Environmentally Conscious Transportation and Logistics Modelling for Agri-Food Supply Chains

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Agriculture and fisheries are areas of deep policy integration at the EU level, organised through the Common Agricultural Policy (CAP) and Common Fisheries Policy (CFP) respectively. To implement and monitor the effects of the CAP and CFP considerable data collection occurs across Member States at the level of primary production. This allows for modelling the economic impacts of existing and potential future policy on, for example, agricultural / fisheries output, incomes, land use / fish stocks through partial and general equilibrium models (European Commission, 2016a; M'Barek *et al.*, 2017).

However, the existing infrastructure for agri-food policy modelling suffers from two main weaknesses. First, modelling focuses on primary production, rather than the whole supply chain. Hence, existing models typically do not capture the linkages between primary producers and downstream actors despite the nature of these relationships shaping profoundly outcomes at the primary level such as farm and fisher incomes (Falkowski *et al.*, 2017). Consequently, evaluating the impact of new EU policy initiatives that take a supply chain perspective (e.g. Directive 2019/633 on Unfair Trading Practices in the agricultural and food supply chain) faces significant challenges within the existing modelling framework. The second main weakness relates to the lack of/limited interactions between policies across sectors as for example, between agriculture, food and transport. The current policy-modelling framework is tailored toward a sectoral approach (e.g., the Farm Accountancy Data Network capturing outcomes of the CAP at the farm level). Yet, the achievement of EU policy objectives increasingly requires an integrated approach (European Commission, 2016b). For instance, the transport sector accounts for approximately one quarter of overall greenhouse gas (GHG) emissions in the EU (European Parliament, 2019) and the Joint Research Centre (2006) estimates that 29% of all consumption derived GHG emissions are food related. Key indicators such as distance between supply chain actors, export capacity, fuel efficiency and green tax incentives are known to influence food prices and output (Soysal *et al.*, 2014). However, the integration of policies in modelling between these two sectors is limited (Petrov *et al.*, 2017).

In response to these gaps, this paper aims to provide a robust model of transportation and logistics for agri-food supply chains for policy support. It undertakes this through two illustrative cases: salmon in Norway and processed tomatoes in Italy, conducted as part of the EU H2020 VALUMICS project. For both cases, we developed multi-echelon, multi-period, supply chain models, informed by the literature (Govindan *et al.*, 2015). The research work carried out in the paper pays attention to experiences and problems encountered in developing the models, data issues, results and sensitivity analysis. Model development, validation and policy recommendation occurred in four stages: (i) mapping supply chain linkages and product flows, (ii) designing the mathematical model, (iii) data collection for parameters of the model and (iv) model validation and deriving policy recommendation. We concentrate on providing key insights pertaining to each stages associated with model development, validation and policy recommendations via stakeholders' consultation (Govindan, 2018).

For the first stage, it was necessary to map the supply chain linkages and understand the nature of flows amongst stakeholders. This could not be accomplished solely from considering the existing literature and available secondary data. Hence, expert interviews were conducted for each case study to refine the conceptual maps. Without adequate conceptualisation of the supply chain, it was not possible to build appropriate mathematical models. Figures 1 and 2 present the supply chain networks for Norwegian salmon and Italian processed tomatoes respectively.

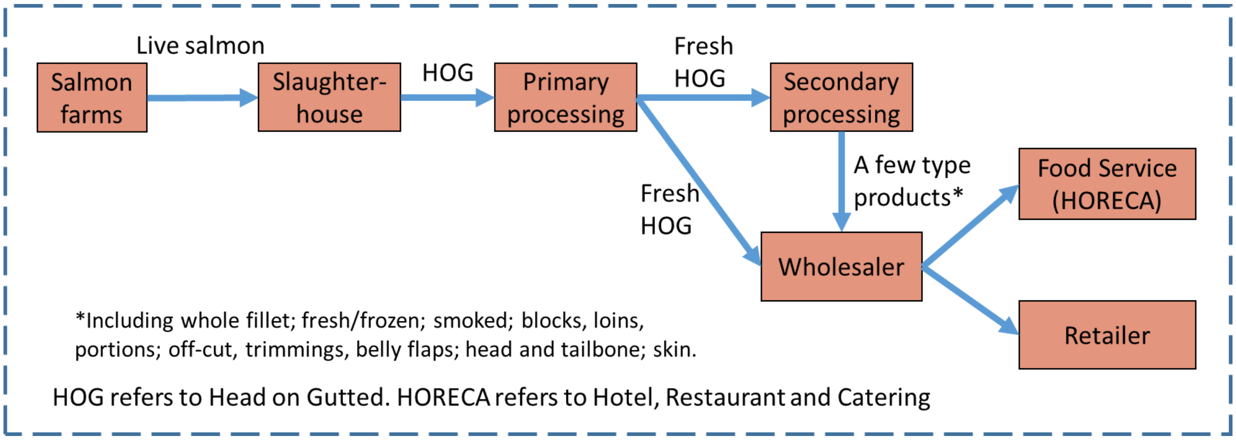

Figure 1: Conceptual framework for the Norwegian Salmon Supply Chain Network

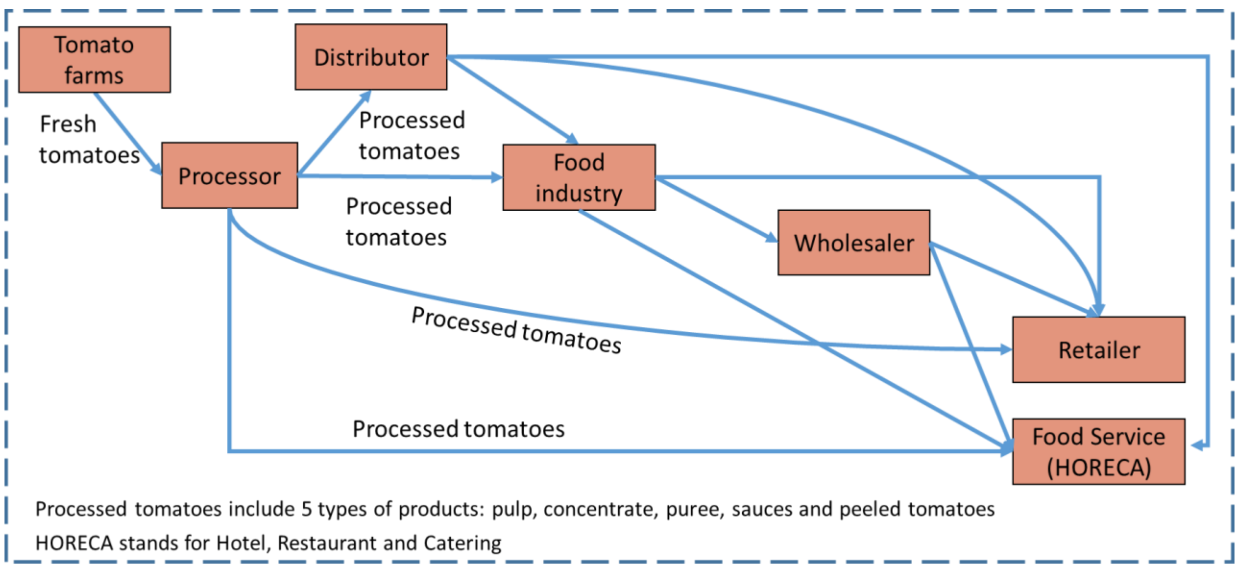

Figure 2: Conceptual framework for the Italian Processed Tomato Supply Chain Network

In the second stage, mathematical models for salmon and processed tomatoes were developed based on the framework presented in Figure 3. The objective function within each mathematical model aims to minimize total cost, comprising of the costs associated with transportation, fuel consumption, inventory holding, processing and residuals/waste. Restrictions associated with carbon emission and wastage are considered for addressing the sustainability aspects. Constraints related to supply, processing capacity, storage capacity, demand, carbon emissions, inventory balancing, transportation capacity, and different modes of transportation between different types of plants and facilities are taken into consideration.

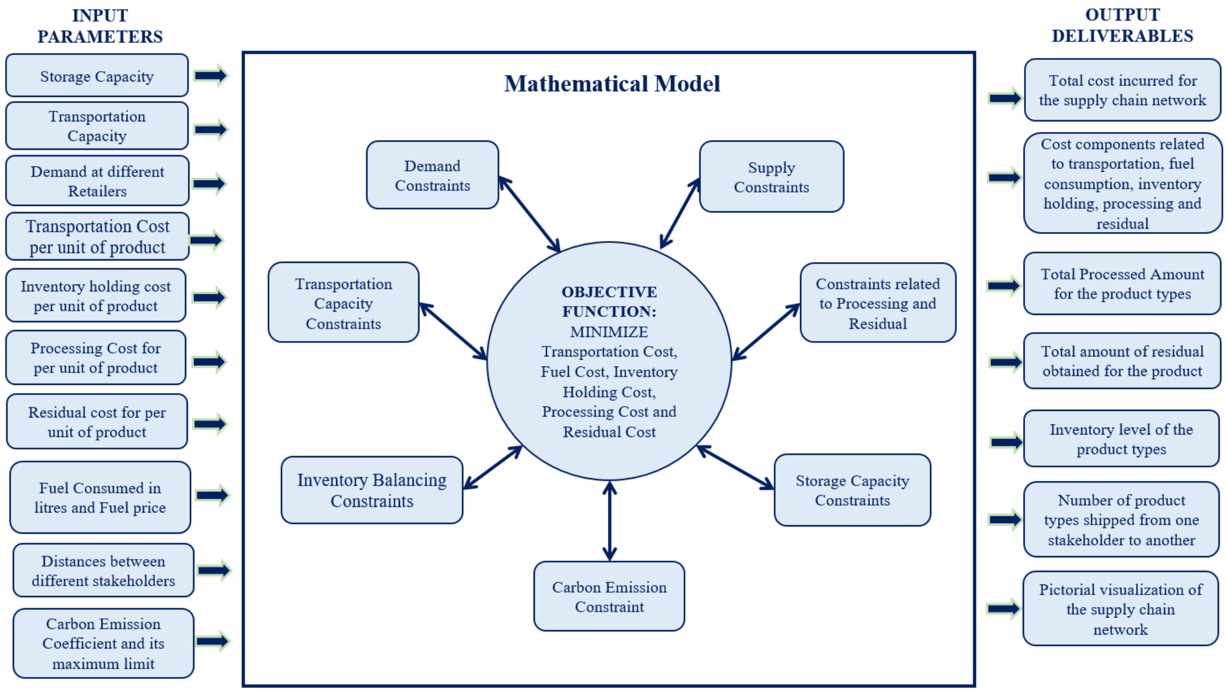

Figure 3: Framework for the model for both products

In the third stage, the primary data collection is performed pertaining to various input parameters provided in the framework of the mathematical model, supplied by the industry stakeholders. Information related to the cost components, capacity restrictions, carbon emission coefficients, and fuel consumption rates considering various scenarios associated with choice of transportation mode and the supply and demand variability in different time periods.

The fourth stage aims to resolve the models and obtain necessary managerial recommendations for various scenarios. The models are valuable for policy makers in terms of understanding the costs and emissions associated with different food supply chains, as well as the effects of particular policy interventions and market developments (e.g. variation in demand, fuel costs, emission and waste constraints). They can aid supply chain managers to make decisions regarding the amount of inventory to be kept in different time periods. The models are developed for a planning horizon consisting of discrete time periods, aiding the possibility of studying demand and supply uncertainty and its consequences in supply chain decision making. Hence, they help decision makers to identify the changes in a supply chain network when different transportation routes are adopted (for example whether maritime routes can be adopted or not in place of road/rail transportation, to address environmental concerns related to fuel consumption and carbon emissions). The models generate valuable insights for supply chain managers, understanding the effects of different scenarios associated with demand and supply uncertainty and the adoption of different transportation routes. Based on the sensitivity analysis, policy implications can be drawn.

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