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Water Footprint Management Policies for Agrifood Supply Chains: A Critical Taxonomy and a System Dynamics Modelling Approach

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During the last decade, as the overexploitation and scarcity of the global natural water resources have led to a plethora of negative environmental, social and economic impacts, the preservation of freshwater resources has emerged as a major challenge for governmental authorities, businesses and consumers. To that effect, the concept of water footprint (WF) has been introduced at a national, corporate and product level. Since national WFs are obtained mainly from agricultural production and food manufacturing or processing operations, WF assessment and management are considered to be of utmost importance for the agrifood industry. In this context, several agrifood companies map the WF of their supply chain networks as a part of their corporate social responsibility programmes. In this manuscript, we first review the scientific literature and several real-world corporate sustainability reports and we then provide a critical taxonomy of management policies that mitigate the water WF at each echelon of an agrifood supply chain (AFSC). Following that, a first-effort System Dynamics (SD) model that effectively captures the dynamics of the WF and water scarcity along the entire supply chains of agrifood products is developed. The obtained simulation results reveal the need for responsible freshwater management across AFSCs in order to reduce the total WF and to further create a green corporate image. The literature taxonomy along with the proposed SD modelling approach is anticipated to provide value-added managerial insights with respect to corporate policy-making interventions towards the sustainable development of the agrifood sector.

1. Introduction

Environmental sustainability holds a prominent position in both the public and private policy-making agenda (Aivazidou et al., 2013). Particularly, the depletion of freshwater resources has emerged as a major concern due to the rapidly increasing rates of freshwater exploitation. Virtually, only 14,000 km^3 of freshwater are available for direct human use (Barilla, 2011). Freshwater resources are threatened by population growth and rapid economic development (Ridoutt and Pfister, 2010) and expected to be further affected by anthropogenic climate change (Herath et al., 2013). In this context, balancing the environmental, social and economic ramifications of global water usage is a critical issue for governments, consumers and companies (McKinsey, 2009). To that end, in order to assess direct and indirect freshwater consumption and pollution, the concept of water footprint (WF) has been introduced. WF is a multidimensional indicator comprised of three components: (i) green WF – volume of rainwater consumed at the farming stage of agricultural products, (ii) blue WF – volume of surface or groundwater consumed during the production of a commodity, and (iii) grey WF – volume of freshwater required to assimilate the load of waste generated during a production process (Hoekstra et al., 2011). From a single product's perspective, WF is the total volume of freshwater consumed or polluted across its entire supply chain (Hoekstra, 2008).
Notably, freshwater is a key constituent in several production systems. Indicatively, the agricultural sector consumes and pollutes approximately 70 % of the global freshwater resources (UNESCO, 2009), intensifying

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global water scarcity. Thus, agrifood companies have to cover food demand under the constraints of sustainable freshwater utilization (Ridoutt and Pfister, 2010). Specifically, it is crucial that corporations ensure sustainability of their entire agrifood supply chain (AFSC) networks through establishing WF management methodologies and practices (Tsolakis et al., 2014).

In this context, the scope of the study is twofold: (i) to provide a critical taxonomy of WF management policies that could be implemented at each AFSC echelon, and (ii) to conduct an analysis of the dynamic behaviour of WF and water scarcity across AFSCs. The remainder of the paper is organized as follows. In Section 2, we provide a taxonomy of the existing academic and corporate research on WF management policies for AFSCs, while in Section 3, we present the development of a System Dynamics (SD) model for WF monitoring and assessment across AFSCs. Finally, Section 4 concludes with directions for future research.

2. Critical literature taxonomy

WF management is essential for promoting environmental sustainability in the agrifood industry (Vanham and Bidoglio, 2013). Nevertheless, the majority of existing WF management practices are rather generic and thus they need to be tailored to particular supply chain cases. To the best of our knowledge, scientific publications that address policies for managing direct or indirect WF across AFSCs are rather limited, while the majority of the existing ones are case specific.

At the farming stage, the growing of crop varieties that fit to the regional climate and water availability profile (e.g. grapes/olives in arid areas) is required (Hoekstra et al., 2011). Alternatively, given that organic production implies less freshwater consumption and pollution, shifting to organic crops could further enhance freshwater sustainability (Brodt et al., 2013). Moreover, the adoption of temporal and spatial irrigation schedules appears to be critical for optimizing land productivity and water efficiency (Hoekstra et al., 2011). Other crucial issues are the implementation of agricultural practices (e.g. soil mulching, drip or trickle irrigation) for reducing water evaporation from the soil (Hoekstra et al., 2011), as well as the optimal application of pesticides and fertilizers for preventing or reducing leaching and runoff effects (Ridoutt and Pfister, 2010).

During the industrial processing stage, monitoring and auditing of water used in food production constitutes a generic water management practice for: (i) identifying processes that generate water losses, and (ii) defining methods for reducing these losses (Tesco, 2013). Similarly, as the upstream levels of an AFSC contribute approximately 90 % of the total WF (McKinsey, 2009), manufacturing companies should select suppliers that deploy water-friendly operations, such as utilization of water-saving equipment, replacement of water-intensive processes or adoption of recycling techniques (Hoekstra et al., 2011). In addition, collaboration with farmers in terms of water stewardship is vital for minimizing the associated water impacts (Coca-Cola, 2014). It is also suggested that manufacturers invest in water-efficient technologies that allow water reuse and recycling (McKinsey, 2009), promote waste water treatment and reduction (Ridoutt and Pfister, 2010), as well as limit toxic chemical substances' utilization during food processing (Ene et al., 2013).

A major share of the indirect water consumption is related to the food products' packaging. Since packaging materials, and especially carton packages, consume significant amounts of water for their production (Herath et al., 2013), practices like: (i) the reduction of unnecessary packaging, (ii) the utilization of water-efficient packaging, and (iii) the limited use of packaging that contains hazardous substances, are considered vital for the minimization of the total WF. Furthermore, water-efficient washers for some types of packages (e.g. bottles) could minimize the products' WF (Coca-Cola, 2014), while investments in water recycling systems could reduce freshwater consumption during the cleansing of agricultural products (Dole, 2011).

Nowadays, although energy-efficiency concerns highlight the use of biofuels as an alternative energy source in the transport sector, the cultivation of biofuel crops competes with food crops for scarce land and water resources (Gerbens-Leenes et al., 2012). At the same time, it is vital to consider the factors of food wastage along the various stages of a supply chain, since food losses are associated with high external costs, including water impact (FAO, 2013). Specifically, poor preservation conditions of food during logistics operations (transportation and warehousing) may lead to increased food waste and thus indirect WF (Ridoutt et al., 2010), as the production of more food products for covering global human needs leads to the consumption of additional freshwater resources.

At the retailing stage, since food losses account for significant freshwater consumption (Barilla, 2012), WF concerns necessitate the reduction of product waste due to limited food shelf-life (Motoshita et al., 2013). Further, WF labelling in food products could be environmentally meaningful for both enterprises and consumers (Ridoutt et al., 2014). To that end, education of consumers about water-friendly food products is ultimately necessary for driving systemic changes towards purchasing decisions and WF impact (Unilever, 2012). In Table 1, a critical taxonomy of the up-to-date WF management policies for AFSCs is provided. The policies are classified according to: (i) the typical AFSC echelons, and (i) their positive environmental impact on freshwater resources for each of the three WF components.

Table 1: Critical taxonomy of the WF management policies

AFSC echelon	WF component			WF management policy
	Green	Blue	Grey	
Farming		✓		Growing of crops needing less water
		✓	✓	Alteration of crops into organic crops
		✓		Temporal and spatial scheduling of irrigation
	✓	✓		Enhancement of water retention in the soil (e.g. drip irrigation)
			✓	Prudent use of pesticides and fertilizers
Industrial processing		✓		Water usage auditing and control
	✓	✓	✓	Selection of water-safe suppliers
		✓		Investment in water-efficient technologies
		✓		Reuse and recycling of waste water
			✓	Prudent use of toxic chemical substances
Packaging	✓	✓	✓	Reduction of unnecessary packaging
	✓	✓		Use of water-efficient packaging
			✓	Reduction of environmentally unsafe packaging
		✓		Investment in water-efficient packaging washers
		✓		Recycling of waste water
Logistics	✓	✓	✓	Prudent use of biofuels in transport
	✓	✓	✓	Reduction of food waste due to poor storage conditions
Retailing	✓	✓	✓	Reduction of food waste due to short shelf-life
	✓	✓	✓	Establishment of WF labelling
	✓	✓	✓	Education of consumers on green purchasing decisions

3. A System Dynamics model for water footprint management

In this section, we provide the analysis of the dynamic behaviour of the WF and water scarcity across an indicative AFSC. Below, the system under study is described in brief, the associated SD model is developed and finally an illustrative numerical example is discussed.

3.1 System description

We consider an AFSC of a single perishable good with a limited shelf-life. We also consider a monopolistic environment, in which all stakeholders are located within a specific region. Except for the retailing stage, the AFSC includes: (i) the farming stage, when the agricultural commodity is cultivated having a limited shelf-life (i.e. few days), and (ii) the processing stage, when row product is processed by the manufacturer into a new packaged food product with longer shelf-life (i.e. one year).

Regarding the farming stage, a single farmer cultivates the agricultural product in a specific rural area. We assume that the crop production is characterized by seasonality and the harvesting operations occur during the summer months, while the productivity per hectare is stochastic. We further assume that the agricultural production is independent from the consumers' demand. After harvesting, the crop yield volume is transported to a single food manufacturer. During the processing stage, the raw products are converted into packaged goods, while the processing and packaging rate is limited by the processor's production capacity level. The final food products are stored in the manufacturer's warehouse and then transported to a single retailer. In order to satisfy the market demand, the retailer holds his own inventory, while he sets a safety stock threshold for placing orders to the manufacturer. We further assume that the consumers' demand is stochastic.

Concerning the supply chain's WF, a significant amount of freshwater resources is consumed and polluted during the farming stage, resulting in green, blue and grey WFs. In the processing stage, the generated blue and grey WFs intensify the regional water scarcity. Finally, taking into account the upcoming water-related policy schemes (European Commission, 2012), the manufacturer aims at decreasing the blue WF at the food processing stage. Specifically, in case the level of blue water scarcity increases, the processor orders lower quantities of raw products from the farmer for reducing the processed products and the related manufacturing WF. The conceptual system under study is illustrated in Figure 1 via the relevant causal loop diagram.

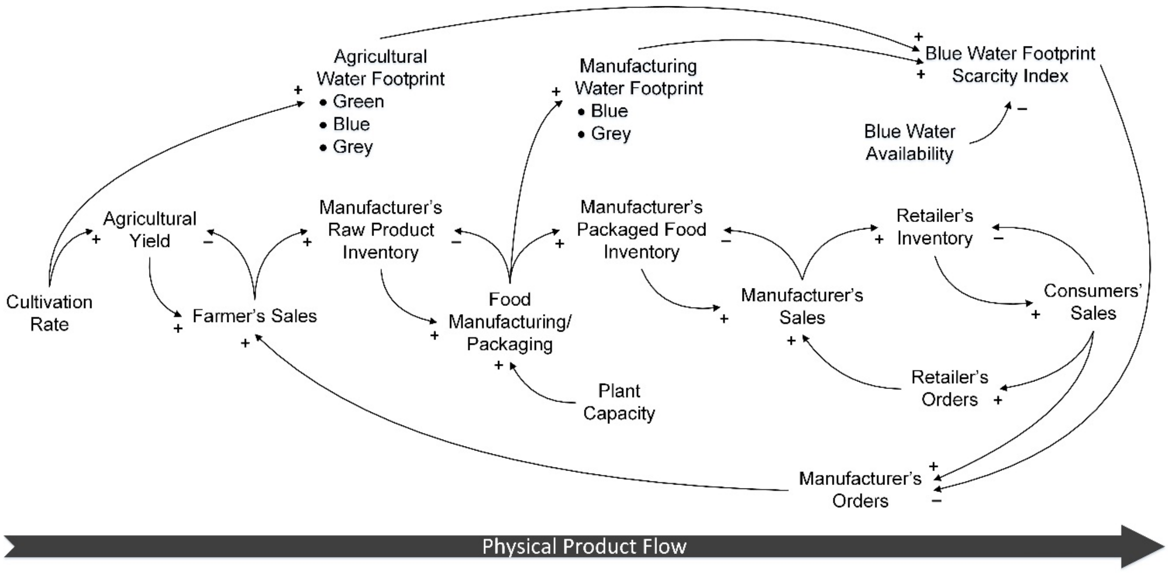

Figure 1: Causal loop diagram of the system under study

3.2 Model development

The system is modelled using the SD methodology in order to capture the causal loops and feedbacks that attach dynamic behaviour to the system. As consumers' demand for packaged food products exhibits a weekly stochasticity, the retailer implements a continuous review (Q, R) ordering policy. Specifically, the retailer orders $Q_{retailer}$ units of processed and packaged food products from the manufacturer when the inventory position drops to the reorder point R. At the same time, the manufacturer's orders are defined by the consumers' weekly demand. Additionally, since the crop production is seasonal, the manufacturer can supply the agricultural commodities from the farmer at a specific time through the year. Therefore, the manufacturer implements a single period Newsvendor model, ordering $Q_{manufacturer}$ units of raw products.
In order to assess the sustainability performance of the reviewed AFSC, the generated WF along with the associated regional water scarcity is monitored. Specifically, the green, blue and grey WF of the farming, processing and packaging stages of the AFSC are assessed, while the retailer's WF is considered negligible. Based on the methodology provided by Hoekstra et al. (2012), we calculate the weekly blue water scarcity as the ratio of blue WF to water availability in a specific region. In addition, considering the manufacturer's goal of reducing the WF of processing, and after the input of various food manufacturers in Northern Greece, the reduction in the order quantity procured from the farmer is dependent on the system's weekly blue water scarcity levels according to Eq(1):

$$\text{\% of manufacturer's order quantity reduction} = \begin{cases} 0.4 \cdot \text{water scarcity}, & \text{water scarcity} < 1 \\ 0.4, & \text{water scarcity} \geq 1 \end{cases} \quad (1)$$

3.3 Numerical example

The applicability of the developed SD model is presented through a specific numerical example related to the production of tomato paste from fresh tomatoes over a period of five years (260 weeks). WF data of tomato and tomato paste were retrieved from the database provided by Mekonnen and Hoekstra (2011) for the city of Thessaloniki, Greece, where all the stakeholders of the AFSC are located. We investigated a Base Scenario, where there is no intervention, and a Policy Scenario, where Eq(1) applies. According to the simulation results, in case the manufacturer performs the policy intervention, the total generated blue WF across the AFSC is reduced by approximately 26 % in the five-year time span. The profile of the AFSC basic operations and the weekly AFSC blue WF are presented in Figures 2 and 3, respectively.

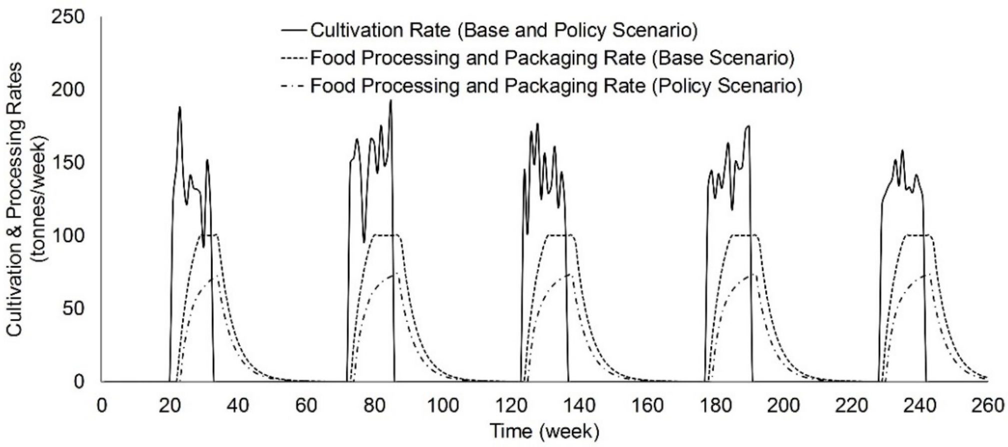

Figure 2: AFSC operations' profile

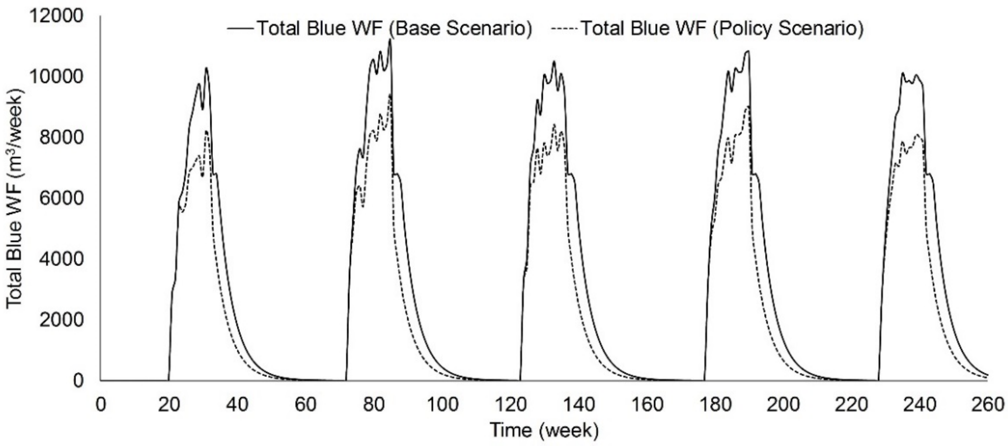

Figure 3: Total blue WF profile

4. Conclusions

In this manuscript, we first provide a critical taxonomy of WF management policies for sustainable AFSCs and we then propose a SD model for the assessment of the WF and water scarcity of a specific agrifood product. The numerical investigation documents that reducing the processed products' volume could lessen the related WF. However, the adoption of freshwater management practices emerges as a more efficient policy intervention that fosters the profitability of the AFSC stakeholders through the production of environmentally friendly agrifood products.

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