Sustainability assessment of last mile logistics and distribution strategies: The case of local food networks

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Abstract

Current trends related to increased sustainability requirements, the application of new digital technologies, and changes in consumer behavior have disrupted conventional food supply chains, entailing challenges for the last mile logistics and distribution of food products. The main aim of this study is to develop a toolset for exploring the sustainability potential of last mile logistics and distribution strategies, employing (1) a centralized distribution network with a click & collect option, (2) a decentralized distribution network with a home-delivery option, and (3) a distributed network based on a crowd logistics concept. For this, a system dynamics (SD) simulation and a multi-criteria decision aid (MCDA) were applied to assess the sustainability performance of these distribution channel options for a case study of a local food cooperative and a logistics service provider in Austria. The sustainability potential of developing a new logistics system in collaboration with these players has been estimated for the first time, while considering the dynamic interplay of all relevant sustainability elements within operational, tactical, and strategic planning. The results show that an integration of the two players into a distributed network strategy based on a crowd logistics concept is the most viable and sustainable option. This highlights the significant role of the logistics sector in proactively innovating services to make sustainable choices easier for the customer.

Keywords: Local food, Distribution, Last mile logistics, System Dynamics, Multi-criteria decision aid.

1. Introduction

Current trends related to the increased importance of local food products (Paloviita, 2010), the application of new digital technologies (McCrea, 2018; Olsen and Borit, 2018), rising sustainability requirements within the food system (Zasada et al., 2019), newly emerging distribution channels in food retailing (Frehe et al., 2017), and changed consumer behavior patterns (Guthrie et al., 2015) have strongly modified the last mile logistics and distribution of perishable goods (Clark and Tilman, 2017).

The latter is expressed in increased online food purchases (e-food) and increased demand for safe, high-quality, and local food (Khan and Prior, 2010). These trends entail logistical challenges, among which are the necessity for short delivery times, bundling of urban freight movements, low loading rates, seasonal variations in distribution networks, coordination of multiple parties (agents), and cost effectiveness (Edwards et al., 2011; Pålsson and Kovács, 2014). Along with the economic challenges, the logistics sector faces social and environmental obstacles to continuing operations while complying with environmental and social standards. The economic optimization of logistics service efficiency, which requires simultaneously satisfying consumption patterns (e.g., online commerce) and reducing the environmental impact and resource intensity of distribution services, represents the overall sustainability of the logistics system (Borza, 2014). Therefore, a sustainability assessment of last mile logistics and distribution requires deep investigation to enhance transparency and coordination and thus increased competitiveness and trust of the key actors throughout the entire supply chain, taking a holistic, multi-actor approach. Achieving sustainability requires the evolution of integrated distribution channels linking the key actors, a synchronization of public/private marketplaces, and the development of sustainable logistics strategies (Neghabadi et al., 2019). By addressing these issues, the present paper aims at developing a toolset for exploring the sustainability potential of various distribution channels for local food systems, integrating the requirements of relevant stakeholders. Moreover, our toolset provides an opportunity to choose the most sustainable distribution channel option, acknowledging the dynamic changes of the sustainability elements within the system. The choice of the most sustainable distribution channel enables economic efficiency, minimized costs, and reduced ecological impacts while meeting consumer expectations. To this end, the paper presents a comparison of three distribution channel options (centralized distribution network with a click & collect option, decentralized distribution network with a home-delivery option, and a distributed network based on crowd logistics) as a decision-making problem for a local food cooperative and a logistics service provider (LSP). The descriptions of the three distribution channel options to be compared for their sustainability performance are described in the Table 1 below, which provides the positive and negative impacts of each option outlined in the literature so far.

Table 1: Descriptions of the distribution channels for online food purchases (adopted from Wang et al., 2006; Ranard et al., 2014; Mladenov et al., 2016; Hübner et al., 2016; Gallay et al., 2017).

Main distribution concepts (term explanation)	**Centralized distribution network with a click & collect option**	**Decentralized distribution network with home delivery**	**Distributed network based on a crowd logistics concept**
Description	Centralized distribution represents the traditional channel, with operations focused to a "central" location. Within a click & collect concept, orders are shipped in customer-ready parcels from a supplier or distribution center to the stores. **<u>Local Food Case:</u>** The consumers order online, and the products are delivered to the central store of the food cooperative, where the consumers pick up their orders. This represents the current situation (very similar to store delivery).	A decentralized distribution network compromises the distribution via smaller warehouses in various regions that can supply the customers more quickly; thus, the products move closer to the customer. **<u>Local Food Case:</u>** The consumers order online, and the delivery process is operationalized by the LSP, which uses its local distribution centers in different locations in Austria (e.g., Linz, Hörsching), delivering the products to the customers in the evening hours.	A distributed logistics system consists of many distribution centers (DC), pick-up stations, mini-hubs, and stores where the parcels can be picked up. Advanced digital technologies enable efficient operation of this system, while applying innovative concepts, such as crowd logistics. "Crowd logistics" is a logistics concept in which logistics service providers (crowd sourcers) outsource logistics processes and/or subprocesses to individuals (crowd sourcees). **<u>Local Food Case:</u>** The consumers order online, and the LSP provides a web application-based solution to track the parcel in real-time and decide where to pick up the parcel or whether to outsource the pick-up to individuals (peer-to-peer).
Positive aspects	Easier standardization of systems and processes through the businesses.	Agility to the expanding consumer networks, shorter lead time for delivery, potentially higher delivery frequencies.	The ability to test systems and markets on a small scale before rolling out the business model, flexible pick-up options for the customers, low average transportation distance.
Negative aspects	Limited business opportunities despite a possible increase in customers.	Loss of direct contact among consumers, farmers, and the food cooperative.	Decentralized inventories and complex transshipment and cross-docking policies, possibly increased operational expenses due to expanded infrastructures.

The contribution of this paper is the development of a toolset for exploring the sustainability potential of last mile logistics and distribution strategies while estimating the impact of future dynamic changes on the design (and choice) of the last mile logistics and distribution options based on a real-world case study. The paper contributes further by applying a mixed-method approach of qualitative and quantitative analyses. The qualitative analyses were conducted based on semi-structured interviews and workshops that aimed to identify the key sustainability elements influencing the local food systems (particularly last mile logistics and distribution). The model development was guided by a case study of a local food cooperative in collaboration with an LSP in Austria to validate the model results with regard to a real-world application (cf., Gruchmann et al., 2019a). The case study also served to describe and weight the causal interlinkages among the relevant parameters. Moreover, the most suitable strategies for both businesses, such as their expansion opportunities (e.g., investments in network infrastructures), were identified. We aggregated these options further into general distribution options according to various network typologies (centralized, decentralized, and distributed). The causal interlinkages among the most relevant sustainability elements (including economic, environmental, and social parameters) were simulated using a system dynamics (SD) model in order to estimate the future evolution of the parameters within different distribution options.

After all the relevant sustainability elements were quantified with the SD model, a multi-criteria decision aid (MCDA) analysis was utilized for outranking the most sustainable distribution options. The decision makers were both the food cooperative and the logistics service provider. Three alternatives to be assessed were: (1) centralized distribution network with a click & collect option, (2) decentralized distribution network with a home-delivery option, and (3) a distributed network based on crowd logistics (Table 1). By combining these two advanced quantitative methods, particularly SD modeling and MCDA, managerial implications are provided for sustainability transformation strategies in local food distribution, and this is among the first studies to provide these insights within this specific industry setting.

The structure of the paper is as follows: The theoretical framework of this study is set in Section 2, analyzing the relevant literature on sustainability gaps within food logistics (Section 2.1), particularly highlighting the operational complexity of last mile logistics and distribution (Section 2.2). Furthermore, the food sector and its sustainability gaps within different stages of the supply chain (food consumption, retail, and last mile logistics) are explicitly discussed. The research design is explained in Section 3, while the case study is described in Section 3.1. The methods of SD and MCDA are presented in Section 3.2 and Section 3.3, respectively. The results of the SD model and its use within the sustainability assessment of the three distribution channels (MCDA) are included in Section 4. The paper is concluded with managerial recommendations on the implementation of sustainable strategies within local food distribution. Discussion and conclusion are provided in Section 5.

2. Literature review

Modern logistics concepts are the foundation of sustainable business strategies and attempt to integrate all actors in fulfilling customer demand (Rahdari, 2016). Increased consumer sensitivity toward the environment (e.g., Liu et al., 2012) and stricter political regulations designed to foster ecological sustainability (Sharfman et al., 2000) entail the need for a strategic realignment of logistics systems while posing various operational challenges, particularly on last mile logistics. Food supply chains are especially sensitive to those continuously changing production-consumption-distribution-regulation systems, being remarkable for their economic efficiency, diversity of firm sizes and types, and responsiveness to changing consumer requirements (e.g., for delivery speed, price, and environmental sustainability (Rai et al., 2019)). Given the decisive role of last mile logistics within food distribution, current challenges are associated with a demand for constantly decreasing delivery times, demand volatility, inventory positioning, and diverse types of marketplaces (Hübner et al., 2016). The latter is driven by the steadily growing e-food businesses (Zeng et al., 2017) and sharing/circular economy business models (Geissdoerfer et al., 2017; Acquier et al., 2019). Therefore, the strategic decisions to be made are related to operational complexity (e.g., assortment type, variety, order time) and distribution structure (e.g., the number and location of warehouses, distribution centers, hubs, stores, and transport networks), while considering environmental constraints (e.g., air and noise pollution, land use changes) (Validi et al., 2014; Barbosa-Póvoa et al., 2017). Along with the economic and environmental impacts, social aspects – such as increasing cooperation among consumers (e.g., crowd logistics in the form of peer-to-peer deliveries) (Giret et al., 2018) and societal damages caused by the sector (e.g., congestions, road safety) (Ranieri et al., 2018) – are considered in this paper, which characterizes the research novelty and complexity of the study. In the following section, we provide an overview of the relevant sustainability issues within last mile systems while identifying the key elements to be considered in the development of the SD model.

2.1. Sustainability gaps within last mile logistics and distribution

Sustainable (food) supply chains can be seen as part of the entire entrepreneurial ecosystem, particularly dependent on collaboration within the stakeholder's social network (Neumeyer and Santos, 2018; Gruchmann et al., 2019a). Therefore, social interaction, peer-to-peer connectivity, and convenience of delivery can be seen as drivers of social sustainability in last mile distribution. Despite individual food consumption patterns driven by cultural and national differences, some general food consumption trends relevant to sustainable development are already evident in most countries of the European Union, which creates a dynamic environment in the market. The most important trends are driven by the consumers' increasing awareness of the food system's impact on climate and health (Reisch et al., 2015). This is expressed by a growing demand for more sustainable food products (Beske et al., 2014), such as local, seasonal, organic, and fair-trade food (Berti and Mulligan, 2016). However, despite the increased sustainability awareness of consumers and their need for sustainable food sources, many authors have reported a mismatch between consumers' preferences and their purchase decisions or willingness to pay for sustainable products and services (Forbes et al., 2009; Napolitano et al., 2010). According to the literature, consumers with increased awareness and openness toward sustainability-related topics might not necessarily realize more sustainable behavior and consumption patterns (cf. attitude-behavior gap) (Schmidt, 2016). Scholars attribute this to the fact that consumers are rarely provided with information and communication that promotes more sustainable consumption choices (especially when it comes to last mile logistics and distribution).

The roles of retailers as change agents promoting sustainable food systems and as mediators to communicate sustainability issues along food supply chains to consumers have been broadly debated in recent years (Chkanikova and Mont, 2015). These issues are mainly explained by the lack of governmental leadership to support retailers in implementing sustainability practices and by increased competition driven by globalization and the complexity of the sector (Smith, 2007; Soysal et al., 2014). Moreover, large supermarkets cannot reduce their food assortment to offer exclusively sustainable products in order to provide an attractive mix (and hence, low search costs) of the high-quality organic products (Reisch et al., 2015). Thus, limiting the central role of retailers within the supply chain while considering e-food business models might give valuable insights into how to use distribution channels in sustainable supply chains (Gruchmann and Seuring, 2018). Yet, e-food business models are not sustainable and operationally efficient per se. Despite the increased environmental awareness of consumers, last mile delivery services are easily neglected by consumers (Reinhardt et al., 2009). This is expressed in the tendency to travel by car to the supermarket for food purchases (depending on distance), which counteracts consumers' own interest in environmentally sustainable grocery shopping. This phenomenon can be explained by a typical "tragedy of the commons," a situation in which individual and social interests conflict (Reisch et al., 2015). Thus, alternative distribution channels, which shorten the accessibility distance of the consumers to regional food markets, would support the sustainability of the entire supply chain.

Last mile logistics and transportation of perishable goods, especially within highly congested urban areas, have not yet exploited their efficiency potential, and they present low levels of consolidation compared to non-food delivery networks when it comes to alternative local food business models. These inefficiencies are due to the fact that the distribution of food products involves mainly small parcels being delivered at high frequencies and due to low customer density (Janjevic et al., 2013; Morganti and Gonzales-Feliu, 2015). Moreover, local food distribution mainly involves the use of small trucks and vans that require sizable consumption of fossil fuel, generating higher quantities of pollutant emissions. The complexity involved in designing last mile logistics for food products is also explained by high operational costs and the environmental impacts associated with cold chains of transport and warehousing (Boyer et al., 2009). As a consequence, there is an urgent need to deal with the key challenges in managing the sustainability of last mile food logistics operations (Akkerman et al., 2010; Soysal et al., 2014). Thus, in the next section, we explore the operational complexity of the last mile logistics system, which provides a foundation to identify the economic factors of last mile logistics.

2.2. Operational complexity of last mile logistics systems

Last mile logistics is a complex system (Olsson et al., 2019) incorporating strategic long-term planning concepts of implementing and controlling the efficient transportation and storage of goods from order penetration to the final customer (Harrington et al., 2016). Related concepts rely on system innovations (both technological and social), with the transformation potential to adapt last mile logistics models to sustainability issues (Ranieri et al., 2018) or to newly designed distribution structures (Lim et al., 2018). Last mile distribution activities focus on distribution channel design, inventory and capacity management, delivery planning, and execution on a tactical planning level. Last mile fulfillment and delivery describe then the process of planning and executing the delivery, representing the operational planning level. Hübner et al. (2016) developed a framework for last mile fulfillment and delivery integrating back-end fulfillment (picking location/automation/integration) and delivery (delivery time/mode/area and returns). Aspects of warehouse operations, distribution centers, and inventory and capacity management are also included at this level (Leung et al., 2018, Melacini et al., 2018). Joining fulfillment and delivery, last mile transportation is another operational planning process, relying on routing, choice of transportation means, consolidation, order processing, and cross-docking concepts (Aljohani and Thompson, 2018). Considering food distribution, last mile operational complexity is even more increased, as the cold chain should be fully respected to maintain the thermal protection of the foodstuffs at every stage of their distribution (de Koster, 2002). Measures that can thus be generated considering operational complexity and distribution structures include:

- Modeling of the logistics system to describe the dynamic behavior of the processes, factors, and their interlinkages across time and space (Démare et al., 2017). An example might be the estimation of the advantages of operational strategies according to changes in delivery windows (Srour et al., 2016) or by offering incentives to shape the demand curve (Chen et al., 2017) while promoting a greater concentration of deliveries per day and/or area (Boyer et al., 2009).
- Other measures might consider speeding up operations through digital technologies (Yang et al., 2017), efficient inventory management (Patil and Divekar 2014), application of total cost approaches (Angelis et al., 2018; Bai et al., 2018), and the establishment of strategic alliances to share and jointly plan logistics infrastructures (Scuotto et al., 2017; Gunarathne et al., 2018; Sana et al., 2018).

Taking into account most of the logistics system elements which are addressed in the literature above, models to analyze and project the dynamic interaction among those elements are scant. Therefore, we propose the following first research question (RQ) of the study:

RQ 1: What are the key sustainability elements of local food distribution, and how do they interact with each other?

The SD model serves as basis for the evaluation of the three distribution channel alternatives. Through applying MCDA such a complex and holistic sustainability assessment of the three distribution channels provides the answer to the second RQ of this paper.

RQ2: Which distribution channel option (centralized, decentralized, or distributed) has the highest sustainability potential with regard to last mile food logistics?

Further, applying the SD model as a valuable tool for estimating the dynamic changes among the key sustainability elements, providing the basis for MCDA sensitivity analysis. This study tackles the estimation of future developments within the concrete case study by answering the third question.

RQ3: How will future changes in sustainability elements influence the ranking of the distribution channels?

3. Research design

To answer the proposed research questions, we used a mixed-method approach of qualitative (literature analysis, semi-structured interviews, workshops with the decision makers, analysis of company documents) and quantitative (SD simulation model and MCDA) analyses. A case study of a local food cooperative (NETs.werk) and an associated LSP (SCHACHINGER Logistics) in Austria was used to obtain input data and validate the quantitative results (the case study is described in detail below in Section 3.1). The qualitative research was carried out to define the key sustainability elements of the last mile and their interactions with each other. During a ten-day workshop series with employees of both the food cooperative and the LSP, we identified relevant key factors for local food logistics and distribution operations, providing further input for the quantitative analysis. Moreover, the participants envisaged the causal dependencies among the factors, which served as a basis for developing a stock and flow diagram (SFD) and afterwards the SD model. The SD model is used to structure and forecast complex systems, whereas the MCDA procedure is applied to select appropriate distribution strategies. The SD simulation provides a view of the possible evolution of the system (the future state of the network and demand) for use in strategy validation and objective definition. The selected strategies may not be the best within the changing environment, however, they are adapted to maintain the best possible management for the moment. A watchdog alarm procedure allows reconsideration of the management of the system in the case of a chaotic evolution or catastrophic event (Kunsch and Brans, 2019). Thus, the combination of these two approaches into a single model is promising for obtaining sustainable strategies in a changing environment. The design of the study is presented in Figure 1.

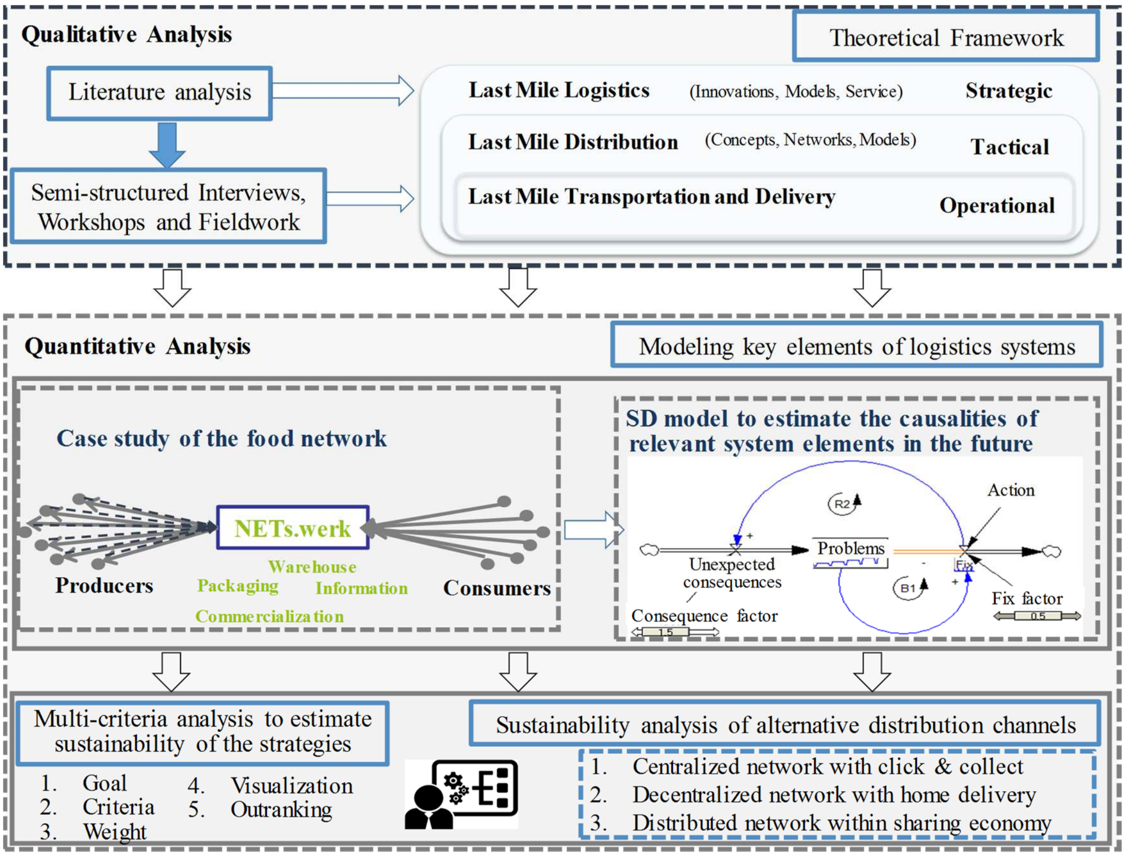


Fig. 1: Design and workflow of the study.

3.1. Case study of NETs.werk and SCHACHINGER

The case study is represented by a local food cooperative: NETs.werk. The company runs an e-food online platform to distribute locally produced, organic food from small farmers in the Linz region of Austria. The company has set up a click & collect business model to offer their products in the region. The products are pre-ordered by consumers in the online shop and collected at one of the NETs.werk branch offices (Figure 2, Model 1). Yet, the company argues that the sustainability potential of this model will be higher if consumer pick-ups are avoided. Thus, NETs.werk considers introducing a delivery service, relying on a local LSP: SCHACHINGER Logistics[1]. So far, SCHACHINGER has primarily conducted business-to-business (B2B) deliveries. Once the company expands its portfolio toward business-to-customer (B2C) deliveries, while cooperating with the local food cooperative, SCHACHINGER may also be able to reduce its operational costs per delivery. The B2B and B2C deliveries can be combined to carry out B2B parcel delivery service during the morning hours and B2C deliveries during afternoon hours (Figure 2, Model 2). Given the existing logistics infrastructure of SCHACHINGER, various last mile distribution options can be assessed, increasing consumer convenience. The collaboration of these two companies is expected to increase the attractiveness of the e-food business model. The collaboration of the two companies might also increase the system's sustainability performance by coordinating the supply chain with further optimizing operations. Yet, these assumptions must be tested via advanced modeling techniques, such as the SD and MCDA described in Sections 3.2 and 3.3, respectively.

[1] http://www.oevz.com/en/news-en/schachinger-logistik-remains-committed-to-sustainability/, 2019

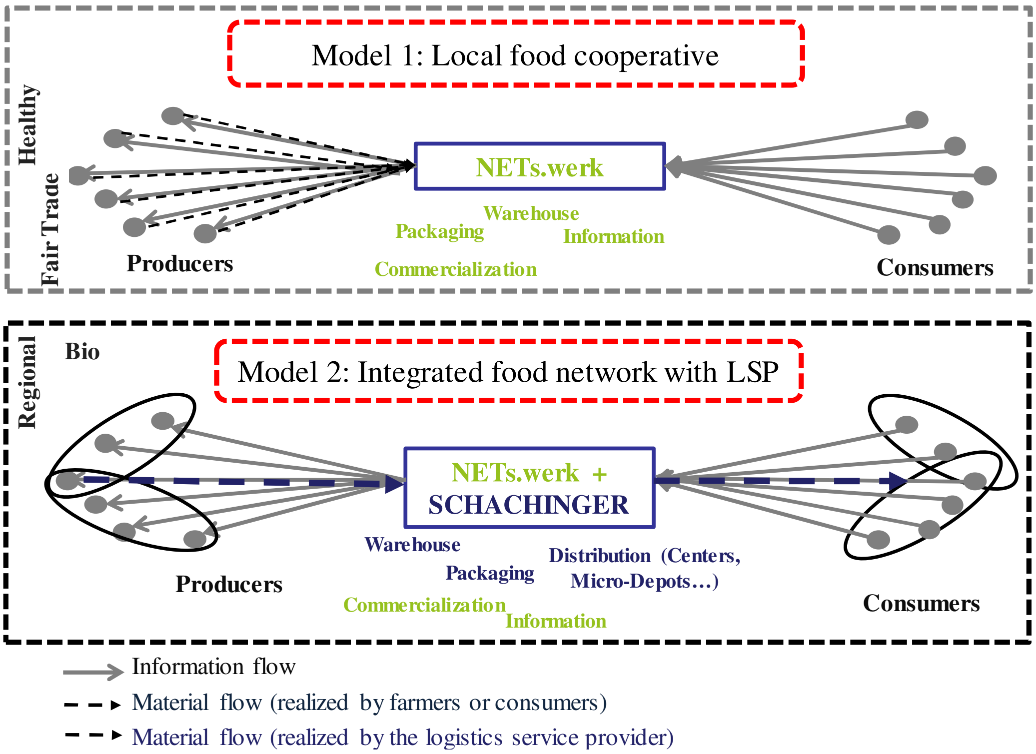


Fig. 2: Distribution models of the local food system within the case study: The model on top represents the current case, in which the local small food retail company runs its online platform (click & collect). The one on the bottom reflects the case in which the LSP is responsible for the distribution system.

3.2. System Dynamics modeling

SD modeling is generally applied to analyze problems of dynamic complexity in a wide range of settings (Sterman, 2000). It deals with the nonlinear behavior of complex systems over time and aims to describe these systems with quantitative models, understanding the system's behavior determined by the feedback mechanisms (Coyle, 1996).

At the first stage, qualitative SD must be mapped through causal loop diagrams (CLDs), which represent the research hypotheses and limit the complexity of the model. CLDs capture the major feedback mechanisms within the system, which are either negative (balancing) or positive feedback (reinforcing loops) (Georgiadis et al., 2005). In the present case, the employees of both NETs.werk and SCHACHINGER identified relevant variables in the system and drew causal connections to establish cause–effect relationships among these variables (thus creating feedback loops). This structured process was guided by the well-known operationalization technique of systems thinking, participatory system mapping (PSM) (Sedlacko et al., 2014; De la Torre et al., 2018).

At the next stage, the CLD is translated into a SFD by describing the stock (state) and flow (rate) variables and their interlinkages. The first ones represent the accumulations (inventories), and the second ones describe the flows (rates) of the system. A specific parameter is considered a stock if it accumulates, can still be measured at any time unit, and can be stocked somewhere being used for any other time unit (Binder et al., 2004). All non-stocks are thus either flows or auxiliaries. The links entering and leaving the stocks represent flows if they can be measured with unit x per time unit once the stock is being measured with the unit x. The other explanatory variables are then the auxiliaries. Thus, rates (flows) affect levels (stocks) via resource flows, whereas levels (stocks) affect rates via information (feedback) links. At the last stage, the model was quantified by providing initial values to all the stocks and formulas for dependencies among the parameters (Binder et al., 2004). The mathematical formulation of the SFD was conducted via a system of differential equations, which were then numerically solved through simulation (Georgiadis et al., 2005).

The main influential factors include the number of consumers, the environmental effects of last mile logistics, logistic infrastructures, operational costs, marketing measures, and behavioral analysis. All of these parameters were described within the sustainability dimensions, serving as a basis for the sustainability assessment of the strategic options with MCDA, the description of which is presented below. These options were identified by NETs.werk and SCHACHINGER according to their strategic planning. The developed options were classified into existing network typologies (centralized, decentralized, or distributed; the strategic options development is beyond the scope of this paper). The SD model of the case study served as a tool to evaluate the dynamic changes of the parameters within three options.

3.3. Multi-criteria decision aid (MCDA): The PROMETHEE method

The MCDA provides decision support to one or more decision makers based on the consideration of multiple criteria, which are in conflict with each other. Within this study, the choice and the weighting of criteria were carried out together with the decision makers of both companies. Therefore, the choice of a particular method or combination of methods should be justified by the specific case application (Marttunen et al., 2017; Baudry et al., 2018). In this paper, we apply the preference ranking organization method for enrichment and evaluations (PROMETHEE), which elicits preferences within MCDA. The outranking method PROMETHEE ranks decision alternatives according to a structured analysis of decision criteria (Brans and Vincke, 1985). The structured analysis is based on a pairwise comparison of decision criteria and alternatives. Representing varying degrees of preferences through preference functions is seen as an advantage of PROMETHEE. Moreover, it compares each alternative on a pairwise basis and aggregates results using criteria weights.

The MCDA process can be categorized into three high-level steps (French and Geldermann, 2005; Belton and Stewart, 2010). In the first step, the formulation of the decision problem is developed, so that all stakeholders and decision makers share a common understanding of the decision problem. The application of creative thinking methods helps identify alternatives and provides an initial insight into decision maker preferences (Keeney, 1992). The definition of the decision problem is completed with the identification of a set of criteria used to evaluate the alternatives. The second step deals with the evaluation of alternatives. This requires the determination of performance scores for each alternative and criterion, which can be determined from the literature, expert interviews, surveys, or system models. Within the present study, the specific case settings were used, and selected parameter values were drawn from the SD model simulation runs. Under the assumption that the alternatives and a criterion hierarchy have been established, the PROMETHEE method can be applied by weighting the criteria, assigning the preference functions, determining the outranking relations, ranking the alternatives, and visualizing the results. The weighting of criteria indicates the relative importance of each criterion for the overall decision. There are two weighting categories: The equal weights method implies that all criteria are of the same importance. The rank-order weighting method has three subcategories: subjective, objective, and combinatorial weighting methods (Cinelli et al., 2014; Guarini et al., 2018). A sensitivity analysis can be applied to analyze the reaction of the results to the changed inputs (e.g., the subjective criteria weights). For our study, the criteria were weighted by the decision makers according to their preferences using the swing weights – by ‘swinging’ the value measure from its worst to its best level (Han et al., 2016).

The ranking of alternatives is conducted according to different PROMETHEE approaches. The most common approaches are PROMETHEE I, which provides a partial ranking, and PROMETHEE II, which creates a total ranking of the considered alternatives (Behzadian et al., 2010; Lerche and Geldermann, 2015). Based on the outgoing and incoming flows, a partial ranking according to PROMETHEE I of all alternatives can be developed. One alternative is preferred if it has a higher net flow than another alternative, making a complete ranking possible. It must be noted that information is lost due to the aggregation of outgoing and incoming flows. The determination of outranking relations allows the expression of the degree of preference between alternatives. Using the weighting factor w_k, the outranking relation $\pi(a, b)$ expresses the preference for an alternative a over an alternative b for each alternative (Equation 1). To calculate the outranking relation, weighted preference values over all criteria must be aggregated (Brans and Vincke, 1985). The average positive outgoing flows $\phi^+(a)$ express the strength of one alternative a with respect to the other alternatives (i.e., the extent to which an alternative is preferred over all other alternatives) (Eq. 2). In contrast, the average incoming flows $\phi^-(a)$ represent the extent to which an alternative is dominated by other alternatives (Eq. 3) (Brans and Vincke,1985).

$$\boldsymbol{\pi(a,b) = \sum_{k=1}^{K} w_k * p_k(d)} \qquad \text{(Eq. 1)}$$

$$\boldsymbol{\phi^+(a) = \frac{1}{n-1}\sum_{k=1}^{K} \pi(a,b)} \qquad \text{(Eq. 2)}$$

$$\boldsymbol{\phi^-(a) = \frac{1}{n-1}\sum_{k=1}^{K} \pi(b,a)} \qquad \text{(Eq. 3)}$$

The net flow $\phi^{net}(a)$, which results from the difference of outgoing and incoming flows, must be calculated (Eq. 4). One alternative is preferred if it has a higher net flow than another alternative, making a complete ranking possible.

$$\boldsymbol{\phi^{net}(a) = \phi^+(a) - \phi^-(a)} \qquad \text{(Eq. 4)}$$

At the final stages, the results should be visualized. Some tools like Visual PROMETHEE make the visualization of results with the GAIA (Geometrical Analysis for Interactive Aid) plane easier while enabling the variation of parameters for a comprehensive sensitivity analysis (Geldermann and Zhang, 2001; Mareschal and Smet, 2009). The aim of the GAIA plane is to transform multi-dimensional data into a new set of variables - the principal components - which are orthogonal and ordered, such that the first few retain most of the variation present in the total of the original variables. In the GAIA plane, alternatives are projected as points in a *k*-dimensional space. Using this method, the unit vectors of the coordinate axes represent the criteria enabling information preservation after visualization (Greco et al., 2016).

4. Results

4.1. SD model and parametrization of the variables within the distribution options

The case study of NETs.werk and SCHACHINGER was applied to estimate the sustainability performance of various distribution channels: (1) centralized distribution network with a click & collect option, (2) decentralized distribution network with a home-delivery option, and (3) a distributed network based on crowd logistics. These options are described by the parameters clustered into all three sustainability dimensions and technological variables. The SD model, as presented in Figure 3, was built considering the following variables:

- economic variables: sales, operational expenses (maintenance costs of distribution centers/pick-up stations, fuel and truck costs, employee costs);
- technological variables: digital applications, use of alternative vehicles;
- environmental variables: CO_2 and NO_x emissions, impact of logistics infrastructure expansion on land use, and
- societal variables: social interaction, convenience of delivery.

The CLD of the SD model representing the interactions among the parameters were created during the workshops with the decision makers. Primary data on the number of customers, purchase frequencies, and current sales were provided by NETs.werk. Some variables with regard to operational expenses were provided by both NETs.werk and SCHACHINGER. For instance, the number of employees in the current case was provided by the local food cooperative, whereas the necessary number of employees in the event of a collaboration was calculated by the LSP. Investments in digitization (creation of new applications to favor peer-to-peer deliveries) and investments in sustainable modes of transportation (alternative vehicles and zero-emission warehouses) were assessed by SCHACHINGER given their current investment strategy. Based on this, CO_2 and NO_x emissions were modeled using the emission data from the databases of environmental agencies (Federal Environmental Office, 2019). The qualitative parameters, such as social interaction and sharing society percentage, were evaluated by the food cooperative because they are in direct contact with their customers, including the views of the customers captured during the workshops. This was done by giving scores to specific qualitative parameters between 1 and 5 points (from not important at all to very important, or from very bad to very good). Finally, the SD model was built using collected data from the case study (Fig. 3). Moreover, the model was validated using the well-known validation tests, such as boundary adequacy tests, dimensional consistency tests, structure assessment tests, parameter assessment tests, extreme conditions tests, and behavior reproduction tests (Sterman, 2000).

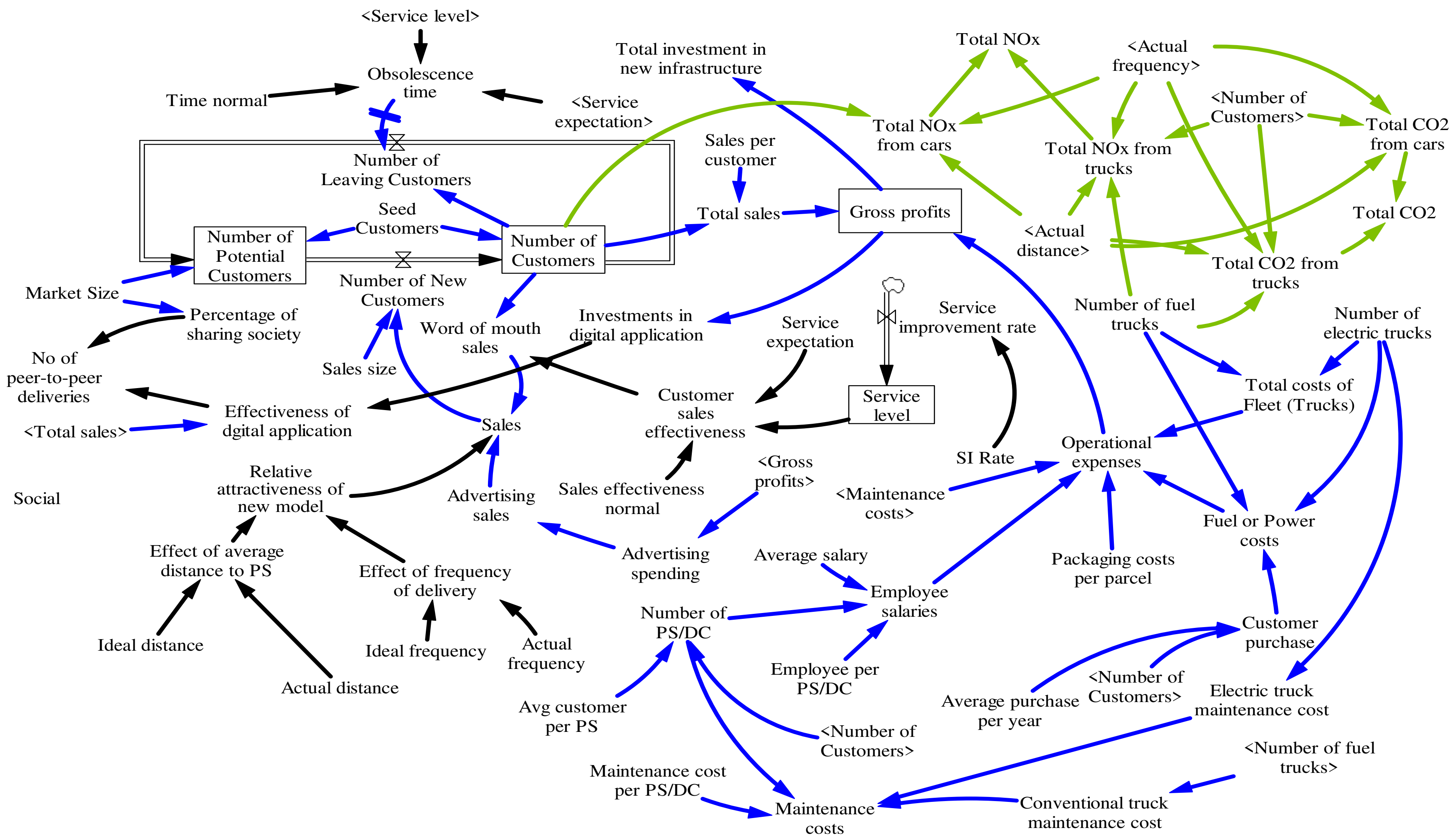


Fig. 3: System dynamics model of a local food distribution network (Note*; *DC = distribution center, PS = pick-up station, SI = service improvement).*

Green arrows connect the ecological parameters, blue arrows connect the economical parameters, and black arrows connect the service parameters.

<..> represents a shadow variable; refers to variables defined elsewhere in a view, in other views, or in an equation.

By simulating the SD model, we obtained the values for the relevant sustainability parameters within the current state of centralized distribution network with a click & collect option. We can also dynamically estimate these values for the future (until the year 2025), according to the current strategic planning of the firm. Furthermore, we have conducted several runs to assess the value changes that will occur if the other distribution strategies are executed in the case of collaboration between the local food cooperative and the LSP. The simulation runs are presented in Figure 4 with some example elements (number of customers, operational expenses, gross profits and CO_2 emissions). The differentiated parameters, with their values and units, are presented in the Appendix (the table of the variables, their units, and the formulas representing the causal dependencies are reflected in Table A-1).

4.2. Description of the alternative options

We estimated the operational costs for different delivery schemes with the help of the SD simulation, namely the decentralized distribution with home delivery option and a distributed network based on crowd logistics (considering peer-to-peer deliveries), comparing both with the click & collect distribution channel as a baseline scenario (Figure 4).

In the centralized case, the food cooperative acts alone, following the business model described in Figure 1, Model 1. If no action is taken, the simulation shows that the business model of NETs.werk will be further profitable and can be scaled while keeping profitability due to increased customers and total sales, while the operational costs increase (please note that for parameter comparison we used the difference of the average value and standard deviation within the time period). The number of customers increases from the current 375 to 521 (Fig. 4a). The operational expenses will accordingly rise to 620,000 euros (b). Given the increase in sales, gross profits continuously increase, reaching 620,000 euros by 2025 (Fig. 4b). The profit per customer also shows an increasing trend (up to 425 euros; the charts are presented in Appendix Fig. A-1). The environmental performance of the business worsens continuously, which is represented in average CO_2 emissions of 675 tons (Fig. 4d) (we did not consider any emissions from the trucks; therefore, the CO_2 emissions per customer remained almost unchanged at 0.5 tons/customer). This behavior of CO_2 is expected because the individual pick-ups with conventional vehicles from the NETs.werk branch offices increase with a growing customer base. In this case, there are no peer-to-peer deliveries expected, given the low coverage of the service infrastructure, investments in digital applications, and the low percentage of those participating in peer-to-peer deliveries.

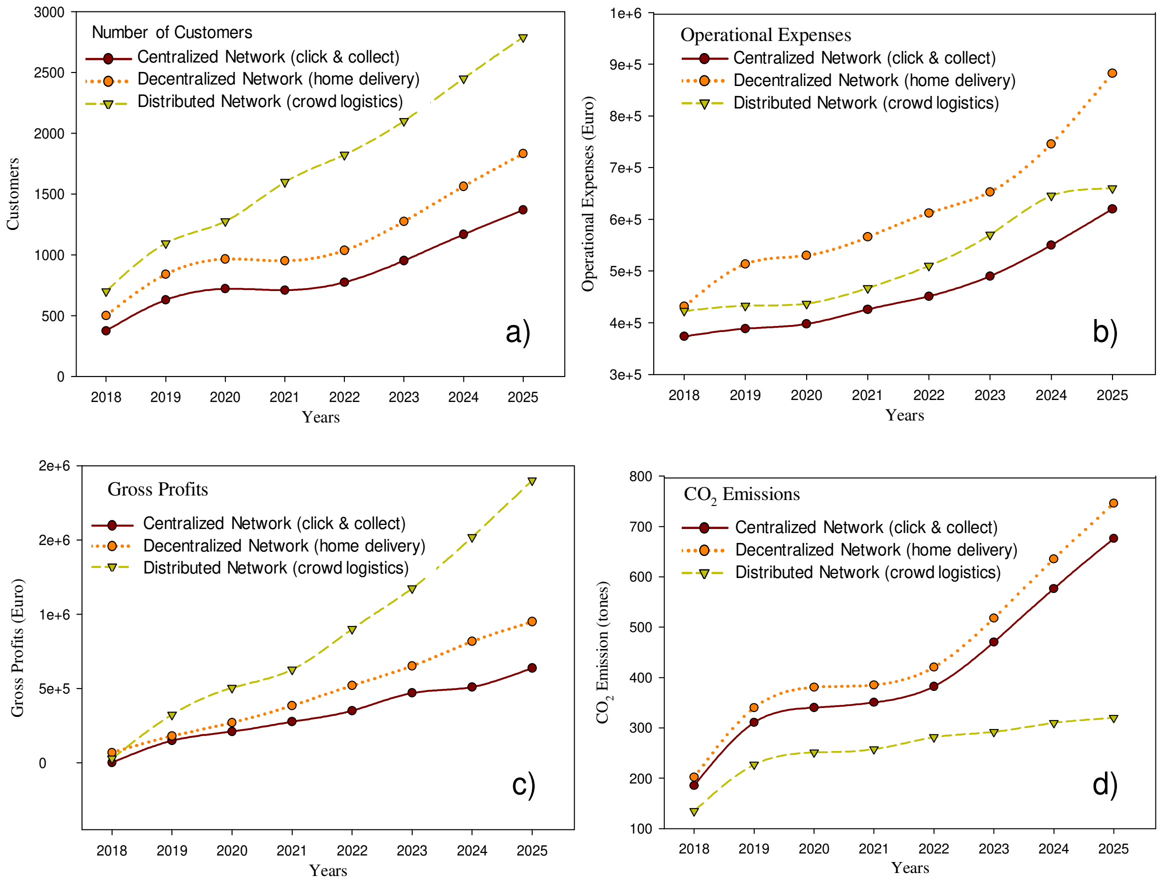


Fig. 4: SD simulation for a business as usual case for the time period of 2018 to 2025 for (a) number of customers, (b) operational expenses, (c) gross profits, and (d) average CO_2 emissions.

Home delivery represents the decentralized distribution channel option. Following the simulation study, even larger increases of total sales can be expected, given the greater attractiveness of the proposed model through increased delivery convenience. The latter causes in a drastic increase consumer numbers especially at the beginning of the introduction of this option. However, being associated with a higher price of delivery and a drastic reduction in social interaction, the number of new consumer stagnates at some point (years 2020-2021), afterwards recovering due to an aggressive expansion of infrastructure coverage and marketing strategies (please note gross profits still continue to increase given the fact that it is a function of not only customer numbers but also sales per customers, which in its turn depends on sales effectiveness). These strategies are related to a sharp increase in operational costs, including costs for the maintenance of distribution centers, employee expenses (increased number of necessary employees), and costs related to the trucks (e.g., an increase in the number of both conventional and alternative vehicles, as well as maintenance and fuel costs). These costs are on average 150,000 euros higher than in the previous option (continuing to increase, and reaching 650,000 euros by 2025, Fig. 4c). In contrast to the baseline scenario, in which CO_2 and NO_x emissions have been calculated only for the conventional vehicles (the customers currently pick up their own orders with private vehicles at the NETs.werk branch offices), in this alternative, we considered emissions from the trucks. While doing so, we defined the emissions as dependent on the ratio of alternative to conventional trucks, their capacity, mean emission rate per km, frequency of delivery, number of consumers, and average distance from the distribution station. The actual distance was calculated using the anonymized data of consumer addresses provided by the local food cooperative. The model results show that the emissions will be on average greater than in the baseline scenario (30,000 tons higher in the case of CO_2) (Fig. 4d), given a strong increase in customers, increased transport distances, a higher rate of emission from the trucks, and, more importantly, because of cold chain emissions.

In the third option of a distributed network system, we also considered crowd logistics operations relying on a sharing economy model (such as peer-to-peer delivery). We assumed a stronger sharing society in which the consumers are environmentally aware, as well as time-sensitive and heavily reliant on digital technologies. Associated with a strong increase in customers who are in favor of this local business model (up to 1,130 people: average value minus standard deviation), a drastic increase in total sales is expected. Gross profits will thus increase up to 2,000,000 euros, and the profits per customer will also increase (reaching almost 800 euros/customer, see Fig A-1). Yet, in contrast to home deliveries, operational costs will not increase as much, given this hybrid form of crowd logistics deliveries, assuming reduced transport costs and employee expenses (Fig. 4c). The only difference is in investments in digital applications, which will be a necessary precursor for this option. Given the smaller pick-up stations (mini-hubs/micro-depots in comparison to larger distribution centers), flexible pick-up options for the customers, and shorter transport distances (thanks to efficiently distributed pick-up stations, flexibly adjusting pick-up sites, and peer-to peer deliveries), pollution release will not increase sharply compared to the centralized and decentralized distribution options (indeed, only a slight increase was simulated). These positive aspects of the distributed networks have also been mentioned in the literature, discussed in Table 1.

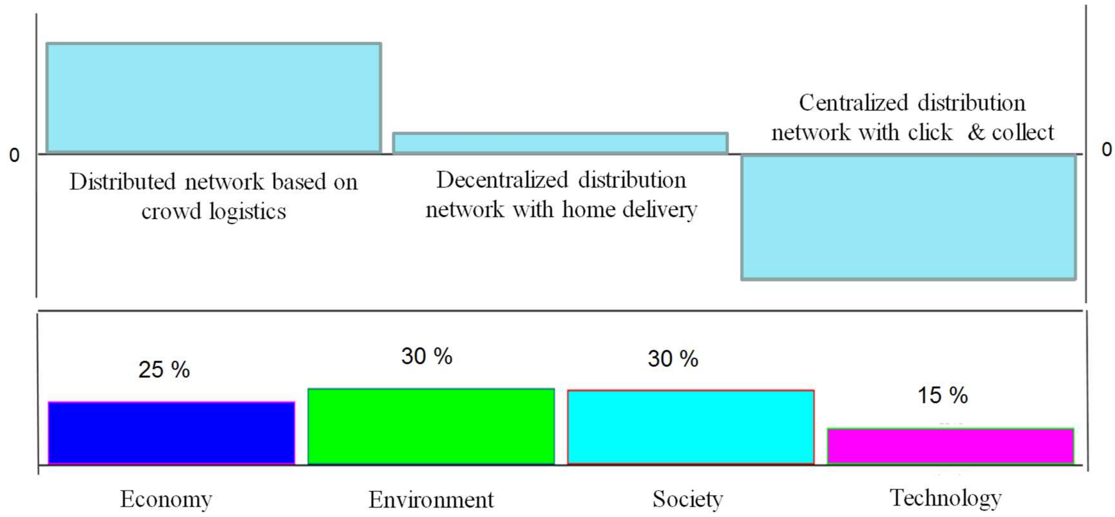
4.3. MCDA results on the sustainability assessments of the three distribution channels

All the parameters (and their values from the SD model) were discussed with the decision makers during the series of workshops, in which these parameters were weighted and assigned to preference function types, along with the indifference and preference values. In general, four clusters of criteria were developed: environmental and societal ones gained the highest weight, with 30% each, whereas economic and technological groups were given 25% and 15% weights, respectively. The criteria within each cluster were given the same weight to keep the weighting procedure manageable. For example, being one of the three criteria within the environment group, CO_2 emissions were given a 10% weight. Clearly, all the environmental impacts of the economic activities are to be minimized, whereas the societal benefit are to be maximized. Within the group of economic factors, the number of customers, and hence also total sales, are ideally maximized while minimizing the operational costs.

In the next stage, the types of preference values were explained to the decision makers. The V-shape preference function (type III) as a special case of a linear function was chosen because it is most suitable for quantitative criteria, and the participants needed to introduce an indifference value (Deshmukh, 2013). This type of function, along with a brief explanation, is included in the Appendix (Fig. A-2). On the contrary, the Usual (type I) and Level (type IV) preference functions were chosen because they were the best suited for qualitative criteria. Given the small number of levels on the criteria scale (e.g., ranging from yes/no up to a five-point scale), if the different levels are considered quite different from each other, the usual preference function is the best choice, as in the case of service coverage and delivery convenience.

The criteria and their values for different distribution options, weights, preference types, preference, and indifference values are included in the Appendix (Table A-2; the values are calculated from SD runs and are presented as the difference between the average value and the standard deviation of each variable during the simulation period). As shown in Table A-2, some criteria perform better in some options than in others; thus, the MCDA analysis provides a powerful tool to outrank several distribution options, relying on aggregated criteria analysis.

Figure 5 shows the outranking of the food distribution channel options. It shows that the distributed network strategy with sharing economy concepts performs best at the given weights of environmental, economic, social, and technological criteria.



Rank	Strategy	ϕ^{net}	$\phi+$	$\phi-$
1	Distributed network based on crowd logistics	0.2817	0.5487	0,2670
2	Decentralized distribution network with home-delivery	0.0339	0.3648	0.0339
3	Centralized distribution network with click & collect	-0.3156	0.2104	0.5260

Fig. 5: Outranking of the three distribution strategies.

To evaluate the strategies in more detail and to understand their differences, we used a GAIA plane (Fig. 6). Figure 6 displays the spider web chart for the different distribution alternatives and allows for the comparison of the strengths and weaknesses of these different strategies. This web chart shows the comparison of scores between various distribution strategies for all criteria. Centralized distribution network (with a click & collect option) provides the best outcome in terms of the reduction of maintenance costs (especially employee costs) and requires almost no investment in logistics infrastructures while providing the highest level of social interaction. Within decentralized distribution network (with a home-delivery option), increased delivery convenience requires wide service coverage and thus higher price of delivery. NO_x and CO_2 emissions explain the variability of the decentralized distribution strategy, given that in this strategy (in contrast to the other two options), the deliveries are carried out with trucks (the light vehicles used in the first strategy release fewer emissions than the trucks, and deliveries with the alternative vehicles used in the third strategy also favor the reduction of emissions). The distributed network strategy is strong in all the criteria consistent with sharing economy concepts like crowd logistics (with peer-to-peer deliveries). The flexibility of delivery timing and location enabled by large investments in digital applications attracts customers, thus also increasing total sales.

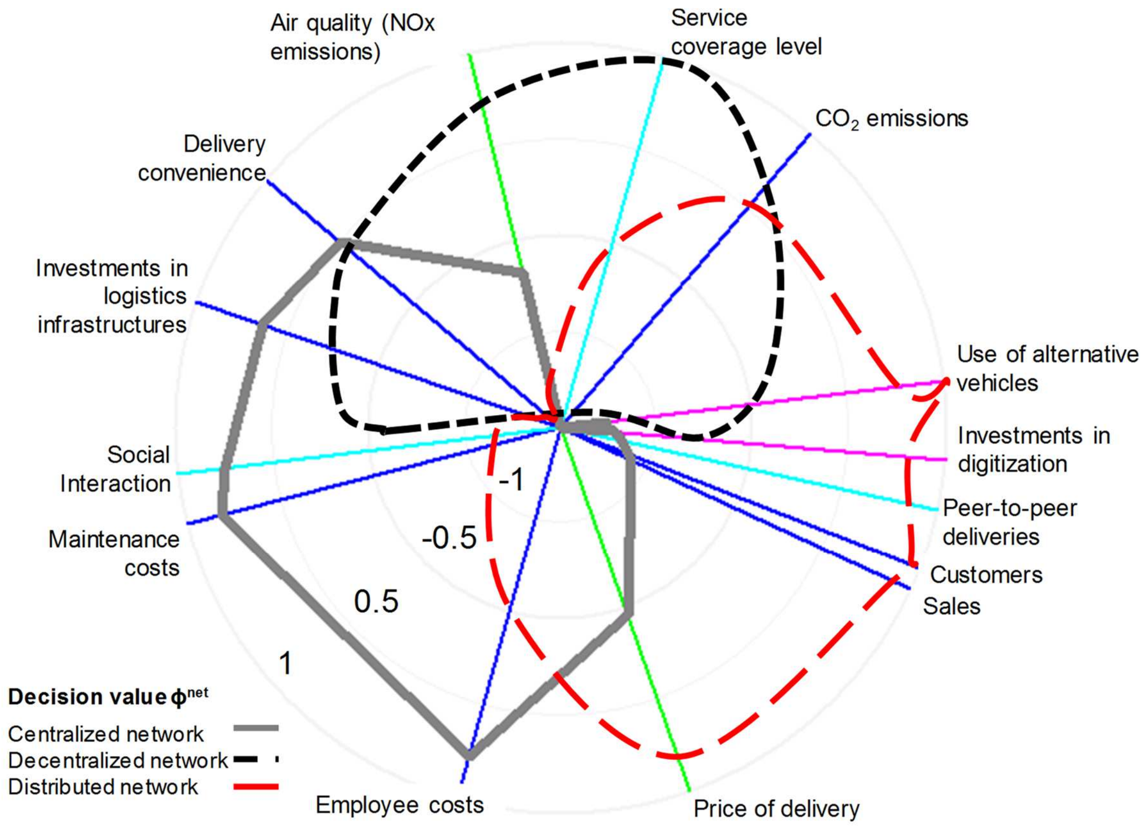


Fig. 6: GAIA Plane with ϕ values for various criteria within three distribution strategies.

These results provide a solid foundation for conducting a more targeted sensitivity analysis to develop a decision catalogue with recommendations on the specific criteria and their weights and thus facilitate the selection of a specific strategy. For this, we used the function of walking weights to estimate the impact of changed weights on the outranking results. Figure 7 below shows the example of the decentralized network with a home delivery option as the preferred distribution option. The example of the centralized network with a click & collect option is included in the Appendix (Fig. A-3).

Decentralized distribution with a home delivery option becomes the preferred strategy if the companies overweigh the investments in logistics infrastructures (from the current 4% to 23%), thus increasing the service coverage level. With an optimized coverage level, the delivery routes will also become efficient, favoring the reduction of air pollution emissions (NO_x) (automatically assigning a higher weight to it, up to 23%), as shown in Figure 7.

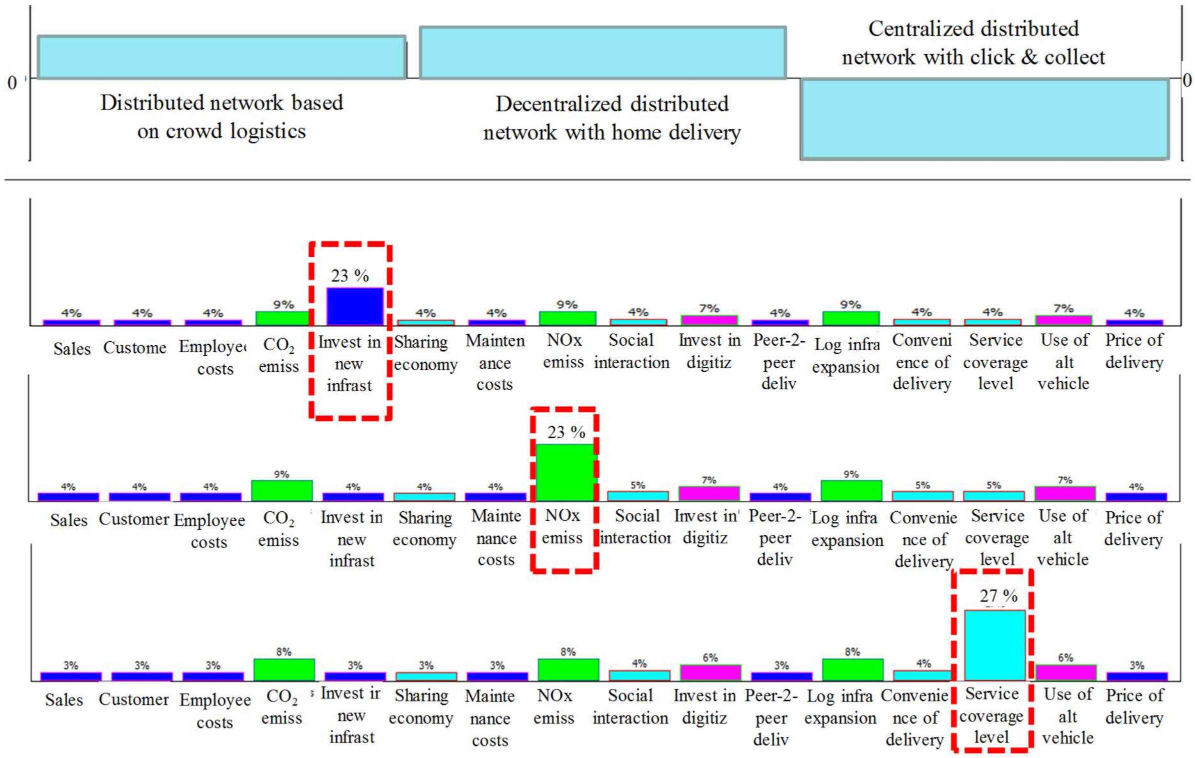


Fig. 7: Sensitivity analysis highlighting the case in which decentralized distribution network with a home delivery option will be the most preferred distribution channel (the red boxes highlight the relevance of the following criteria: investments in new logistics infrastructures, NO_x emissions, and service coverage level).

5. Discussion and conclusion

5.1. Positioning the results into the existing literature

In operations and supply chain management, the last mile refers to the physical goods delivery process involving a set of operational activities necessary to carry goods to the final drop point within the direct-to-consumer market (Aized and Srai, 2014). Last mile logistics is therefore critical because it is responsible for the supply of goods to the customers, all while facing high inefficiencies not only in delivery costs but also in environmental and social issues.

By systematically analyzing the relevant sustainability elements of the last mile logistics system and modeling their interactions in this study, we assessed the sustainability potential of three distribution strategies within a local food supply chain. Thereby, we simulated the diffusion of a local food business model by matching food supply and demand. By operating an e-food online platform and offering a click & collect distribution as baseline strategy, the present study validated the potential of including additional logistics services in the existing business model. The results can be summarized and discussed in the following manner:

- The coordination of food logistics and distribution is a complex decision-making problem within the last mile. Thus, a holistic approach that includes the network types of distribution channels, demand uncertainties, different decision-making processes, and particularly the sustainability aspects of food supply chains must be considered. This is in line with Akkerman et al.'s (2010) review of quantitative operations management studies on the strategic, tactical, and operational levels of distribution management. Integrated solutions based on food distribution networks and demand volatility were also addressed by Diabat et al. (2016), who considered a distribution network consisting of a depot, a group of customers, and several homogeneous vehicles. The authors highlight the need to simultaneously make decisions about the warehouse and transport routes based on a novel "arc-based formulation," which leads to sensitivity analyses with parameters being individually adapted and the solution being subsequently improved. The present study confirms their findings by studying more complex structures.
- To further optimize last mile logistics and distribution, there are potentials in the collaboration between food production systems and LSPs. Having collected and analyzed the needs of LSPs in local food supply chains, Martikainen et al. (2014) developed two potential service offerings for LSPs and food companies in general, highlighting the high efficiency potential of collaborating with an LSP. This is explained by the adaption of supply chain management practices to the

particularities of local food production being characterized by short chains and intensive horizontal and vertical networking (Engelseth and Hogset, 2016).

- If distributed network strategies based on crowd logistics concepts are employed, local food supply chains perform more sustainably than centralized and decentralized distribution alternatives (such as click & collect). This is in line with the proposed supply policy in a two-echelon centralized supply chain with a single retailer and a single supplier – as suggested by Sazvar et al. (2014) –based on a stochastic, mathematical model. Their model is also confronted with uncertain customer demand, as in the case of the present study. Yet, in the case of collaboration between a food cooperative and an LSP, a centralized distribution strategy is argued to be highly sustainable. Therefore, we considered alternative distribution strategies – such as distributed networks relying on crowd-logistics concepts – applying an MCDA approach in a local food supply chain. In this vein, Validi et al. (2014) already applied a multi-objective optimization model, which minimizes CO_2 emissions from transportation and total costs, while comparing various distribution channels for the dairy industry. Also in line with Rai et al. (2017), our study showed that crowd logistics solutions have a high sustainability potential for the supply chain.

5.2. Managerial implications

Dynamic changes in consumer requirements (e.g., environmental awareness, a preference for local and seasonal food), innovative technological applications, and policy regulations on environmental impacts pose challenges for last mile logistics, on the one hand. On the other hand, these trends provide opportunities to the LSPs to innovate their service portfolios. The innovation of the service portfolios can be achieved by developing more sustainable distribution channels, investing in the re-alignment with traditional food production systems by including logistics service offers (e.g., coordination of the last mile), all while further optimizing distribution networks and operations (e.g., route optimization, understanding demand dynamics).

Summing up MCDA results on sustainability assessment of various distribution channels, managerial insights can be generated from our study and combined into recommendations to design more sustainable last mile logistics and distribution options. By targeting specific customer groups, managers need to take the following results into account when choosing distribution channel options:

- If the weights of the economic, environmental, social, and technological groups of network and demand parameters are set equal, distributed network solutions (with crowd logistics options) will be the preferred option based on the proposed model. Distributed network solutions will be outranked only if the economic parameters gain an absolute weight of 90%, making the other parameters almost irrelevant.
- The centralized distribution network with a click & collect option (comparable to stationary retail, in which consumers pick up their goods themselves) should be the preferred option if the employee and maintenance costs of the logistics infrastructure are ranked significantly high by the managers (from current 4% to 40%) or if social interaction becomes significantly more important for the consumers. Here, consumer queries on their sustainability preferences are highly recommended.
- A decentralized distribution network with a home delivery option should be the preferred distribution channel if investments in new logistics infrastructures – and thus service level coverage – becomes more important (20% more important in comparison to the current situation) or if air quality (especially NO_x emissions) is more relevant than in the current situation.

5.3. Contribution, limitations and future research avenues

In order to select the most sustainable and efficient distribution strategy according to the future requirements of key stakeholders, a deep understanding of the relevant sustainability elements is necessary. To achieve such an understanding, it is important to examine dynamic interactions and forecast future states of the system. In this paper, we showed that a combined method of SD simulation (which enables modeling of the current and future interactions among the system's relevant elements) with MCDA (which enables weighting of these elements) is a powerful tool for determining the company's most suitable strategy. This combination of methods can be applied not only for choosing the right distribution channel but also for other managerial decisions. In this sense, MCDA has already proven to be an appropriate evaluation tool for assessing sustainability in different sectors.

For instance, Wątróbski (2016) compiled an overview of MCDA methods that were applied to selected green logistics problems. Han and Trimi (2018) further developed criteria to design and evaluate social commerce based on reverse logistics processes, examining the reverse logistics practices of three major global firms. In addition, Yazdani et al. (2017) utilized MCDA to investigate agricultural supply chains in France to select the best logistics provider. In this line, Vidal Vieira et al. (2017) proposed a framework for designing operations at retail distribution centers by studying the three elements of distribution strategy, internal activities, and the characteristics of the distribution operations. Recently, Moktadir et al. (2018) examined the interrelationships of barriers to SSCM practices for a leather industry in Bangladesh. However, to the best of our knowledge, an application of MCDA based on the quantified and projected state of sustainability elements within last mile logistics and distribution of local food products was carried out for the first time in this paper.

A combination of MCDA and SD into a single model has already been applied by Springael et al. (2002) to analyze congestion problems in urban areas. A conceptual model has been set up to illuminate the behavior of car commuters and their underlying decision processes. In contrast to our approach, Springael et al. (2002) propose the direct blending of the MCDA-calculations into the equations of the SD model; thus, the modeled system incorporates the varying behavior of car commuters in making their choice of a departure time. We used a SD model to obtain the interlinkages of the system components, quantifying them and then using those as input for MCDA, in which the decisions are made at a system level and not at the agent's level. The combination of SD simulation and MCDA, however, is not without limitations. To make the model a useful representation of the reality, researchers must rely on existing concepts and theories in order to build a model that reflects a certain target society's core characteristics for investigation. Accordingly, quantitative models cannot fully represent the reality and are limited to a set of parameters. Future research, in this line, might extend our model with additional parameters to increase model completeness.

A possible extension for future research would be to include political elements in the SD model in order to be well prepared for possible governmental pressures (e.g., the introduction of carbon taxation and pricing). Moreover, the results would have been more reliable if other stakeholders, such as consumers or policy makers, had participated in the workshops. Another possible extension of the SD model in the future could include food waste and inventory management. Neglecting these parameters within SD model, as well as some other economic parameters (such as dynamic pricing, etc.) represent the limitation of the model. Even though inclusion of more parameters would make the model closer to the real world, it would make the model more complex to communicate to the decision-makers as well as to conduct the simulation runs. Moreover, as the model was developed through participatory approach, its completeness validation would be even more complex, if even larger amount of parameters was included. While we acknowledge that checking the completeness of requirements is one of the most important aspect of model validation, it is often challenging especially in a PSM scenario where the parameters in the model are driven by the stakeholder's perceptions about the system. Another limitation of the SD modeling approach is its limited capability to analyze the spatial dynamics of a system, even though SD is well suited to evaluate the temporal dynamics of a system. While we were able to model the environmental impact of various delivery options, the SD approach does not allow to simulate the location and spatial configuration of the distributed network's elements (pick-up stations, micro-depots). Another component, which could not be precisely modeled, was behavioral patterns of system agents (consumers). This gap could be fulfilled through applying agent-based modelling, which follows the logic of aggregation from individual behavior of an agent into the system related to the number of similar agents (Huang et al., 2014). Thus, following our approach to build a SD model, which represents the global interdependencies and dynamics of many factors, a thorough information on aggregation can be obtained, after having modeled the agents' behavior in a more complex and detailed level (Borshchev and Filippov, 2004).

Another limitation of the study is related to the MCDA approach, which is based on individual expectations and weighting systems of the relevant criteria. Thus, in order to give broader managerial recommendations, the MCDA analysis should be conducted in various regions, involving broader spectrum of stakeholders and decision-makers (a variety of food cooperatives and logistics service providers). We have already started to generating innovative food business models, combining results of six food cooperatives from Germany and Austria (cf., Gruchmann et al., 2019b). In the next step, we will systematically combine this information into SD and MCDA models to translate the results into managerial recommendations in the food logistics sector providing detailed information on sustainability performance of various distribution options.

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Appendix

Table A-1: List of variables used in the SD model for the basic scenario (PS = pick-up station, DC = distribution center, SI = service improvement).

Name	Definition	Units
Actual distance	50	km
Actual frequency	52	trips/year
Advertising sales	0.05/100*advertising spending	widget/week
Advertising spending	0.05*Gross profits	$/week
Total CO_2 from cars	190*Actual distance*Actual frequency*Customers	g
Total CO_2 from trucks	1079*Number of fuel trucks per PS*Actual frequency*Actual distance	g
Total NO_x from cars	0.535*Actual distance*Actual frequency*Customers	g
Total NO_x from trucks	366*Actual distance*Actual frequency*0.8*Number of fuel trucks per PS	g
Average salary	48000	Euros/year
Average customer per PS	1000	person [10000, 100000, 5000]
Conventional truck maintenance cost	1400*Number of fuel trucks	undefined
Customer purchase	Average purchase per year*Customers	purchase
Customer sales effectiveness	WITH LOOKUP (Service level/Service expectation*Sales effectiveness normal)	widget/person/Year [0, 1, 0.1]
Customers	INTEG (new customers - leaving customers, seed customers)	person
Effect of average distance to PS	WITH LOOKUP (Actual distance/Ideal distance)	dmnl
Effect of frequency of delivery	WITH LOOKUP (Actual frequency/Ideal frequency)	undefined
Effectiveness of dgital application	Total sales/Investments in digital application*0.01	dmnl
Electric truck maintenance cost	1500*Number of electric trucks	undefined
Employee per PS/DC	3	employee/PS
Average purchase per year	RANDOM NORMAL(1000, 2000, 1500, 300, 1500)	purchase/person
Employee salaries	Average salary*Employee per PS/DC*Number of PS/DC	Euros
FINAL TIME	2030	Year
Fuel or Power costs	Customer purchase*((1.2*0.01*Number of fuel trucks)+(0.01*0.001*Number of electric trucks))	undefined
Gross profits	Total sales - Operational expenses	undefined
Ideal distance	5	kms/DC
Ideal frequency	150	trip/year
INITIAL TIME	2018	Year
Investments in digital application	0.01*Gross profits	undefined
Leaving customers	DELAY1I(Customers/obsolescence time, 1, 0)	person/year
Maintenance cost per PS/DC	360*52	Euros/year
Maintenance costs	(Maintenance cost per PS/DC*Number of PS/DC) + Electric truck maintenance cost + Conventional truck maintenance cost	Euros
Market Size	50000	person
New customers	Sales / sales size	person/week
No of peer-to-peer deliveries	effectiveness of digital application*0.4*Percentage of sharing society	purchase
Number of electric trucks	2	truck [0, 10, 1]
Number of fuel trucks	8	undefined
Number of PS/DC	WITH LOOKUP(ABS(Customers/Avg customer per PS))	DC [1, 10, 1]
Number of trucks per PS	Number of electric trucks+Number of fuel trucks	truck [0, 10, 1]
Obsolescence time	(Service level/Service expectation*Time normal) + 2	year [0, 200, 5]
Operational expenses	Employee salaries + Fuel or Power costs+Maintenance costs + Packaging costs per parcel + Total costs of fleet (trucks)	undefined
Packaging costs per parcel	0.5	Euros/purchase/person
Percentage of sharing society	0.4*Market Size	undefined
Potential customers	INTEG (leaving customers - new customers)	person
Relative attractiveness of new model	(Effect of average distance to PS*Effect of frequency of delivery)	dmnl
Sales	DELAY1((DELAY1(Word of mouth sales, 1) + DELAY1(Advertising sales, 1))*(1 + Relative attractiveness of new model), 2)	widget/year
Sales effectiveness normal	1	widget/(person*year)
Sales per customer	1000	Euros/person
Sales size	1	widget/person [0.5, 0.1]
Seed customers	375	person
Service expectation	0.95	undefined
Service improvement rate	SI RATE	dmnl [0, 1]
Service level	INTEG (Service improvement rate)	dmnl
SI RATE	0.05	dmnl [0.05, 1, 0.05]
Time normal	1	year [0.5, 1]
Time step 0.0625	The time step for the simulation	year
Total CO_2	Total CO_2 from cars + Total CO_2 from fuel trucks	g
Total costs of fleet (trucks)	12000*Number of fuel trucks + 20000*Number of electric trucks	Euros
Total investment in new infrastructure	0.05*Gross profits	undefined
Total NO_x	Total NO_x from cars + Total NO_x from fuel trucks	g
Total sales	Customers*Sales per customer	Euros
Word of mouth sales	Customers*customer sales effectiveness	widget/year

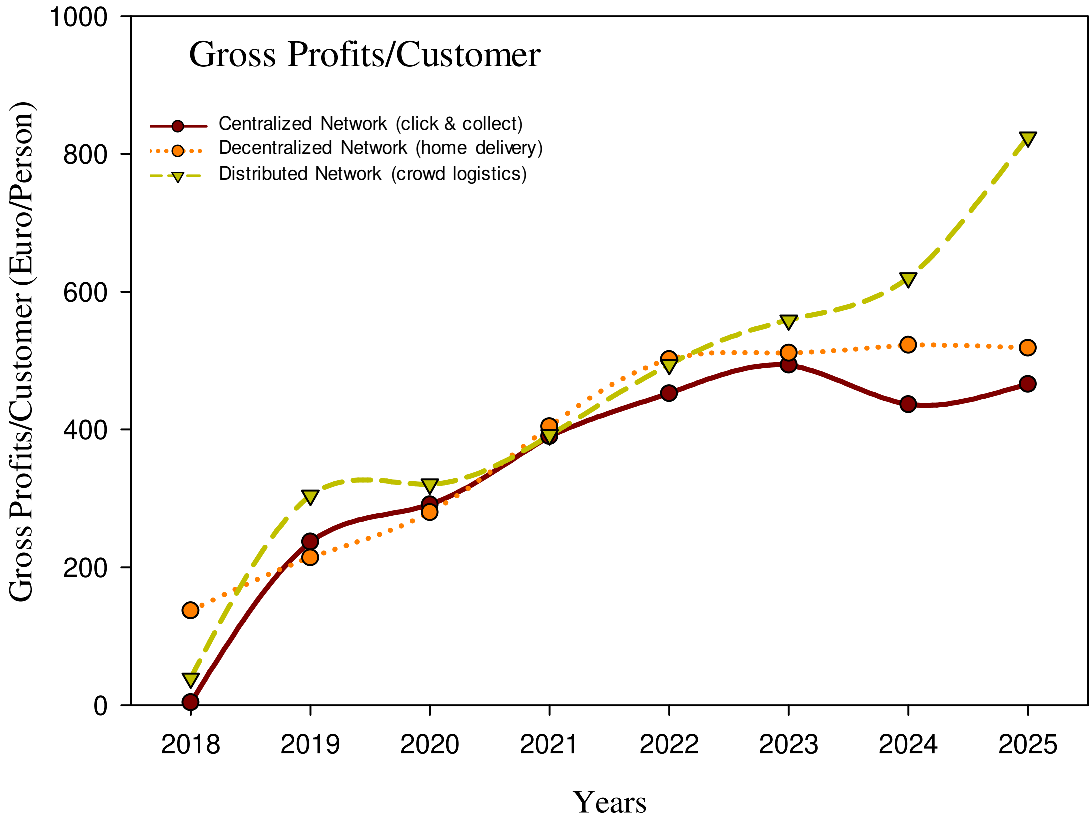

Fig. A-1: SD simulation results of gross profit per customer for three distribution options.

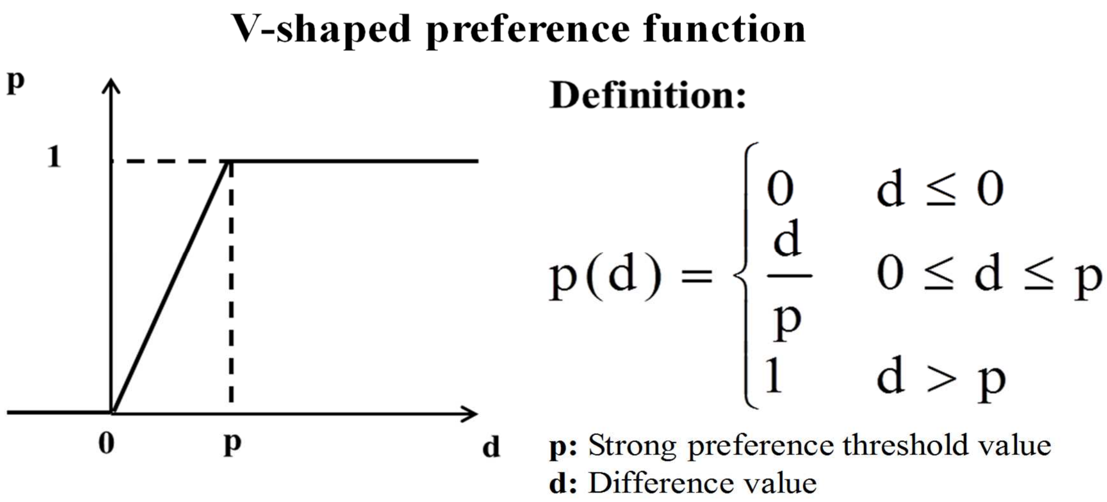

Fig. A-2: A V-shaped preference function, which has been used for almost all quantitative criteria in this paper.

Table A-2: List of variables used in the MCDA for three distribution alternatives. along with their weights, preference function types, and indifference and preference values.

Variables	Unit	Weights (%)	Min/Max	Preference Type	Indifference Value	Preference Value	Centralized Distribution with Click and Collect	Decentralized Distribution with Home Delivery	Distributed Network within Sharing Economy
Environment		**30**							
Total CO_2	t CO_2/year	10	min	V-shape		200	257	300	205
Air Quality (NOx emissions)	kg/year	10	min	V-shape		33	136	156	120
Impact of Infrastructure Expansion	5-point scale	10	min	Usual			1	3	5
Economy		**25**							
Total Sales	€/year	4.1	max	V-shape		1.1 mln	375,000	600,000	1,500,000
Customers	People	4.1	max	V-shape		1,000	525	724	1130
Price of Delivery	€/delivery	4.1	min	V-shape		5	0	5	5
Employee Costs	€/year	4.1	min	V-shape		361,000	144,000 (10 pcs)	600,000	400,000
Investment in Phys. Infrastructure	€/year	4.1	min	V-shape		43,700	0	12,000	45,000
Maintenance Costs	€/year	4.1	min	V-shape		29,000	30,000	38.000	52,000
Society		**30**							
Sharing Society	%	5	max	V-shape		42.25	15	30	60
No. of Peer-to-Peer Deliveries	No. of del	5	max	Linear	3,000	7,000	0	1,000 (10% of customer purchases)	8,000 (40%)
Social Interaction	5-point scale	5	max	Level	1	4	5	3	1
Service Coverage	5-point scale	5	max	Usual			1	3	5
Delivery Convenience	5-point scale	5	max	Usual			1	5	4
Technology		**15**							
No. of Alternative Vehicles	Number / %	7.5	max	Level	1	4	0	1 (5 trucks)	4 (70% of all customer purchases)
Investments in Digital	Euros	7.5	min	V-shape		45,800	14,000	30,000	60,000

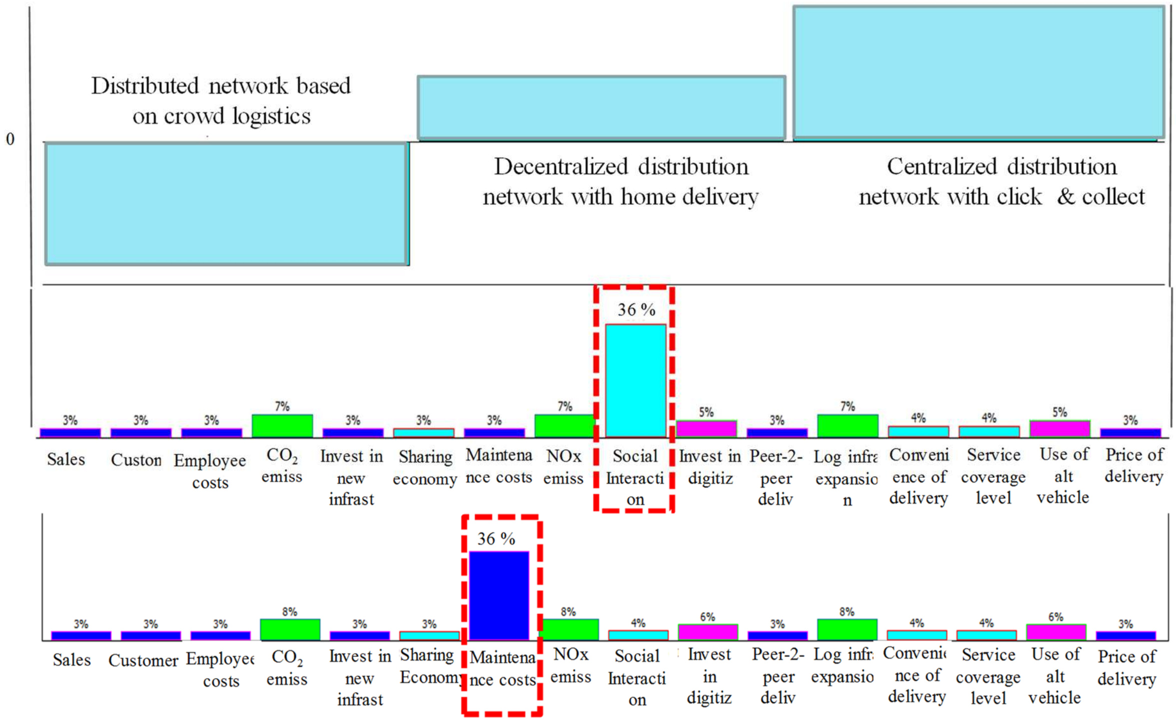

Fig. A-3: A sensitivity analysis highlighting the case in which centralized distribution with a click & collect option will be the most preferred distribution channel (social interaction and maintenance costs gain significant relevance).