarios identified for policy implementations with relevance to fairness, resilience, sustainability and integrity of food supply chains and systems.

Building the models together

The different phases of the VALUMICS approach were enacted through group model building sessions over four workshops where expertise within the project consortium was used to identify the structure, challenges and perceptions of the value chains and systems being discussed. The partners represent a multi-disciplinary team of 21 partners coming from 14 European countries and two Asian partner countries. The expertise includes food-, and agri- scientists, engineers, economists and social science experts.

The workshop sessions enabled the group to have an adaptive group learning, to use the same language within the group in the systems conceptual mapping and also to have the common modelling platform, where different topical parts could be linked together. After each workshop, new insights and questions are formed and addressed - adding to the overall understanding (Olafsdottir et al., 2018).

Generic food supply maps

For the analysis, VALUMICS has used the following base definitions of the food value chain and the food systems:

Food Value chains

The food value chain is comprised of the stages of the path of the food products starting with inputs, primary production, manufacturing, logistics and transportation, wholesale and retail sectors until consumers

Food Systems

Food system comprises the food value chains/networks and in addition, waste management and all the supporting and interacting activities

The idea of the system model building is to first work on an aggregated level and then explore company to company relations to gain a more in-depth understanding of the functioning of the chains. The model that will provide the tool to be developed by the VALUMICS group is being developed in layers. The core layer consists of a physical product flow that can be fitted to different types of supply chains. Additional layers can be attached to this core layer. These include the value chain with price mechanisms and the decision chains that can vary between cases.

Causal loop diagrams

A generic simplified system model according to Meadows (1970) has been adapted to VALUMICS which includes the main dynamic market drivers of an integrated food supply system as shown in the causal loop diagram in Figure 3. The feedback structure presented in this simplified model is repeated for every supplier/customer relationship in the supply system. It features a reinforcing profit-seeking loop (marked with an R) and several balancing feedback loops, two of which (B1 and B2) regulate the market through price setting.

The reinforcing profit-seeking loop is based on the idea that increased profit expectations drive the downstream flow of products in the chain by increasing willingness and means to engage in value adding activities and supplying products to a market while limiting costs. All else excluded, more products to the market will mean that more can be taken from the market which in turn increases revenues and thereby profit and thus increases willingness to engage in value adding activities even further. This generates a reinforcing profit maximization loop that pushes products downstream towards customers and pulls material from upstream suppliers. The chain of agents, each aiming at maximizing profit, therefore, adds up to a reinforcing supply system (Gudbrandsdottir *et al., 2018).*

This system is however also regulated by price through market dynamics, that is, the relationship between supply and demand. On the supply side, higher prices positively affect profits, eventually adding to supply and the amount available for sale in the market. This, in turn, has a negative effect on price, thus creating a negative loop (marked B1) that regulates the profit driven reinforcing loop of the supply system. On the demand side, there is a second feedback loop (B2) that has a similar balancing effect. Price negatively affects demand so higher price leads to lower demand. Demand controls the amount that is taken from the market so the lower the demand the larger the amount that is left in the market, which in turn will lead to a price decrease. This structure results in two balancing feedback loops, a demand loop (B2) and a supply loop (B1) that together regulate the market through price setting. These balancing loops are well documented in the system dynamics literature as first reported by Meadows (1970) and further advanced by Sterman (2000).

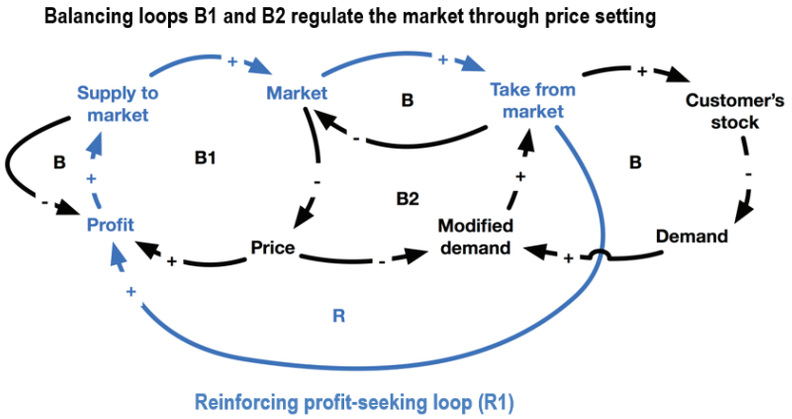

Figure 3 A simplified model of the main drivers of the integrated supply system

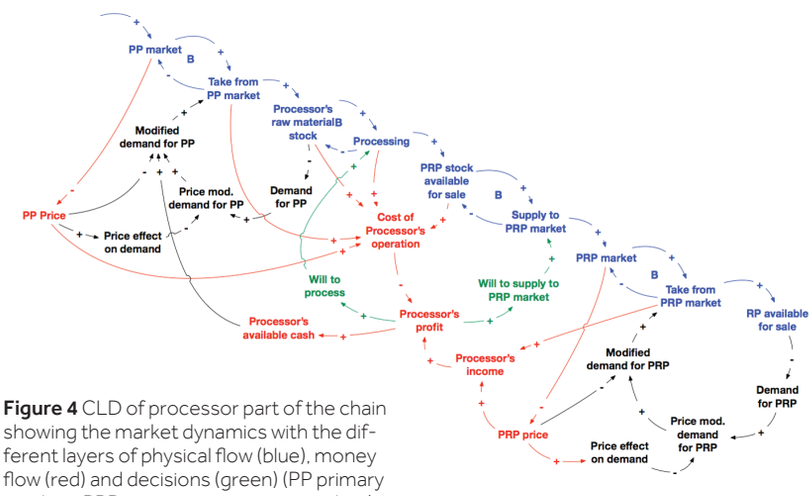

Figure 4 CLD of processor part of the chain showing the market dynamics with the different layers of physical flow (blue), money flow (red) and decisions (green) (PP primary product, PRP primary processing product)

This simplified supply system model has further been adapted in VALUMICS for the case studies and presented as integrated supply-, value- and decision chain causal loop diagram (CLD) by Gudbrandsdottir et al. (2018) as shown in Figure 4.

System thinking has thus been applied to develop the VALUMICS food supply system framework with a focus on market dynamics. Studying the structure and dynamics of food supply systems as integrated supply-, value- and decision chains has underscored the complexity of such systems and the need for more food system specific research. In particular, the case studies which are in progress during the integration and exploration phases of the project will provide a more in depth understanding of the behaviors of actors that influence decisions.

Next steps

Food systems are integral parts of societies and their functioning in the long and short term is vital. Models of food supply systems can serve as a foundation to identify policy intervention opportunities, specifically focusing on resilience, integrity, fairness and sustainability. The multidimensional feedback structure of food supply chains, driven by profit and regulated by market dynamics, results in nonlinear behaviour that calls for a modelling approach that can capture the dynamics of systems with inherent feedbacks and delays, like system dynamics. However, the model also needs to be able to capture the complexities and heterogeneity of agent interactions and decision making.

As the VALUMICS project moves forward, it will implement a holistic system framework, supported by new advances in theory, modelling and data gathering, which is required to capture and understand the dynamics and interactions in food systems from providers of farm inputs to consumers, including the waste managers and policy makers.

Studying the structure of such systems as integrated supply-, value- and decision chains has underscored their complexity and the need for further, more food system specific research. The next steps include more work on the

case studies, further conceptual modelling on both local and global scale, and also to integrate the case studies together.

Further analysis and update of the flowcharts and CLDs through feedback and collaboration of participants of the different case studies (salmon to fillets, beef to steak, dairy cows to milk/butter, wheat to bread, tomatoes to canned tomatoes, and including insects and grain and protein crops to feed) is part of ongoing activities in the project.

The outcome will be the basis for the next step in the modelling phase which will focus on parametrisation and operationalising decision rules for the model, in particular with a focus on fairness and distribution of value added in the food supply chain from farmer to the consumers. This work will integrate the learning from the analysis performed in the project in the case studies and includes work on assessment of environmental and social dimension of food chains by life cycle assessment, assessment of transportation, logistics, risk and resilience.

A review of policy and governance intervention done by VALUMICS partners will also provide a basis for evaluating governance and power structure in food chains linked to economic studies on food chain organisations, price formation, persistence of supply chain relations, assessment of economies of scale and technical innovations, and finally a statistical analysis of agribusiness profitability.

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