AN INTEGRATED FRAMEWORK BASED ON TRIPLE BOTTOM LINE ACCOUNTING AND STAKEHOLDERS' PERSPECTIVE TO PROMOTE SUSTAINABLE FACILITY LOCATION AND ROUTE ALLOCATION NETWORK DECISIONS

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Abstract

Sustainable operations are becoming important for companies, after the United Nations 2030 agenda that emerges countries to move toward sustainable development. Taking care of the environment, society, local communities, and related stakeholders are components of sustainable development that are affected by companies' operations. The facility location/demand allocation/route assignment decisions (hereinafter network) for a company is an operation that has varying economic, environmental, and social outcomes (three pillars) for the company and the related stakeholders. Having an integrated decision support framework that considers three pillars simultaneously and incorporates stakeholders' preferences seems necessary in the network design to reach a sustainable network and promote sustainable development. This framework is missing in the literature. We present a framework that integrates multi-objective mathematical modeling (MOMM) (Anvari & Turkay, 2017) and multi-actor multi-criteria analysis (MAMCA) (Macharis et al., 2012). MOMM generates a pool of feasible sustainable solutions based on three pillars. Then MAMCA analyzes the feasible solutions for each stakeholder. The company (investor) uses these analyses to decide on the best sustainable solution, which satisfies the three pillars and reduces future risks of conflicts among stakeholders. We apply our approach to an original case to establish the network for a juice company in Turkey using real data.

Keywords: Sustainability, Multi-Objective Optimization, Business Impact Assessment, Multi-Actor Multi-Criteria Analysis, Stakeholder Analysis

Authors' individual contribution: Conceptualization — S.A., C.M., and M.T.; Methodology — S.A.; Software — S.A.; Validation — S.A. and M.T.; Formal Analysis — S.A.; Investigation — S.A.; Resources — S.A., C.M., and M.T.; Data Curation — S.A.; Writing — Original Draft — S.A.; Writing — Review & Editing — M.T.; Visualization — S.A.; Supervision — M.T.; Project Administration — S.A. and M.T.; Funding Acquisition — M.T.

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1. INTRODUCTION

United Nations have defined 17 goals as sustainable development goals (SDGs) to provide peace and prosperity for people and the planet. These goals emerge countries and companies to take action to end poverty and empower communities by introducing the sustainable development agenda to be reached by 2030. The 2030 agenda can be a reality, when all stakeholders have a strong commitment to implement global goals and consider sustainability in every action (United Nations [UN], n.d.). The facility location/demand allocation/route assignment decisions (hereinafter network design) are among the most important operations management problems that can affect the sustainable development agenda. Sustainability is a requirement for these decisions due to emerging environmental and social concerns as an outcome of the company's operations. The environmental and social criteria need to be fulfilled while maintaining competitiveness by meeting customer needs and related economic criteria (Seuring, 2013). In addition, the network decisions can affect stakeholders' concerns such as income, employment, the standard of living, security, climate, etc. (Liu et al., 2008). Stakeholders can affect the successful operation of a company, either. Stakeholders are any group of people, organized or not organized, who have a stake in a particular issue or system and can affect or will be affected by the outcome of the project (Macharis et al., 2012). Projects are usually at risk of unacceptable delays or construction problems in the absence of a method that can deal with the different preferences of related stakeholders. If the project management approach does not take into account the interests of different stakeholders and policymakers, the policymakers may ignore or the stakeholders may be offensive (Walker, 2000). Therefore, considering stakeholder concerns in the network design seems necessary and affects the SDGs.

Considering the UN agenda, an improved environmental and social outcome, together with the satisfaction of related stakeholders for the network design problem can act as a competitive advantage for organizations and help to reach the SDGs (Turkay, 2008). The sustainability emergence and stakeholder power in the network design motivated us to answer this question:

RQ: How to design the best facility location/demand allocation/route assignment network for a company that satisfies the economic, environmental, and societal issues while being attractive to all related stakeholders?

We did study the literature to find out the related aspects, applications, important criteria, and related contributions to address this question.

A common approach to achieving sustainability is the concept of triple bottom line accounting of sustainability (TBLaS). This concept states that for a system to be sustainable, a minimum performance should be achieved in the economic, environmental, and social aspects (Elkington, 1994). In our literature review process to find out articles that play a role in sustainability literature, we found two papers that are focusing on the sustainability concept. Anvari and Turkay (2017) have studied a framework to define the set of Pareto optimal solutions for the facility location problem (alternative networks) considering the TBLaS. The framework named sustainable location considering triple bottom line (SLTBL). The alternatives as outcomes of the SLTBL are guaranteed to be feasible in terms of TBLaS with quantitative values. But they do not analyze stakeholder concerns. In another paper, Macharis et al. (2012) introduced the multi-actor multi-criteria analysis (MAMCA) for multi-criteria analysis regarding all related stakeholders (actors). While Anvari and Turkay (2017) obtain a set of alternative networks regarding three dimensions. Macharis et al. (2012) analyze the predefined location alternatives (not necessarily networks) to select the best one regrading the perspectives of different actors and show the positive/negative impacts of each alternative on each stakeholder criteria and the agreement/disagreement among stakeholders.

However, the predetermined alternatives for MAMCA are pursued from the literature or screened based on their feasibility and early involvement of stakeholders. These alternatives are not accurate and most of the time impossible to define them when there are various locations with a large number of parameters. The literature research showed there is no work in the open literature that systematically incorporates TBLaS factors and the different stakeholders' concerns simultaneously in the process of network design, with a focus on quantitative analysis and mathematical models. Especially, the focus on social objectives is limited and there is no work that can answer our designed question.

We investigate SLTBL and MAMCA integration to fill this important gap and analyze the interplay between MAMCA and TBLaS. We build a comprehensive model to help the company decide on the best possible network that considers TBLaS criteria and stakeholders' concerns simultaneously, and helps to reach sustainable development. Specially, we use the power of mathematical modeling to design the alternative network. Using this model we answer this question: *How to design the best facility location/demand allocation/route assignment network for a company that satisfies the economic, environmental, and societal issues while being attractive to all related stakeholders and help to reach sustainable development?*

This sustainable development can respond to the increasing pressure from governments, consumers, non-governmental organizations (NGOs), and media (Seuring, 2013) towards a more reliable economic investment. Putting the corporate objectives, stakeholder preferences, and public interests together makes a win-win condition (Rasmi, et al., 2019). We consider the stakeholders in both the SLTBL and MAMCA parts of integration. In the SLTBL part, we take into account the concerns of all related stakeholders to define the parameters and their priority. This leads to some changes in the mathematical model of Anvari and Turkay (2017). In the MAMCA part, we include stakeholders by analyzing each alternative for each stakeholder.

We propose the first framework in the literature which integrates the three dimensions of sustainability and stakeholder management. First, the objectives are mathematically modeled for each pillar including the validated parameters with their corresponding priority weights. The multi-objective model (MOM) is solved and the efficient alternatives are defined. Second, any other tangible or intangible criteria related to stakeholders' opinions are defined. These criteria can be common with the SLTBL parameters or are not necessary for the range of the three pillars to consider in the mathematical model. This is because we consider stakeholders in both parts, but their concerns can be different in the SLTBL part and MAMCA part. Here, a multi-criteria analysis is performed for the defined alternatives for each stakeholder (actor) individually and then for all actors together. The novelty of this work is that it simultaneously uses the mathematical programming strengths to find feasible sustainable alternatives based on TBLaS and all stakeholder concerns, builds on the trade-off situations among environmental, social, and economic goals, and then incorporates individual stakeholder strategies to promote a win-win situation and earn a competitive advantage for the company. The company owner is the main decision maker and uses the outcomes of this framework to decide on the best option for the company. We applied our approach to determine the sustainable network of a juice manufacturing company in Turkey. The various analysis conducted showed that the model tends to decentralize. The social utility gets better while the environmental effect becomes worse and vice versa. The outcome of MAMCA for this case showed that the best preference of other stakeholders is the alternatives that have higher social utility. The good news is the preference of the investor (company owner) is not necessarily the least cost one and had a good performance in social and environmental and stakeholders concerns. This shows using our framework we could design network alternatives that can help to reach sustainable development not necessarily with lower profit for the investor.

The remainder of the paper is structured as follows. In Section 2, the literature is discussed in detail, then the existing gaps and our proposed contribution is summarized. Section 3 presents the research methodology, Section 4 shows the application and discussion of the results on a realistic case and Section 5 summarizes the conclusions.

2. LITERATURE REVIEW

In this section, we review the related work in the area of supply chain management, network design, and location decisions. We consider any kind of facility location and network design problem that investigates at least one type of sustainability or stakeholder analysis. Quantitative approaches are some alternatives to solve the problem. These approaches are generally classified into the four categories of life cycle assessment (LCA), equilibrium models; multi-criteria decision making (MCDM), and analytical hierarchy process (AHP) method. These models do not focus on the economic goals and they usually compare the existing alternatives based on their environmental performance by applying LCA (Cholette & Venkat, 2009) or AHP (Hsu & Hu, 2009). Regarding the sustainability criteria, the literature review shows that most of the papers available in the literature consider environmental issues in addition to the economic dimension. CO_2 emission and energy demand (Dukkanci et al., 2022), natural capital, resources such as water, energy, and waste generation (Seuring, 2013). Environmental performance (Banasik et al., 2017) is the environmental objectives in addition to the economic cost that has been considered. Some papers have focused on economic and social pillars, mostly investigating the service level (Ho, 2007; Stummer et al., 2004), and the cost of unsatisfied demand as their social consideration.

Some papers consider three pillars (Tautenhain et al., 2021; Dukkanci et al., 2022; Abdullahi et al., 2021). But none of them considers designing a sustainable network together with stakeholder consideration and analysis. Yu et al. (2022) design a multi-period competitive supply chain framework considering environmental policies and consumer preferences for sustainability. Jin et al. (2021) formulated a game-theoretical model that managers' optimistic bias might discourage investment in green product development. Surprisingly, under certain conditions, green optimism can be detrimental to all stakeholders. This study shows the importance of managers' views and considering all stakeholders while designing companies special supply chain. Abdullahi et al. (2021) consider the sustainable vehicle routing problem that takes into account the three dimensions of sustainability with a focus on the negative effect of transportation on the three pillars. Dukkanci et al. (2022) focus on minimizing the total fuel consumption, maximizing the total welfare of the drivers by encouraging equitable payment across drivers and low total driver cost, and maximizing the total welfare of the customers through fairness in terms of delivery times.

Another alternative model to solve the problem is a meta-heuristic algorithm used by Rafigh et al. (2022). They propose a framework for a sustainable supply chain network. They consider total cost, environmental emissions, and job opportunities to cover the criteria of sustainability. The alternative technique is the technique for order preference by similarity to the ideal solution (TOPSIS) used by Govindan et al. (2016) to rank alternative potential locations with respect to the three dimensions of sustainability. None of these works deals with mathematical models to design a sustainable network and quantifies the social concerns to embed into a mathematical model. Although, some works have considered the criteria of the social dimension, but they are limited and examined on pre-defined special locations, not a comprehensive method applicable to all location problems.

In addition to these papers, the literature includes a number of review papers as a comprehensive information resource. Terouhid et al. (2012), Ramstetter (2011), Chen et al. (2014), Eskandarpour et al. (2015), Shekarian et al. (2022), and Khan et al. (2021) review the sustainability considerations in supply chain management. According to these papers, the sustainability consideration from the social dimension received limited attention in the network design and facility location literature. Literature does not effectively address sustainable development requirements from the TBLaS perspective to help the decision maker. Also, they are ignored in mathematical and optimization models (Khan et al., 2021). The recent literature research of Sánchez-Flores et al. (2020) shows lagging behind in emerging economies' research versus developed ones in sustainable supply chain management. Based on the review paper of Seuring et al. (2022) on the status quo of theory development in Sustainable Supply Chain Management (SSCM), research on stakeholder management issues, supplier development, emerging economies, and the environmental and social impact of supply chains in such contexts is needed.

In a recent paper, Anvari and Turkay (2017) consider three pillars simultaneously and design a multi-objective mathematical model for the facility location problem. This paper balances the economic, environmental, and social pillars, based on concerns of the three pillars and the strategic perspective of the decision maker. However, the model design and solution selection need to be improved to incorporate other stakeholders and have a more reliable outcome of a sustainable alternative. The overview of the literature shows the importance of stakeholders' participation in the decision process and different methods to deal with it (Tuzkaya, 2009). One of the important stakeholders is the board. Osemeke et al. (2020) study the board's influence on corporate social responsibility (CSR) among public liability companies using normative compliance theory. They found that non-executive directors (NEDs) and board size are positively and significantly correlated with CSR, while the executive director is negatively and significantly related with CSR. This shows the importance of incorporating different ideas in the board that is kind of incorporating more stakeholders. In another study, Celentano et al. (2020) investigate the relation between board independence and CSR disclosure. They used the ordinary least squares (OLS) regression method and the information from Italian companies. They show a positive and significant relationship between board independence and CSR disclosure. Lahjie et al. (2021) also showed that a lack of corporate governance in monitoring and supervisory mechanisms, as well as a high concentration of managerial ownership, can significantly contribute to low levels of CSR. Nigri et al. (2020) insist on having an integrated sustainable performance management system to integrate sustainable development goals into business. They integrate the benefit-driven indicators into B corps performance management systems and analyze if these indicators are used by managers to support internal decision-making. They show how value-based organizations are moving toward an integrated sustainable performance management system. Sveen et al. (2020) examine sustainability attitudes and actions among managers of Norwegian small and medium-sized enterprises. They define four groups of managers. They find that most managers are skeptics and that the adaptors group is the smallest. They conclude that sustainability initiatives tend to be lagging behind.

These review papers show the role of the board in understanding CSR, incorporating other stakeholders, and incorporating different groups to reach sustainability. Norese (2006) uses the ELECTRE method to compare sites and select the best site to do an environmental impact assessment procedure. Some papers combine AHP with a goal programming model (Ho, 2007), with a weighted linear utility function (Sharifi et al., 2006), and with techniques of fuzzy set theory (Filippo et al., 2007) to do selection analysis. Tuzkaya (2009) uses a combination of fuzzy AHP with the preference ranking organization method for enrichment evaluations (PROMETHEE) to select the transport mode that minimizes the negative effects on the environment in the Marmara region of Turkey. However, in most of the papers, a common value tree and even common weights for all stakeholders are built. Building a common tree needs much discussion and sometimes is not even reachable. Macharis et al. (2012) propose a MAMCA method to involve all stakeholders with their explicit points of view without a need to converge to common criteria. The MAMCA methodology has been applied to various decision problems (Macharis et al., 2010), but only on the pre-defined limited number of distinctive alternatives in order to be able to manage the problem discretely. These alternatives are usually defined based on project developers, the government, and some other stakeholder ideas. The feasible alternatives usually are not easy and most of the times impossible to dene when we have a network with various parameters and more than one decision criteria. Therefore, investigating a framework that satisfies the stakeholders while being able of dealing with lots of different alternatives seems interesting. Integration of multi-criteria decision-making (MCDM) methods with optimization techniques is missing in the literature for sustainable supply chain management (Paul et al., 2021).

Figure 1. Literature structure

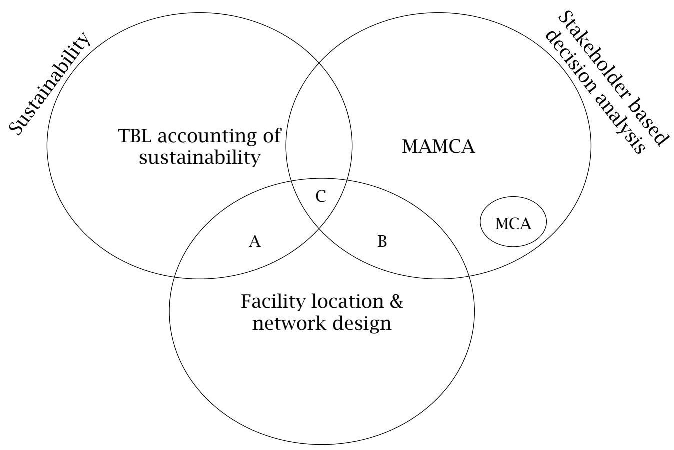


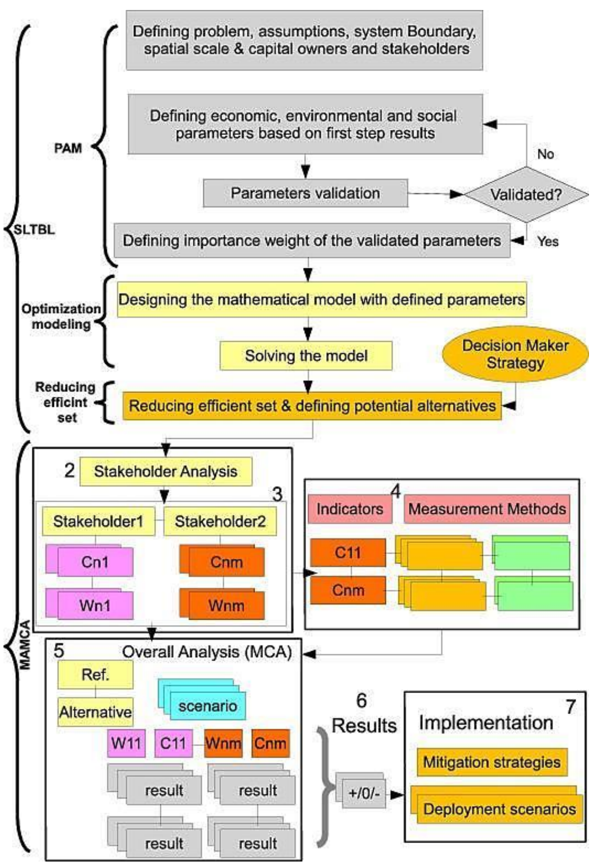
Figure 1 represents the literature and our contribution. Regarding part C, there is a lack of systematic work which considers all related stakeholders and sustainability dimensions to define the parameters, integrates all related issues as well as the interrelations among sustainability dimensions to find feasible alternatives, and finally incorporates all stakeholders in the selection process of the best alternative. We fill this gap in this paper. Also, it is valuable to investigate win-win situations in addition to trade-offs in the multi-objective method. Another issue is less empirical research on the formal assessments offered by quantitative models, especially in part C. We aim to fill this gap as well. We also improve part B by comparing with Anvari and Turkay (2017) by adding other stakeholder concerns. We add job-family balance and labor availability as two important concerns. We consider the budget limit that is very important for the investor and the employee training that has cost for the company and is affected by some characteristics in each location. Also, the tax rate is different for different locations and is considered. We incorporate the sensitivity to the emission which differs for each location. Finally, the number of laborers assigned for each facility and the number of equipment installed are considered.

In summary, this paper contributes to the literature as follows. It improves the systematic incorporation of the three pillars of sustainability together with their corresponding interrelations and different stakeholders' preferences in the decision structure to decide on the best supply network. The integrated framework is comprehensive and reliable in the sense that it integrates all criteria that may affect the network configuration and all essential steps of the sustainable location selection algorithm in an easily applicable framework. It provides a consistent approach to incorporate all related parameters, stakeholder concerns, and restrictions to result in feasible sustainable alternatives. It guarantees to reflect the perspectives of all actors and promote a win-win situation. The framework is flexible to adopt to modifications in the facility location problem and other problems. It deals with real multi-mode network configurations, sensitive to different location characteristics and every preference of individual stakeholders. It investigates a more comprehensive social utility analysis by quantitatively modeling different social concerns, and promotes social responsibility and business practice, rather than just thinking about the work condition and customer satisfaction. It quantifies the qualitative/quantitative criteria with proper metrics to calculate the effects of every parameter with accessible reliable data. It is a contribution to empirical research which fills the gap on systematic sustainable location selection for a complex model, linking the real data (collected from different data sources, expert surveys, and stakeholders discussions) of many parameters to formal assessment and deals with real outcomes for a juice manufacturing company.

3. RESEARCH METHODOLOGY

Figure 2 shows our proposed framework for the sustainable facility location problem that incorporates multi-actor perspectives. This framework is applicable to any problem incorporating sustainability, but our focus is on the location decision/network design problem. The framework starts with the analysis of model parameters based on problematic assumptions and stakeholder concerns, continues with the optimization model of the problem, defines the feasible alternatives, and analyzes different stakeholder perspectives over defined alternatives. Therefore, it satisfies our goal of reaching a feasible solution in terms of TBLaS based on stakeholder concerns and estimating the probability of success/failure of the project based on the satisfaction of all actors. The first part of the framework which includes the first three sections of the framework is the SLTBL part. It includes process analysis method (PAM), optimization modeling, and reducing efficient set sections. The second part is MAMCA which corresponds to the fourth section of the framework. In this paper, our decision problem is defining the location of facilities, the corresponding transportation network, the transport mode in the network, facility capacity, and the number of laborers employed in each location.

Figure 2. The SLTBL-MAMCA joint framework



The framework helps us with the process of defining general and stakeholder concerns and parameters and provides methods to design sustainable alternatives. It shows how the decisions differ when we consider sustainability and stakeholders' concerns. We perform input level aggregation in the SLTBL part where the stakeholders agree on a common set of criteria to find the feasible solutions in terms of TBLaS. Here, the goal is to balance the economic, environmental, and social objectives to matter the limits and common interests. In the MAMCA part, we do output level aggregation, where each stakeholder has an individual value tree. The following describes the four sections of the proposed framework.

3.1. Process analysis method (PAM)

The first section of the framework is a process analysis method (PAM), which investigates the definition of decision parameters for the problem, validation, and interactions. The problem is identified and detailed with its important aspects, goals, and initial assumptions. The system boundary of the problem, its spatial scale, related stakeholders, and capital owners are also defined to have a clear analysis of related parameters. Analysis of historical, legal, and administrative documents, interviews with related parties, literature, NGO concerns, and subject matter expert experience are used to specify the stakeholders.

Here, we define the national level for the system boundary; years for spatial scale; the investor as the capital owner; and government, society, NGOs, employees, customers, and local communities, as the stakeholders. We assume that the suppliers, competitors, and contractors have the same support level for any selected location and do not affect our results. Also, we do not add the supplier locations to the network and ignore the incoming flow. We only consider the potential facility locations and determined demand locations in this work. The economic, environmental, and social parameters are specified based on the expectations of the capital owners, stakeholders, problem assumptions, system boundary, and spatial scale, and embedded into the mathematical model. We use concerns of stakeholders, subject matter expert opinion, some sampled people from the potential locations, and sustainability literature (Chen et al., 2014; Terouhid et al., 2012; Ramstetter, 2011; Seuring et al., 2022; Paul et al., 2021; Sánchez-Flores et al., 2020; Khan et al., 2021), NGO and sustainability reporting guidelines (Global Reporting Initiative [GRI], https://www.globalreporting.org/) to specify the parameters. The parameters with the same value in all locations, or with the same investor policy are ignored due to their non-discriminatory role in the solution of the location network. Also, the post-operation cycle is not considered; there is no priority level for people of different ages, gender, and income groups. We define proper indicators in a way that can measure the corresponding economic, social, and environmental parameters' effects using available standard values. We also validate the parameters including their measurement indicators to make sure that our parameters and indicators are reliable and acceptable.

In the economic dimension, we investigate cost instead of profit assuming the company has a determined market share and price. On the environmental side, life-cycle assessment-based criteria such as energy and CO_2 emissions (Cholette & Venkat, 2009), natural capital (Ukidwe & Bakshi, 2005), or resources such as water, land, energy, and waste (Georgiadis & Besiou, 2009) are taken into account. The resource need and consumption are considered as a constraint to put away any decision that makes a location out of resources. On the social side, we focus on employment, development, employee job-life balance, and ease of doing business that can influence the location decision. We assume the company has the same policy regarding internal criteria like work conditions and gender diversity. We insist on equity in job and development distribution, satisfied level of access to medical faculties and education, security to laborers, and equal work condition to satisfy the human rights emphasized by Vurro et al. (2009) and community equity emphasized by Terouhid et al. (2012). Once the parameters are defined, a validation process based on the work by Cloquell-Ballester et al. (2006) is applied to verify the quality of parameters and indicators. The parameters should pass a 3S validation process including self, scientific, and social validation stages. The self-validation stage is done by the working team, the scientific validation stage is based on the experience and judgments of independent experts and the social stage is applied by those who are affected by the project including public/institutional, self-employed businesses, citizens, and non-profit/NGOs. If the results show any problem, the parameters are redefined to increase the model accuracy from the early stages. More details about the validation process are provided in the supplementary part (Cloquell-Ballester et al., 2006). When the parameters are finalized, they are assigned proper priority weights to develop a realistic model. The subject matter experts' and stakeholders' opinions were used to assign the weights using Saaty's (1990) pairwise comparison method.

3.2. Optimization modeling

The aim of the optimization model is to find an efficient solution for the problem. The optimization model is designed based on the output of PAM regarding the TBLaS. There is no upper bound on the number of facilities. However, the capacity of facilities is bounded based on resources (land and water) limitations and demand. Transportation is outsourced and the links of transport modes have a flexible capacity. The initial material is assumed to be available at facilities and the customer demand must be satisfied completely. Regarding the TBLaS, the model attempts to minimize the economic cost and environmental effect and maximize the social utility, simultaneously.

The problem is represented as the following multi-objective mixed-integer linear programming (MO-MILP) model:

$$Min[Z_E \ \ Z_G - Z_S]$$

subject to: (1)

$$x_{tij} \leq DM_j a_{tij} \quad \forall i,j,t$$

Table 1. Notation of mathematical model (sets, parameters, decision variables, respectively)

Explanation of sets, parameters, decision variables	
$i \in FL$: Potential facility location index	$j \in DP$: Demand location index
$t \in TMP$: Transport mode index: air, train, truck, and ship	$r \in \{1, 2, ...\}$: Social utility criteria number index
QW_i: Available water, after all, needs at facility location $i \in FL$	w: Solid/water waste per production unit
WGE_i: Wage effect on training cost (based on living cost) at location i	JLR_i: Jobless rate at location i
AES_i: Air emission sensitivity at location i	WS_i: Waste sensitivity at location i
WG_i: Wage cost per employee at facility location i	P_r: Priority weight of each social criteria r
QH_i: Available worker at facility location i	HSL: Highest security level at the national level
UT_i: Utility cost per product at location i (water/electricity)	POD_i: Population density at location i
$HIDV$: Highest value in the set of (100 - DV_i)	EAL_i: Education access level at location i
ω_e: Value of range of education access level over three	NOT_i: Number of teachers at location i
PSP_i: Potential school population at location i	NOS_i: Number of schools at location i
PUP_i: Potential university population at location i	$ROEAL$: Range of education access level
$PopH_i$: Potential hospital bed demand at location i based on population	UNC_i: University capacity at location i
PSS_i: Potential school seat demand based on population at location i	MAL_i: Medical access level at location i
ω_m: Value of range of medical access level over three	NOD_i: Number of doctors at location i
$NOHB_i$: Number of hospital beds at location i	Pop_i: Population at location i
DW: Amount of waste per square meter of construction	LN: Required land needed per equipment
wr: Required water per unit product (liter)	CTP: average cost of training
D_{tij}: Distance of facility i and demand location j by transportation mode t.	σ: Average selling price in dollar
a_{tij}: is 1 if the transportation mode t is available between i and j	CEP: Carbon emission per product
CF_t: Unit transportation cost from facility i to demand point j.	$PODC$: Population density of a country
LCP: Productivity of each labor per period (liter per year)	CL_i: Land cost per square meter at location i
EDF_i: Education effect in training cost at location i	$DepY$: Depreciation period
TX_i: Tax rate per product sold at location i	SR_i: Social reaction risk at location i
QL_i: Available land after considering all related needs at facility location i	BDG: Available budget of investor
LL_i *(\$/hour)*: Labor cost per hour in location i	L_i: Number of laborers in each facility
MAG_i: The value gain per employment considering medical access rate if location i selected (medium access level, higher value)	DV_i: Development value at location i DM_j: Demand of demand point $j \in DP$
EAG_i: The value gain per employment considering the education access rate if location i selected (medium access level, higher value).	C: Production capacity per equipment
$MH(hour/m^2)$: Manpower needed (hourly) to construct a square meter of land	SL_i: Security level of each location i
AET_t: Amount of emission (CO_2) released per unit of product transport per kilometer with transportation mode t (grams per liter (kg))	CQ: Cost per equipment
$ROSL$: Range of security level (highest - lowest level in the national level)	$ROMAL$: Range of medical access level
X_{tij}: Amount of product flow from facility location i to demand location j with transportation mode t	
Y_i: A positive integer showing the number of equipment installed at location i	
L_i: is a positive integer specifying the number of hired workers in location i	

$$\sum_{i}\sum_{t} X_{tij} >= DM_j \quad \forall j \in DP \qquad (2)$$

$$\sum_{j}\sum_{t} X_{tij} \leq C * Y_i \quad \forall i \in FL \qquad (3)$$

$$\sum_{j}\sum_{t} X_{tij} \leq L_i * LCP \quad \forall i \in FL \qquad (4)$$

$$L_i \leq QH_i \quad \forall i \in FL \qquad (5)$$

$$L_i \leq QH_i * Y_i \quad \forall i \in FL \qquad (6)$$

$$LN * Y_i \leq QL_i \quad \forall i \in FL \qquad (7)$$

$$wr \sum_{j}\sum_{t} X_{tij} \leq QW_i \quad \forall i \in FL \qquad (8)$$

$$Y_i \leq \sum_{j}\sum_{t} X_{tij} \quad \forall i \in FL \qquad (9)$$

$$\sum_i \sum_j \sum_t X_{tij} * UT_i + \sum_i WG_i * L_i + \sum_i (y_i * CQ + y_i * LN * CL_i)/DepY + \sum_i \sum_j \sum_t X_{tij} CF_t * D_{tij} + \sum_i L_i * CTP * EDF_i * WGE_i \le BDG \quad (10)$$

$$X_{tij} \ge 0 \quad \forall i, j, t \quad (11)$$

$$Y_i \in \{0, 1, 2 \ldots\} \quad \forall i \quad (12)$$

$$L_i \in \{0, 1, 2 \ldots\} \quad \forall i, j, t \quad (13)$$

Equation (1) allows any flow from a facility to a demand location by a transportation mode only if that mode is selected/available and the shipment is at most equal to the corresponding demand. Equation (2) quantifies the customer demand by the fill rate metric. Equation (3) defines the number of established equipment. Equations (4), (5), and (6) are for the job-family balance based on labor work capacity for 8 hours/day, the available labor limit, and labor assignment for the established facility, respectively. Equations (7) and (8) satisfy the resource consumption limits based on available resources. Equation (9) limits establishing a facility if any product is produced in any location. Equation (10) is the cost limit of the investor budget. The last three are constraints of decision variables (positive and integer). The respective objective functions of TBLaS are formulated below.

The *economic objective:* Z_E is expressed as a summation of Eq. (14), (15), (16), (17), (18), and (19):

$$Utilitycost = \sum_t \sum_j \sum_t X_{tij} * UT_i \quad (14)$$

$$WageCost = \sum_i WG_i * L_i \quad (15)$$

$$SetUpCost = \sum_i (Y_i * CQ + Y_i * LN * CL_i + LN \;\; MH \;\; LL_i \, Y_i)/DepY \quad (16)$$

$$TransportationCost = \sum_i \sum_j \sum_t X_{tij} * CF_t * D_{tij} \quad (17)$$

$$TrainingCost = \sum_i L_i * CTP * EDF_i * WGE_i \quad (18)$$

$$TaxCost = \sum_i \sum_j \sum_t \sigma * X_{tij} * TX_i \quad (19)$$

The *environmental effect*: Z_G is formulated as a summation of Eq. (20) and (21):

$$CarbonEmission = \sum_i \sum_j \sum_t X_{tij} * AET_t * D_{tij} + \sum_i \sum_j \sum_t CEP * AES_i * X_{tij} \quad (20)$$

$$LandPollution = \left(\sum_i DW * WS_i * y_i * LN \right)/DepY + \sum_i \sum_j \sum_t X_{tij} * WS_i * w \quad (21)$$

Finally, the *social utility*: Z_S of the total network is defined as:

$$Z_S = \sum_r P_r S_r \quad (22)$$

where, S_r in Eq. (22) shows the value gain for social criteria r calculated in Eq. (23), (24), (25), (26), and (27), respectively, and P_r equals the priority weight for that criteria.

$$JobDistributionEquity = \sum_i JLR_i * POD_i/PODC * L_i \quad (23)$$

$$DevelopmentEquity = \sum_i (100 - DV_i)/HIDV * L_i \quad (24)$$

$$SecurityLevel = \sum_i (HSL - SL_i)/ROSL * L_i \quad (25)$$

$$EducationAccessLevel = \sum_i EAG_i * L_i \quad (26)$$

$$\text{where, } EAG_i = \begin{cases} EAL_i & EAL_i \le \omega_e \\ 1 - EAL_i & EAL_i > \omega_e \end{cases}$$

$$EAL_i = (NOT_i/PSP_i) * (NOS_i/PSP_i) * (UNC_i/PUP_i), \;\; \omega_e = ROEAL/3$$

$$MedicalAccessLevel = \sum_i MAG_i * L_i \quad (27)$$

$$\text{where, } MAG_i = \begin{cases} MAL_i & MAL_i \leq \omega_m \\ 1 - MAL_i & MAL_i > \omega_m \end{cases}$$

$$MAL_i = (NOD_i/Pop_i) * (NOHB_i/Pop_i), \;\; \omega_m = ROMAL/3$$

Model description: For the economic costs, Eq. (14) calculates the utility cost based on per-product consumption and Eq. (15) defines the wage cost based on the number of laborers employed in each location. Equation (16) quantifies the set-up cost with the $CQ\ Y_i$ showing the equipment cost, $LN\ CL_i\ Y_i$ showing the land cost, and $LN\ MH\ LL_i\ Y_i$ showing the construction cost. Due to the long-term usage of the settled facility, we defer the set-up cost over a long term defined by parameter *DepY*. We consider sea, rail, road, and air transportation as four transportation modes that have different costs and distances. Equation (17) quantifies transportation cost based on the unit transportation cost of each mode per product multiplied by the total shipment and total distance traveled by each mode. We consider training laborers at each selected location. However, the average cost of training is affected by the education level and average wage (based on living cost) in each location. Therefore training cost is calculated based on these effects on average training cost and the number of assigned laborers. Tax cost is the last one in the economic category that has a different tax rate value (σ) in each location and is defined for total production at each facility.

For the environmental effect, we focus on emission and waste. The first part of Eq. (20) refers to the amount of emission released during transportation based on distance, amount transported, and unit product transport emission (CO_2). The second part quantifies the emission released during operation for the total production which is affected by the emission sensitivity in each location. The emission sensitivity is affected by population density and geographical tree density of location. Equation (21) includes the construction waste and production waste, respectively. The amount of waste produced per square meter and per product is used with the total land use and production in each facility. Again the waste sensitivity affects the waste amount effect which is calculated based on the population density of the location and location ranking of aquifers and dry soil among the candidate locations. A location with a higher population density and higher aquifers level is more sensitive to waste. We assume that waste treatment technology be the same in all locations. Since the construction waste is high for the long term it is depreciated over the long term (*DepY*).

Social responsibility is a multidisciplinary and multi-stakeholder issue and measuring all of the related aspects are challenging. International Guidance Standard on Social Responsibility — Discovering ISO 26000 is a guiding reference for social criteria published by International Standard Organization (ISO, 2010). ISO 26000 defines seven core subjects for social responsibility: labor practices, organizational governance, the environment, human rights, consumer issues, fair operating practices, community involvement, and development. We investigate the social parameters based on ISO 26000 core aspects and discussion with the stakeholders.

Equation (23) quantifies the social impact of a company in providing job opportunities as follows. The higher the unemployment rate (JLR_i) and the higher the population density of location (POD_i), the more urgency to jobs in that location and higher impact with a higher number of laborers (L_i). To have a coordinated magnitude with other criteria we divide over the population density of the country (*PODC*). In this problem, the network configuration does not change the number of created jobs. With the idea that all people have the right of living in a developed location. Promoting a fair distribution of development helps welfare and community development. Equation (24) quantifies the project's social effect on regional development. Establishing in locations with lower development values ($100 - DV_i$) and assigning more laborers (L_i) will gain more social value. To have a coordinated magnitude with other criteria the result is divided over the population density of the country (*PODC*).

The security level of the location is important for the company to have access to materials, distribute its products, and operate without major security risks and for the employees to live in a safe location, and improve their social life for maintaining their performance. As shown in Eq. (25) the locations with better security levels ($HSL - SL_i$) and higher L_i will have a better outcome. The result is normalized by using a coordinated margin by dividing over a range of security levels (*ROSL*). SL_i is quantified using crime rate and the number of reported incidents available statistical data sets in the country. Higher SL_i means it has lower security. A satisfactory level of access to the medical facility is a priority for employees; and for the company to reduce facing the employee retention problem. Locations with a higher level of access are usually developed locations. Giving a higher value to them forces the model to select developed locations that are in contrast with social responsibility. We promote social responsibility while satisfying the access level by defining (MAG_i) as the social value that the project gains from each location access level (MAL_i) and giving a higher value for locations with medium access levels (consider the way we treat (ω_m). The number of doctors (NOD_i) and hospital beds ($NOHB_i$) overpopulation (Pop_i) quantifies MAL_i as shown in Eq. (27). Education level is important for the company to hire well-educated workers, and for the incoming employees to have access to good education. We use the same strategy and quantification method for the medical access level and give higher value to locations with a medium access level. The number of schools (NOS_i), number of teachers (NOT_i), and capacity of universities (UNC_i) divided by their respective population size are used to quantify the value that the project gains regarding its effect on access to education.

Our MO-MILP model has conflicting objectives and a set of efficient solutions instead of one optimal solution. Generation methods and especially the ε-constraint method are among the popular methods (Laumanns et al., 2006; Mavrotas & Florios, 2013; Rasmi & Turkay, 2019) to solve this type of problem. Among them, AUGMECON2 (Mavrotas & Florios, 2013) proved to have better performance. We use AUGMECON2 as the solution algorithm. Details of AUGMECON2 are provided in Appendix A and Mavrotas and Florios's (2013) paper.

The result of the optimization model is a set of efficient solutions based on TBLaS. In this step, special restricted regulations and limitations can delete any of the solutions and any strict strategy of the decision maker can select any solution. The solutions that pass this step are in the pool to be analyzed with MAMCA for a sustainable and win-win selection based on the individual stakeholders' perspectives.

3.3. Multi-actor multi-criteria analysis (MAMCA)

In this part of the methodology, we investigate which feasible solutions that come out of the SLTBL will have the support of stakeholders. Even if the investor is the final decision maker, having a complete image of other stakeholders' preferences helps to reach a better decision with a lower risk of failure. The original MAMCA includes seven steps. In the original MAMCA, the first step is the problem definition and possible alternative identification. The second step determines the related stakeholders to contribute to the evaluation process. In our integrated framework, we ignore the first and the second steps of the original MAMCA because we have already defined the stakeholders and alternatives in the SLTBL part.

Step 3: The evaluation criteria based on stakeholder objectives are defined. In MAMCA, the criteria are the objectives of the stakeholders, not the effects of the actions. For any stakeholder, an initial criteria list based on the literature, NGO concerns, and subject matter expert opinion is specified. Then, a set of interactive discussions with stakeholders are done to evaluate the predefined criteria, add their new criteria, and set up a hierarchical criteria tree. Every stakeholder has its own requests. For each stakeholder, the defined criteria are assigned a priority weight manually or using technical methods.

AHP is the popular method in that the relative weights of each element in the hierarchy are calculated by comparing all lower-level elements against the criteria with which a causal relationship exists. Weight assigning in AHP uses Saaty's (1990) method. Table 2 illustrates Saaty's (1990) scale used for pairwise comparisons. The other weight is the stakeholder weight in a project. We give equal weight to all stakeholders in order to express our respect for each point of view on an equal basis. Also, a sensitivity analysis can be performed on different weights.

Step 4: In this step, the identified criteria are evaluated by constructing indicators (also called metrics or variables) to provide a scale to measure each alternative contribution to each criterion. Indicators can be quantitative or qualitative. Based on the literature, results from the SLTBL part and/or stakeholder/expert consultations, each alternative performance is measured for its contribution to specified criteria. Then each alternative is compared with others in terms of each criterion, or the information directly entered in the evaluation table.

Step 5: In this step, the overall analysis and ranking are done. Each alternative is evaluated on the specified criteria for each stakeholder using the indicators and measurement methods and for each actor, an evaluation table is set. There are multiple ways to evaluate a criterion. With our framework, most of the evaluation comes out of the evaluation in SLTBL. Within the MAMCA methodology, AHP or PROMETHEE are used as methods to aggregate the results.

Step 6: The evaluation done in the previous step leads to alternative rankings for each stakeholder. It also shows that for each stakeholder which elements have a significant positive or a negative impact on the sustainability of the corresponding alternative. This guides the investor to check which points of view are in disagreement and their possibility to come to a consensus. Also, a sensitivity analysis can be done for each actor to see how robust the results are.

Step 7: The analysis done with MAMCA supports the decision maker with valuable information to guide her/him to select the best alternative considering the advantages and disadvantages of each solution for each stakeholder. This will give the investor the necessary insights to dene the best implementation path, taking into account the potential negative aspects, for example by compensating for that.

Table 2. Binary comparison between criteria of the same hierarchy branch

$C_{i,j}$: and $C_{k,l}$: (∀i, j, k, l)	*Comparison outcome*
1	I consider the $C_{i,j}$ criterion to be equally important to the $C_{k,l}$ criterion.
3	I consider the $C_{i,j}$ criterion to be slightly more important than the $C_{k,l}$ criterion.
5	I consider the $C_{i,j}$ criterion to be more important than the $C_{k,l}$ criterion.
7	I consider the $C_{i,j}$ criterion to be considerably more important than the $C_{k,l}$ criterion.
9	I consider the $C_{i,j}$ criterion to be absolutely more important than the $C_{k,l}$ criterion.

4. APPLICATION AND DISCUSSION OF THE RESULTS

We apply the method to a real case study to show how the methodology works. The case is a fruit processing facility to produce juice in Turkey and satisfy the Turkish market. The initial budget limit is around USD 60 million. Our method helped the company managers towards the best alternative selection. Reviewing juice production sector specialties' ideas, literature, close related cases, concerns of NGOs, government strategies and regulations, and discussing with samples of local people, guided us to dene the significantly related stakeholders. Then we used the same sources to predefined criteria and discussed with stakeholders to finalize the parameters and criteria.

Table 3 shows the parameters used in the SLTBL part embedded in the mathematical model and Table 4 shows the related objectives important to each related stakeholder. This table is considered as a criteria tree in which the different stakeholder groups are listed with their objectives. The global objective of the analysis as the root of the tree is the best decision out of each stakeholder preference analysis. If necessary, the tree can be expanded to additional sub-criteria of any objective. For example, the operation cost includes training, tax, transportation, and wage. However, we analyze the main objective which is operations cost, while it can also be done individually for each sub-criteria. A validation process is applied to the criteria with their corresponding indicator before embedding them in the SLTBL part to ensure that they can properly quantify the economic, environmental, and social impact. The result of the validation process is presented in Table B.2, Appendix B.

In the SLTBL part, we give equal weight to economic cost and environmental effect criteria since the cumulative cost seems logical, and both air emission and land pollution are very important for the ecosystem and society. However, the social dimension criteria took different priority weights as 0.21308, 0.11628, 0.15908, 0.21308, and 0.29858 for equity in job distribution, development distribution, education access, medical facility access, and security level. Also, as shown in 4 different weights are assigned to each stakeholder's objectives. We use the AHP method (Saaty, 1990) and stakeholder/subject matter expert opinion to assign weights.

A point here is the value given to the locations in the education and medical access criteria. In the SLTBL part, we give more value to locations with medium levels to satisfy the incoming employees, and investors, and maximize the social value gain. This value matters for some of the stakeholders, while for some others the real existing value of medical, education, and development level for existing situation matters. Both values are quantified to be used when necessary. The real data with references for all parameters of the case study are provided as supplementary material. Although we illustrate our approach to network design problems for juice production, our methodological framework is applicable to other problems and other cases in different countries.

Table 3. Three pillar parameters

Dimension	*Parameter*	*Max/Min*	*Explanation*
Economic cost	Setup cost	Min	A sum of equipment cost and land cost
	Utility cost	Min	
	Wage cost	Min	
	Transportation cost	Min	
	Training cost	Min	
	Tax cost	Min	
	Budget limit	Satisfaction	Satisfied with a constraint
Environmental effect	Air emission	Min	A sum of transportation and production emission
	Land pollution	Min	A sum of construction and production of solid and liquid waste
Social effect	License to operate	Max	Reduced conflict due to support of NGOs, government, community
	Equity in job distribution	Max	
	Equity in development distribution	Max	
	Security level	Max	
	Equity in education level	Max	
	Equity in medical access level	Max	
	Demand satisfaction	Complete satisfaction	Satisfied with a constraint
	Job-family balance	Satisfaction	Satisfied with a constraint
	Equity in land consumption	Satisfaction	Satisfied with a constraint
	Equity in water consumption	Satisfaction	Satisfied with a constraint

Table 4. Stakeholders and their criteria (as the stakeholders' objectives)

Stakeholder	*Criteria*	*Max/Min*	*In SLTBL*	*Explanation*	*Priority*
Investor	Setup cost	Min	Yes	A sum of land cost, construction cost, and production equipment cost	17.20%
	Operation cost	Min	Yes	A sum of utility cost, wage cost, transportation cost, and training cost	12.86%
	Tax cost	Min	Yes		9.12%
	Ease of doing business	Max	Yes	Licence to operate due to support of NGOs and community	9.54%
	Existing medical access level	Max	No	The access level based on the equity in the SLTBL part	9.43%
	Security level	Max	No	The access level based on the equity in the SLTBL part	18.24%
	Existing education level	Max	No	The access level based on the equity in the SLTBL part	7.87%
	Budget constraint	Satisfaction	Yes	Satisfied with all alternatives with a constraint in the SLTBL part	–
	Resource availability	Satisfaction	Yes	Satisfied with all alternatives with a constraint in the SLTBL part	–
Government	Air emission	Min	Yes	The total CO_2 emission from transportation and operation	33.03%
	Land pollution	Min	Yes	The total waste from construction and operation	16.52%
	Tax income	Max	Yes	Embedded as tax cost for the investor in the SLTBL part	19.39%
	Equity in job distribution	Max	Yes		14.54%
	Equity in development distribution	Max	Yes		16.52%
	Equity in resource consumption	Satisfaction	Yes	Satisfied with all alternatives with a constraint in the SLTBL part	–
	Job-family balance	Satisfied	Yes	Satisfied with all alternatives with a constraint in the SLTBL part	–
Community	Air emission	Min	Yes	The total CO_2 emission from transportation and operation	33.97%
	Land pollution	Min	Yes	The total waste from construction and operation	23.90%
	Equity in job distribution	Max	Yes		28.09%
	Equity in development distribution	Max	Yes		14.04%
	Equity in resource consumption	Satisfaction	Yes	Satisfied with all alternatives with a constraint in the SLTBL part	–
	Job-family balance	Satisfied	Yes	Satisfied with all alternatives with a constraint in the SLTBL part	–
NGO	Air emission	Min	Yes	The total CO_2 emission from transportation and operation	24.80%
	Land pollution	Min	Yes	The total waste from construction and operation	12.40%
	Equity in job distribution	Max	Yes		11%
	Equity in development distribution	Max	Yes		11%
	Equity in medical access level	Max	Yes		24.80%
	Equity in education access level	Max	Yes		16%
	Equity in resource consumption	Satisfaction	Yes	Satisfied with all alternatives with a constraint in the SLTBL part	–
	Job-family balance	Satisfied	Yes	Satisfied with all alternatives with a constraint in the SLTBL part	–
Employee	Existing medical access level	Max	No	The access level is based on the equity in the SLTBL part	27.78%
	Existing security level	Max	No	The access level is based on the equity in the SLTBL part	36.58%
	Existing education level	Max	No	The access level is based on the equity in the SLTBL part	23.26%
	Existing development level	Max	No	The access level is based on the equity in the SLTBL part	12.38%
	Job-family balance	Satisfied	Yes	Satisfied with all alternatives with a constraint in the SLTBL part	–
Local people	Rate of gain over cost	Max	No	Pollution as cost and job/development opportunity as a positive gain	100%
	Job-family balance	Satisfied	Yes	Satisfied with all alternatives with a constraint in the SLTBL part	–
	Equity in resource consumption	Satisfaction	Yes	Satisfied with all alternatives with a constraint in the SLTBL part	–

The network topology consists of 7 potential facility locations and 8 demand locations in Turkey. The facility locations are Istanbul, Bursa, Samsun, Gaziantep, Ankara, Adiyaman, and Trabzon, and the demand locations are Konya, Sivas, Antalya, Izmir, Van, Adana, Erzurum, and Malatya. The real network, available connections, detailed list of metrics, and their values are given in Table B.3, Appendix B. We implemented the optimization model in GAMS 24.1.3, and run it on a laptop computer with a 2.5GHz Intel core i5CPU and 8GB RAM under Windows 7 operating system. The model solution generates a set of 64 Pareto optimal solutions. Among them, 14 solutions are repeated and 50 solutions are unique. The model statistics and solution report for both the pay-off section and the augmented ε-constraint method section are shown in Table 5. Figure 3a represents the unique Pareto optimal solutions with the x-axis showing the solution assigned number and the y-axis representing the normalized values of each objective function in the corresponding Pareto solution. Each unique Pareto optimal solution includes information on opened facilities, the number of equipment established in each open facility, the number of laborers hired in each open facility, the production amount in each open facility, the designed transportation network, allocated demand, and the resulting value for economic, environmental, and social dimensions. Figure 3b represents the Pareto optimal solutions in three dimensions. The SLTBL part is done by producing the alternatives with criteria values ready to be entered in the MAMCA part.

Figure 3a. Pareto-optimal solutions: Solution set for the case study

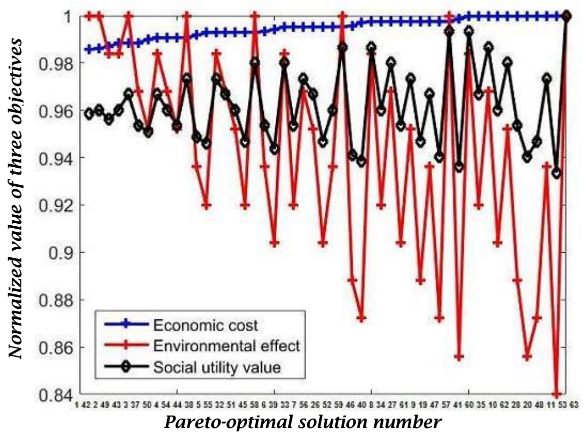


Figure 3b. Pareto-optimal solutions: Three dimension graphic of Pareto optimal solution set

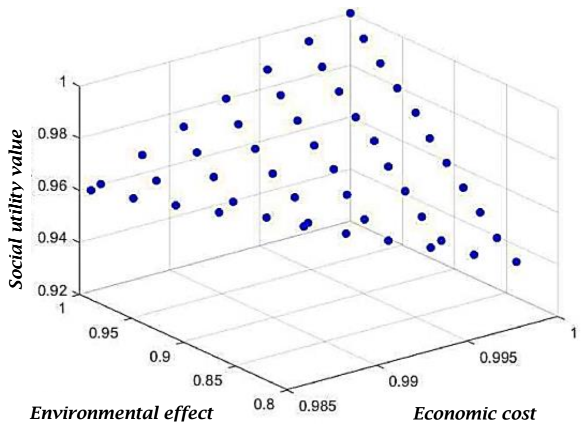


Table 5. Model and solution statistics for the example

	No. of equations	*No. of variables*	*No. of discrete vars.*	*Average CPU time per iter. (sec)*	*Average No. of iters*
Pay-off	531	249	7	0.064	62
ε-constraint	533	251	7	0.05	53

In the SLTBL part, we can alternatively see the trends, relation, correlation, and sensitivity of the three pillars.

Centralization or decentralization: The model tends to decentralize. The set-up cost is depreciated because the facilities are considered as an asset. Therefore, the operation costs get high importance in the economic dimension. By decentralizing the network transportation cost is decreased which leads to a lower final cost. Also, other costs such as utility, and wages have different values in different locations. By decentralization, the model balances the different costs. It is worth mentioning that this result is for our applied case and we do not generalize it for every other case.

The triple bottom line accounting: A balanced solution in three dimensions is the outcome of the mathematical model here. The number of inner trade-offs in each dimension and the trade-offs between dimensions is high and that results in different combinations. Studying the all different combinations shows a decreasing trend for environmental effects and increasing social utility while the economic cost increases.

The preferred alternative selection: The selected Pareto-optimal solutions as the output of SLTBL are entered in the MAMCA as input alternatives. We classified the alternatives based on their economic, environmental, and social values. The result was 21 groups. The alternatives in each group have very close values. One alternative from each group is selected to enter the MAMCA randomly. This is done to make a clearer and smooth analysis in the MAMCA without loss of valuable information, while it is also possible to enter all the solutions. MAMCA can work both based on the AHP method and the PROMETHEE method. We prefer the PROMETHEE method to do our analysis as it is a more quantitative decision-making technique and therefore is more reliable to work with quantitative data. Investors, community, employees, government, NGOs, and local people are the stakeholders we considered for this project. Figures 4a, 4b, and 4c show the analysis results for the investor, government, and society. Figures 5a, 5b, and 5c show the analysis results for NGOs, employees, and local people. Finally, Figure 6 shows the analysis results for the multi-actor analysis.

Figure 4a. Alternatives evaluation and weight chart from the investor perspective

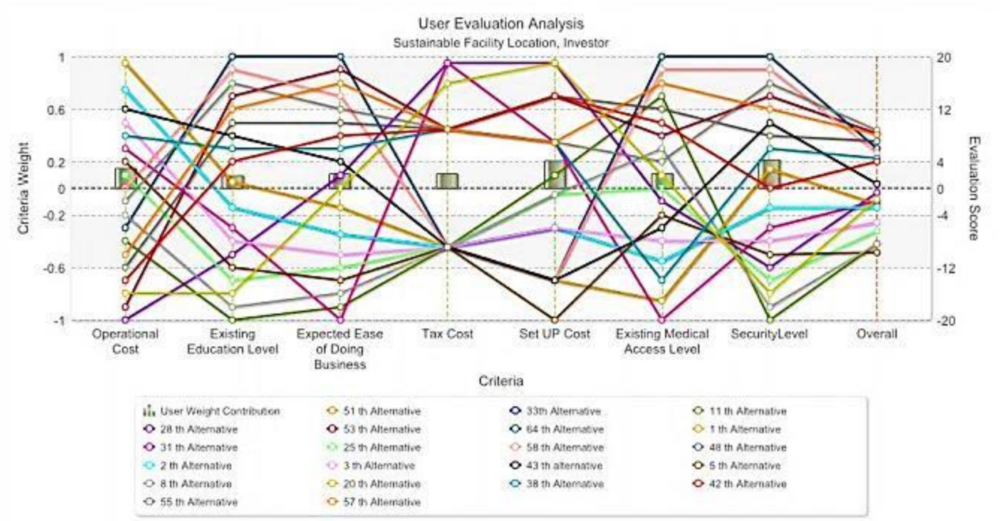


Figure 4b. Alternatives evaluation and weight chart from the government perspective

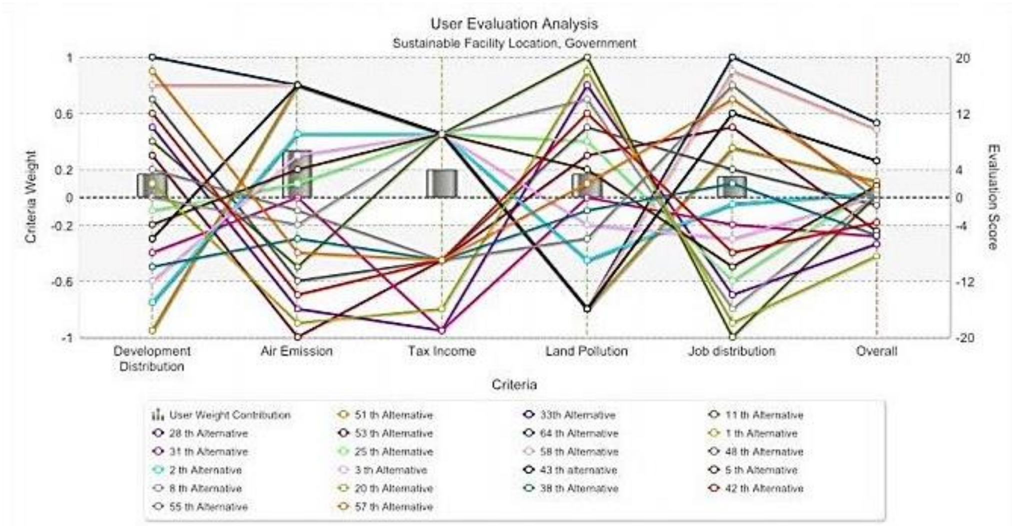


Figure 4c. Alternatives evaluation and weight chart from the society (community) perspective

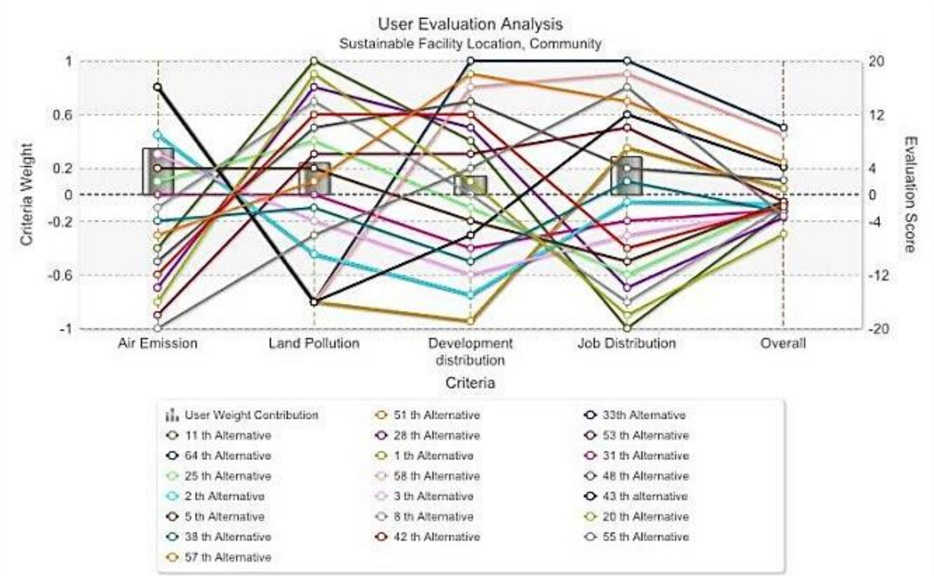


Figure 5a. Alternatives evaluation and weight chart from NGOs perspective

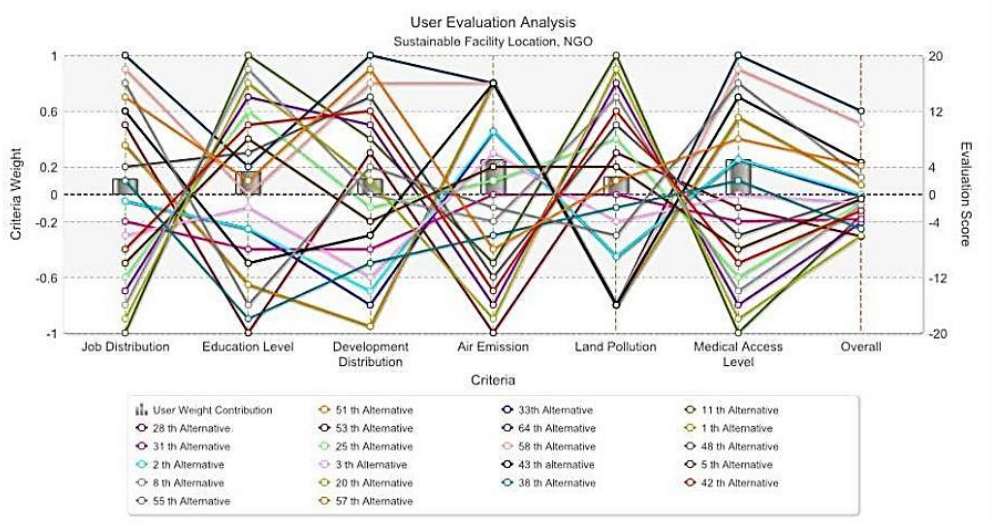


Figure 5b. Alternatives evaluation and weight chart from employees perspective

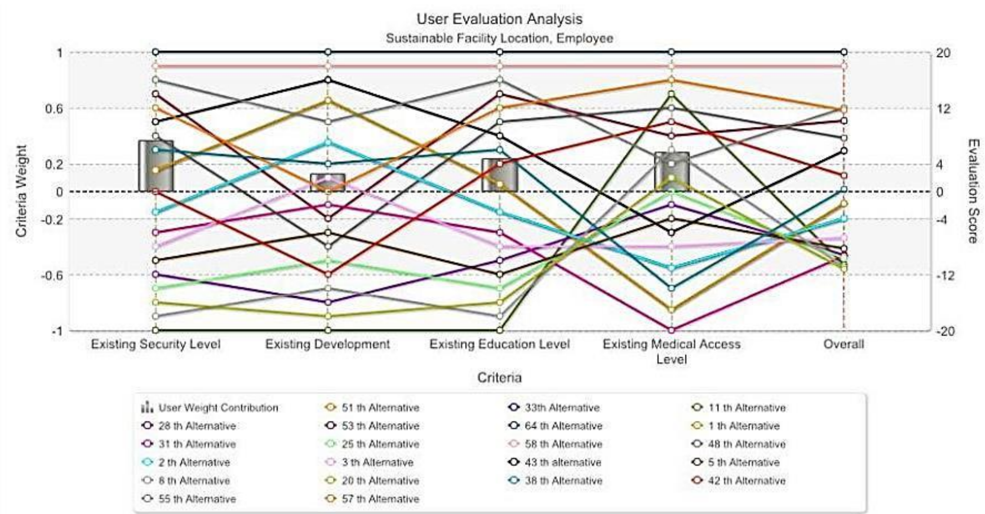


Figure 5c. Alternatives evaluation and weight chart from local people perspectives

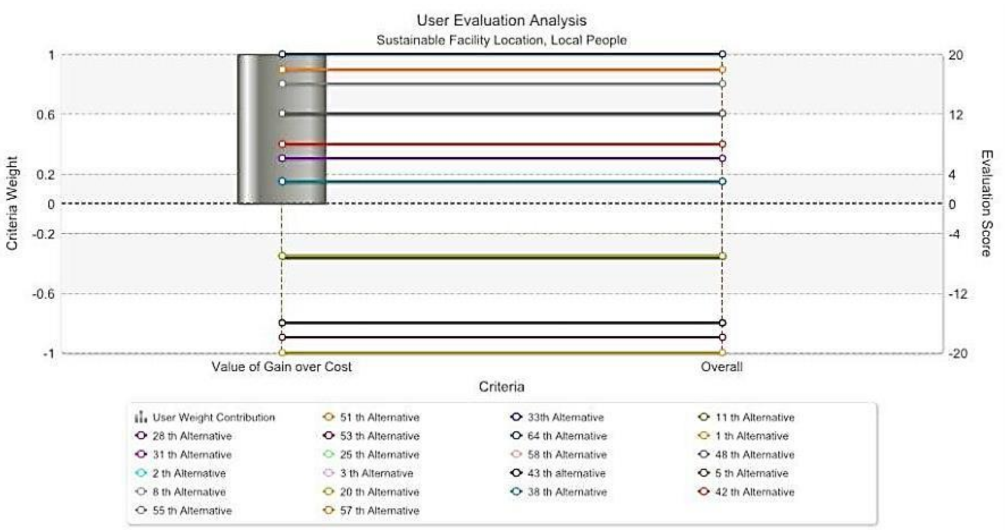
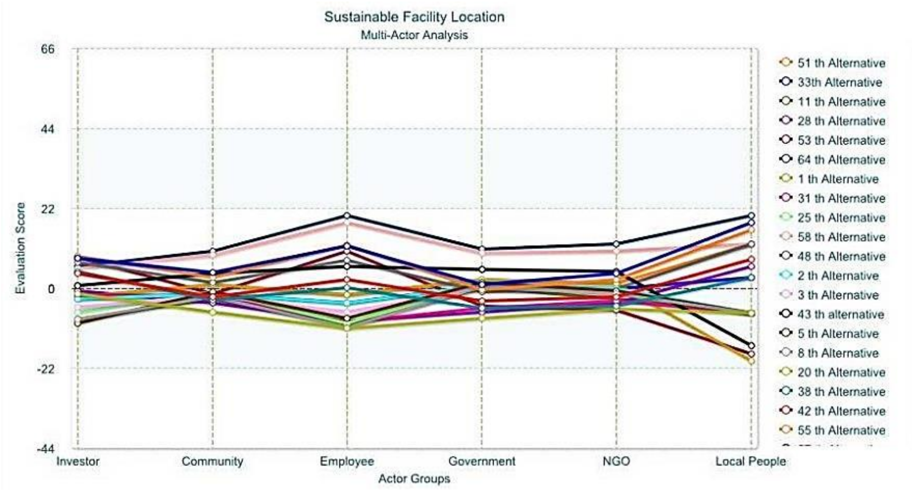


Figure 6. Alternatives evaluation from all stakeholders' perspectives



The analysis shows that the 64th alternative is the preference of all stakeholders, while it is ranked fourth for the investor. This is while the 55th alternative is the preferred alternative for the investor. It is ranked third for the employee and local people and fifth for the government and NGOs, and it has a negative value for the community. Now, the company (investor) should decide on the network based on its strategy. If she/he insists on her/his preference, she/he should check the other stakeholders' reactions by considering a power weight for each stakeholder and analyzing the power of their reaction. For example, if here the reactions for the 55th alternative are not a serious problem then she/he may select it. The reaction power weight is also different for different stakeholders. For example, the government has more power than the community in some cases. The other way is to see where the preferred alternative of others is in the ranking of investors. Here, the 64th alternative has just a 0.48% higher cost for the investor. Hence, if the investor is more flexible she/he may select this option. Therefore, the investor should decide on the final option based on its strategy considering the power of stakeholders or it can have a round table discussion with stakeholders and discuss the preferred alternative. If she/he could not select an alternative it can dene the priority weight for each stakeholder and use the overall axis to dene the final ranking leading to the best solution. However, this overall result should be analyzed with care and may need refinement with respect to its visualization.

Figure 7 shows the preferred alternative of the investor; the 55th Pareto optimal solution. Also, Table 6 shows the detailed values captured in the 64th Pareto optimal solution. It shows the opened facilities, the number of established equipment (facility capacity), and the number of workers hired in the opened facility. Columns 4–11 show the demand allocation with a transportation mode from the opened facility.

The MAMCA results have some interesting issues worth mentioning: first, the preferred alternative for the investor is not the one with the lowest cost. This means that other criteria are becoming important that can change investor preferences from pure economic selections. Second, the preferred alternative for other stakeholders is the one that has a 1.45% higher cost in return for the ideal level of social utility and 81% lower environmental effect than when we just consider economic objectives. This shows with just a 1.45% higher cost we have better levels for social and environmental objectives.

These results are for this special case and they may differ if the case and related data change. However, the theoretical framework is the same and applicable to other cases.

Figure 7. The details of the 55th Pareto-optimal solution

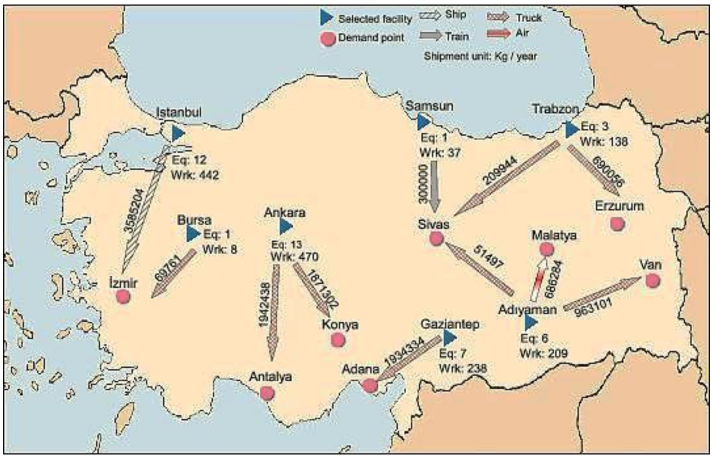


Table 6. Summary of the 64th Pareto optimal solution for location/allocation decisions

Facility	*No. of equipment*	*No. of workers*	*Konya*	*Sivas*	*Antalya*	*Izmir*	*Van*	*Adana*	*Erzurum*	*Malatya*
Istanbul	13	450				Ship-3654966				
Samsun	2	69		Train-561441						
Gaziantep	7	238						Truck-1934334		
Ankara	13	470	Truck-1871302		Truck-1942438					
Adiyaman	6	203					Truck-963101			Air-686284
Trabzon	3	146							Truck-690056	

5. CONCLUSION

We present a two-level methodological approach and an integrated comprehensive framework for facility location/demand allocation/supply assignment problem (network design problem) which includes the mathematical modeling to generate the feasible alternatives in terms of TBLaS in the first level (SLTBL), and multi-actor multi-criteria analysis (MAMCA) to analyze the generated alternatives from the SLTBL level based on individual stakeholder perspectives in the second level. The reason to design this framework is to help the business owner (usually investors) to decide on the best network for their company not only by focusing on the economic outcomes but also on the environmental and social outcomes, and the related stakeholders' concerns. Considering the environmental outcome, social outcome, and stakeholder concerns has become a very important part of company decisions after the United Nations urged companies to take action towards sustainable development. The government, NGOs, local communities are forcing companies to have sustainable activities, and ignoring them can lead to economic loss. The framework is a contribution for the literature by providing a theoretical framework to design a sustainable network. Based on the discussion we had in the literature review part, we can tell that this is a unique work integrating the TBLaS and MAMCA. It is reliable since it involves all criteria and stakeholder concerns, any threshold and assumption, flexible with the decision-maker strategies, and guarantees the satisfaction of each dimension's limitations. This framework is a contribution to the sustainable operations literature as it promotes the corporate social and environmental responsibility, unpacks hidden risks and opportunities, strengthens license to operate, and designs new methods for business practice regarding their operating network. It deals with different trade-offs in the SLTBL part while providing win-win situation using MAMCA.

We applied our approach to determine the optimal network of a juice manufacturing company in Turkey. They did various analyses conducted on this special case study. The analysis showed that the model tends to decentralize. The social utility and environmental effect move in the same direction mean that one gets better while the other becomes worse. The outcome of MAMCA for this case showed that the preference for the business owner (investor) is not necessarily the least cost one, Also, the best preference of other stakeholders is the alternatives that have higher social utility. The result shows that the investor can reach a high level of social satisfaction with just some more investment, which is expected to return back to the investor in the long term as customer loyalty and competitive benefit. These results are for this special case and they may change if we apply on a different case. However, the idea of this paper is to design a theoretical framework that is applicable to different cases and we do not insist on the result of this special case. We just apply this framework to a real case to show its applicability. The main decision-maker is the company (investors). The company may select among all the feasible networks that satisfy the problem limitations. However, this framework provides insight information about all the possible networks and the company can decide based on the outcomes of each alternative in terms of social outcome, environmental outcome, and stakeholder concerns. The empirical application showed how this method can satisfy different stakeholders while selecting a sustainable solution that is in line with the company strategy.

We claim that the way our method works with real quantitative data is very valuable contribution to the quantitative analysis literature. It shows the real difference rather than only judgments that are usually the base in most of decision analysis systems. Our framework is capable of dealing with large number of parameters/data and alternatives which is a drawback in descriptive methods. Also, these exact solutions are more reliable compared with descriptive methods with their comparison-based analysis. The framework helps to reach a clear image of the network, to consider all important concerns, to measure, and select a solution for the company based on the company (investor) strategy, that is satisfactory for all stakeholders, and in the range of acceptable environmental and social concerns. Therefore, it provides comprehensive information to avoid the future potential conflicts and ignore an unsuccessful investment. Our method is flexible to be applied on other cases with different strategies, criteria, and values. There are some limitations in the current work that can be considered in the future research. First of all, we did not consider the possible correlation among criteria and how they can change the game. As a future work, this correlation can be included in the research on a led study. We did assume that some variables are fixed, but they can change. For example, we decided on the cost of transpiration based on the current price, but the price can change. Using stochastic or robust optimization and working with statistical data can be a good way to deal with dynamic variables, and consider time effect and uncertainty in the parameter values as a future work. Also, we consider some parameters based on current knowledge in the literature. If the new parameters come up, it worth to dene them and including them in the model. Finally, we assumed that the supply is available in the facility. The method can be extended to an entire supply chain to be more comprehensive and capture all related effects.

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APPENDIX A

The algorithm for AUGMECON2

Using AUGMECON2, the model is transformed as the following where optimizes f_1 and uses f_2 and f_3 as constraints:

$$Min\ f_1(x) + eps * \left(S_2/(fmax_2 - fmin_2) + 10^{-1} * S_3/(fmax_3 - fmin_3)\right) \tag{A.1}$$

Subject to:

$$f_2(x) + S_2 = fmin_2 + t * (fmax_2 - fmin_2)/q_2 \tag{A.2}$$

$$f_3(x) + S_3 = fmin_3 + t * (fmax_3 - fmin_3)/q_3 \tag{A.3}$$

$$x \in S \ and\ S_i \in R^+ \tag{A.4}$$

where, S_2, S_3 are the surplus variables of the respective constraints, $fmin_i$ and $fmax_i$ are the minimum and maximum value of objective functions from the payoff table (when they are treated as single objective), $fmax_i - fmin_i$ is the range of f_i, t is the counter for the specific objective function, and q_i is the number of equal intervals in the range of f_i and $eps \in [10^{-6}, 10^{-3}]$. With this formulation the solver will find the optimal for f_1 and then it will try to optimize f_2 then f_3. The method reduces the number of redundant solutions using bypass coefficient as:

$$b = int\left(S_i/\left((fmax_i - fmin_i)/q_i\right)\right) \tag{A.5}$$

when, $b >= 1$, shows that the same solution will be obtained in the next b iterations and we can bypass them.

APPENDIX B

Table B.1. Real data for the case study (Part 1)

Parameter	*Standardization way*	*Reference*
Priority weight of each social criteria	Based on judgment	Qualitative data
Available water at each location	Direct use	Turkish Statistics Institution (https://www.tuik.gov.tr/)
Utility cost per product at each location	Water consumption/product * unit water cost + gas consumption/product * unit gas cost	GazElektrik (n.d.), Ngoc and Schnitzer (2008), "Profile on the Production of Packed Juice and Syrup" (2015)
Waste sensitivity at each location	Normalized population density * location geographical aquifer weight	Arslan-Alaton et al. (2005), Turkish Statistics Institution (https://www.tuik.gov.tr/), Turkish Ministry of Forestry and Water Management (http://www.ormansu.gov.tr/), Nufusu (https://www.nufusu.com/)
Emission sensitivity at each location	Normalized population density * location geographical forest/aquifers weight	Arslan-Alaton et al. (2005), Turkish Statistics Institution (https://www.tuik.gov.tr/), Turkish Ministry of Forestry and Water Management (http://www.ormansu.gov.tr/), Nufusu (https://www.nufusu.com/)
Solid/water waste generated per unit of production	10350 grams/unit product, direct use	Ngoc and Schnitzer (2008)
Wage per employee per period (year) in each location	Direct use	Turkish Statistics Institution (https://www.tuik.gov.tr/)
Wage effect on training cost	1 - (medium wage value - location wage value)/ different location wage range	Turkish Statistics Institution (https://www.tuik.gov.tr/)

Table B.1. Real data for the case study (Part 2)

Parameter	*Standardization way*	*Reference*
GHG emission	GHG emission (grams) per kg cargo/km of transportation, direct use Air = 0.7, Truck = 0.18, Train = 0.014, Ship = 0.02	Weber and Matthews (2008), Green-house gas emission list (http://www.co2list.org/files/carbon.htm), Tennessee-Tombigbee Waterway (https://www.tenntom.org/), BluSkyModel (http://www.blueskymodel.org/)
Value gain regarding medical access level of location	Normalized value with higher weight to medium level	Turkish Statistics Institution (https://www.tuik.gov.tr/)
Value gain regarding education access level	Normalized value with higher weight to medium level	Turkish Statistics Institution (https://www.tuik.gov.tr/)
Value gain regarding development rate	Normalized value with higher weight to lower level	Is Bank (https://ekonomi.isbank.com.tr/en /Pages/home.aspx), Erhan Gül and Bora Çevik (2015)
Available labor at location	Job-less rate * population	Turkish Statistics Institution (https://www.tuik.gov.tr/)
Value gain regarding jobless rate	Normalized with higher weight to higher rate	Turkish Statistics Institution (https://www.tuik.gov.tr/)
Demand of each demand point	Average consumption/person/year: 9 liter * location population	Akdağ (2011), Nufusu (https://www.nufusu.com/), Hurriyet News (https://www.hurriyet.com.tr/), Turkish Statistics Institution (https://www.tuik.gov.tr/)
Value gain regarding security level	Normalized value with higher weight to higher rate	Turkish Statistics Institution (https://www.tuik.gov.tr/)
Required land need per equipment	400m^2: direct use	Figuerola and Rojas (1997)
Default facility construction waste	6.9kg/m^2: direct use	Jalali (2007)
Cost per equipment	208000$: direct use	"Profile on the Production of Packed Juice and Syrup" (2015)
Production capacity per equipment	300000 (liter): direct use	"Profile on the Production of Packed Juice and Syrup" (2015)
Average productivity of each labor in a period	8108 liter/one year: based on 8 hours/ day work	"Profile on the Production of Packed Juice and Syrup" (2015)
Required water per unit product	20 (liter): direct use	Ngoc and Schnitzer (2008)
Average cost of training	1000: direct use	Average Turkey training workshop costs
Travel distance in km by any mode	Direct use	Turkey General Directorate of Highways (http://www.kgm.gov.tr/), Turkish State Railways (http://www.tcdd.gov.tr/), Google Maps (https://www.google.com/maps), Turkish Ministry of Transport, Maritime, and Communications (http://www.denizcilik.gov.tr), Yuticikargo (https://www.yurticikargo.com/)
Transportation cost per product/km	Air = 0.016$, Truck = 0.0083$, Train = 0.0066$, Sea = 0.005$: Direct use	Freight companies such as THY Cargo, PTT
Unit land cost	Direct use	Real estate agencies
Education effect in training cost	1 - ((medium education level - location education level)/education level range)	Turkish Statistics Institution (https://www.tuik.gov.tr/)
Available land at location	Direct use	Turkiye Ziraat Birliği Odaları (https://www.tzob.org.tr/), Turkish Ministry of Forestry and Water Management (http://www.ormansu.gov.tr/), Nufusu (https://www.nufusu.com/)
License to operate due to support of NGO/customers	Multiplication of gained value regarding development rate education level, medical access level,jobless rate	Is Bank (https://ekonomi.isbank.com.tr/en /Pages/home.aspx), Erhan Gül and Bora Çevik (2015)
Carbon emission per product	70 gram/liter: direct use	Rahim and Raman (2015)
Tax rate for location	Depends on location: direct use	EU Turkey Business Development Center (http://www.trakyaabigem.org/bolgesel-yatirim-haritasi)
Social reaction risk	Possibility of reaction due to social/political problems	Subject matter expert judgment: qualitative
Depreciation year	20: Direct use	Based on average bank credits periods
Selling price dollar	3: Direct use	Average market price of 1 liter juice in Turkey

Note: The table gives the values of parameters together with their references.

Table B.2. The scientific-validation results for the social parameters

		Weight	*Job opportunity*		*Develop rate*		*Land availability*		*Water availability*		*Healthcare level*		*Security level*		*Education level*		*License to operate*		*Job-family balance*	
			Mean	*Variance*	*Mean*	*Variance*	*Mean*	*Variance*	*Mean*	*Variance*	*Mean*	*Variance*	*Mean*	*Variance*	*Mean*	*Variance*	*Mean*	*Variance*	*Mean*	*Variance*
Conceptual coherence	Definition	0.33	4.92	0.1	4.9	0.12	4.8	0.15	4.5	0.16	4.55	0.19	4.9	0.2	4.6	0.23	4.6	0.21	4.8	0.02
	Relevance	0.31	4.55	0.24	4.8	0.16	4.89	0.1	4.98	0.17	4.58	0.23	4.6	0.17	4.56	0.2	4.35	0.18	4.82	0.06
	Interpretation/meaning	0.36	4.89	0.26	4.54	0.18	5	0.16	4.54	0.2	4.7	0.22	4.92	0.25	4.51	0.22	4.34	0.17	4.53	0.03
Total			4.79		4.72		4.89		4.65		4.62		4.81		4.55		4.43		4.70	
Operation coherence	Formulation	0.25	4.91	0.2	4.41	0.21	4.87	0.23	5	0.19	4.6	0.2	4.8	0.28	4.55	0.16	3,89	0.22	4.53	0.1
	Data and units	0.21	4.4	0.11	4.49	0.09	4.5	0.2	4	0.05	4.2	0.06	4.9	0.12	4.9	0.15	4.1	0.16	4.47	0.11
	Measuring method	0.27	4.52	0.2	4	0.09	4.7	0.12	4.54	0.1	4.54	0.18	4.63	0.2	4.54	0.21	4.23	0.17	4.3	0.1
	Sensitivity accuracy	0.27	4.6	0.21	4.5	0.18	4.73	0.22	4.63	0.25	4.59	0.1	4.8	0.12	4.52	0.17	4.2	0.14	4.6	0.17
Total			4.6		4.33		4.71		4.57		4.48		4.78		4.62		4.1		4.47	
Utility	Reliability 1.indicator	0.2	4.79	0.2	4.9	0.32	5	0.34	4.52	0.19	4.2	0.13	4.2	0.1	3.9	0.12	4	0.23	5	0.12
	Reliability 2.sources	0.2	5	0.3	4.53	0.2	4.52	0.21	4.6	0.16	4	0.11	3.9	0.1	3.83	0.05	3.9	0.21	4.9	0.1
	Availability/applicability	0.23	5	0.1	4.46	0.12	4	0.08	4.57	0.1	4.57	0.2	4.15	0.12	4.34	0.18	4.1	0.19	4.9	0.09
	Information 1.security	0.17	4.97	0.28	4.49	0.21	4.57	0.18	4.75	0.14	4.58	0.3	4	0.1	4.61	0.2	4.1	0.18	4.7	0.25
	Information 2.cost	0.2	4.9	0.21	4.7	0.27	4.6	0.3	4.8	0.17	4.9	0.2	4.89	0.3	4.58	0.2	4.3	0.21	4.8	0.27
Total			4.92		4.6		4.52		4.64		4.45		4.23		4.24		4.07		4.866	
Conceptual coherence index		0.32	1.53		1.51		1.56		1.49		1.48		1.54		1.46		1.41		1.50	
Operation coherence index		0.45	2.07		1.95		2.11		2.06		2.02		2.15		2.08		1.845		2.01	
Utility index		0.23	1.13		1.06		1.03		1.07		1.02		0.97		0.98		0.93		1.12	
Final evaluation value			4.73		4.52		4.72		4.61		4.52		4.66		4.51		4.19		4.63	

Note: The table shows the scientific evaluation results for defined parameters.

Table B.3. Transportation links availability

	Konya			*Sivas*			*Antalya*			*Izmir*			*Van*			*Adana*			*Erzurum*			*Malatya*		
	Air	*Train*	*Sea*	*Air*	*Train*	*Sea*	*Air*	*Train*	*Sea*	*Air*	*Train*	*Sea*	*Air*	*Train*	*Sea*	*Air*	*Train*	*Sea*	*Air*	*Train*	*Sea*	*Air*	*Train*	*Sea*
Istanbul	461	-	-	696	-	-	482	-	964	328	-	218	1265	-	-	707	-	-	1018	-	-	851	-	-
Bursa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Samsun	504	1003	-	182	402	-	690	-	-	848	-	-	680	1126	-	486	900	-	445	946	-	368	651	-
Gaziantep	442	665	-	300	513	-	594	-	-	914	-	-	553	741	-	183	295	-	464	838	-	164	266	-
Ankara	231	675	-	356	610	-	386	-	-	521	-	-	923	1282	-	390	679	-	719	1101	-	501	807	-
Adiyaman	510	-	-	246	-	-	677	-	-	979	-	-	456	-	-	275	-	-	353	-	-	65	-	-
Trabzon	713	-	-	268	-	-	904	-	1808	1114	-	1671	422	-	-	585	-	-	180	-	-	319	-	-

Note: Since road transportation is available among all locations, the other available transportation modes only are shown. The sign "-" shows that the corresponding mode of transport is not available in that link.

Figure B.1. Criteria evaluation radar chart: Investor

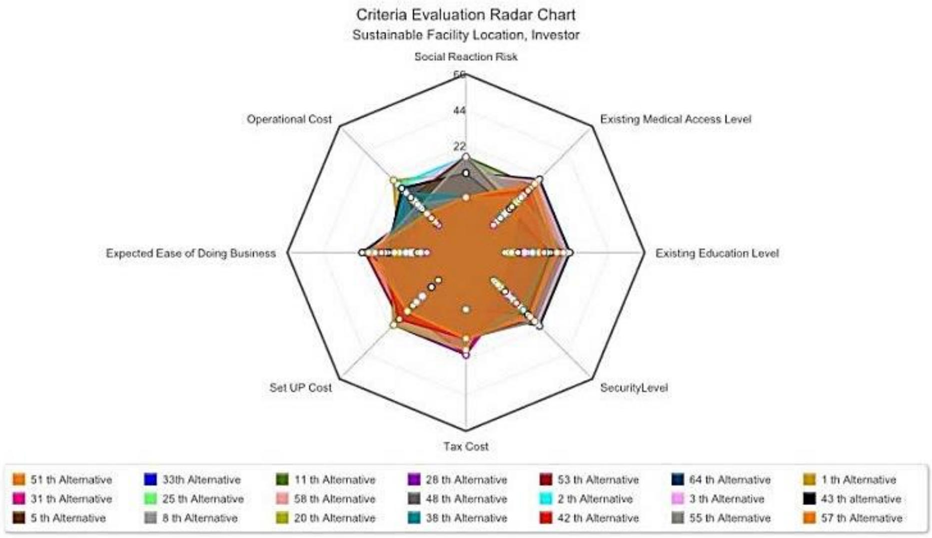

Figure B.2. Criteria group evaluation chart: Investor

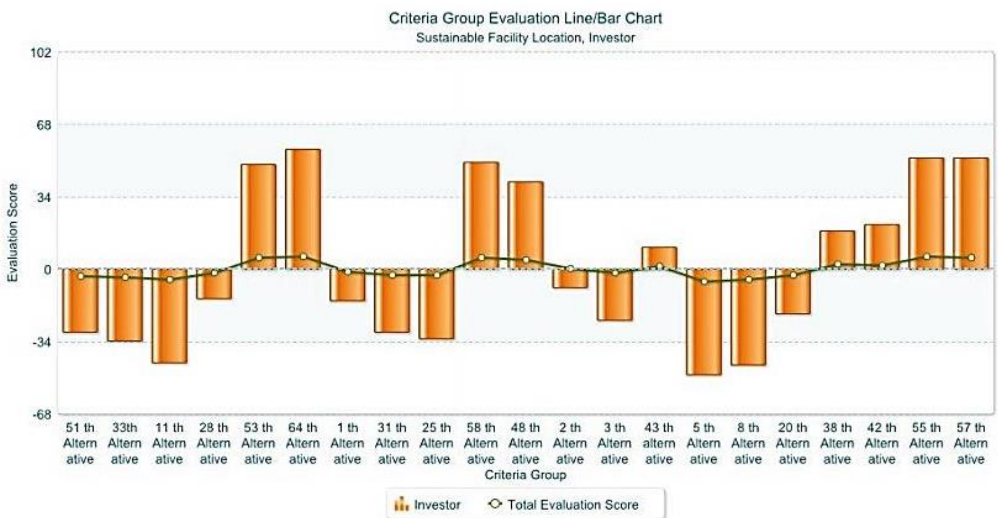

Figure B.3. Criteria evaluation radar chart: Community

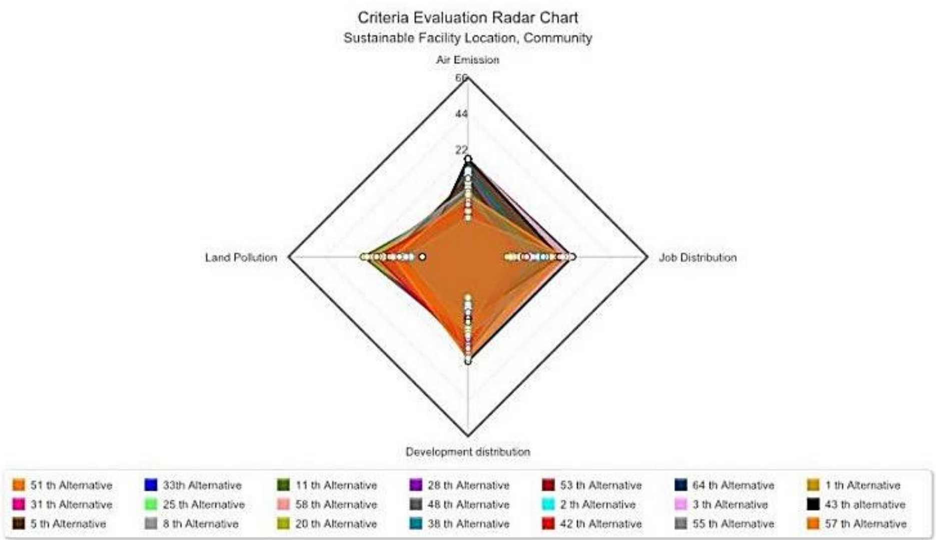

Figure B.4. Criteria group evaluation chart: Community

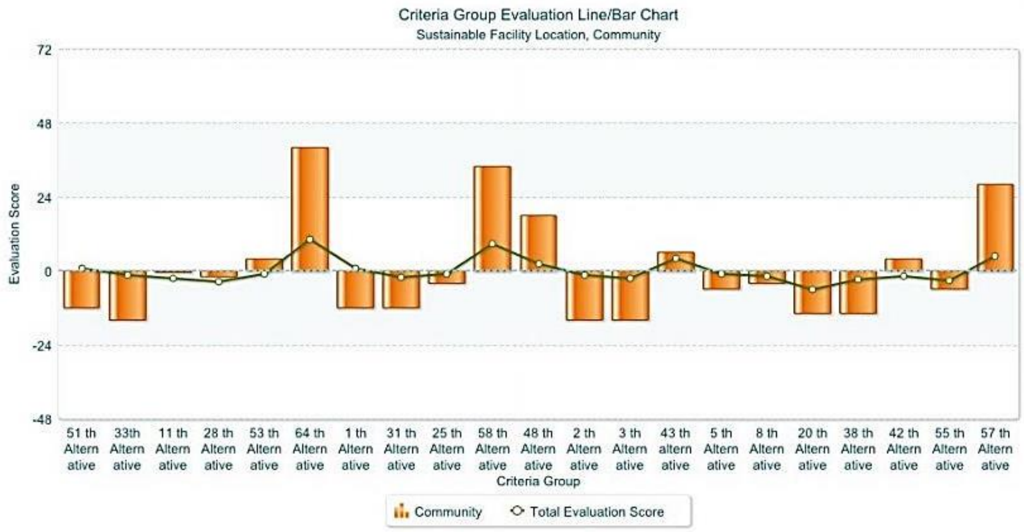

Figure B.5. Criteria evaluation radar chart: Government

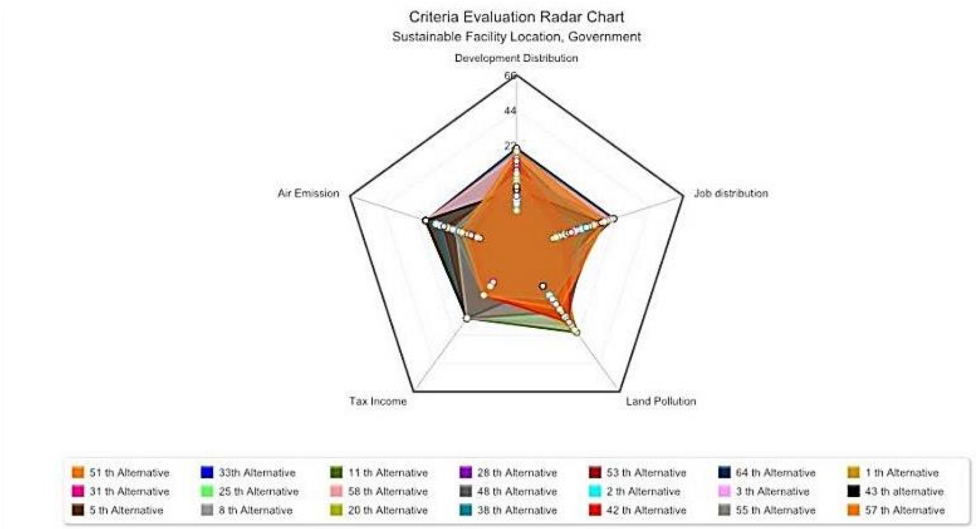

Figure B.6. Criteria group evaluation chart: Government

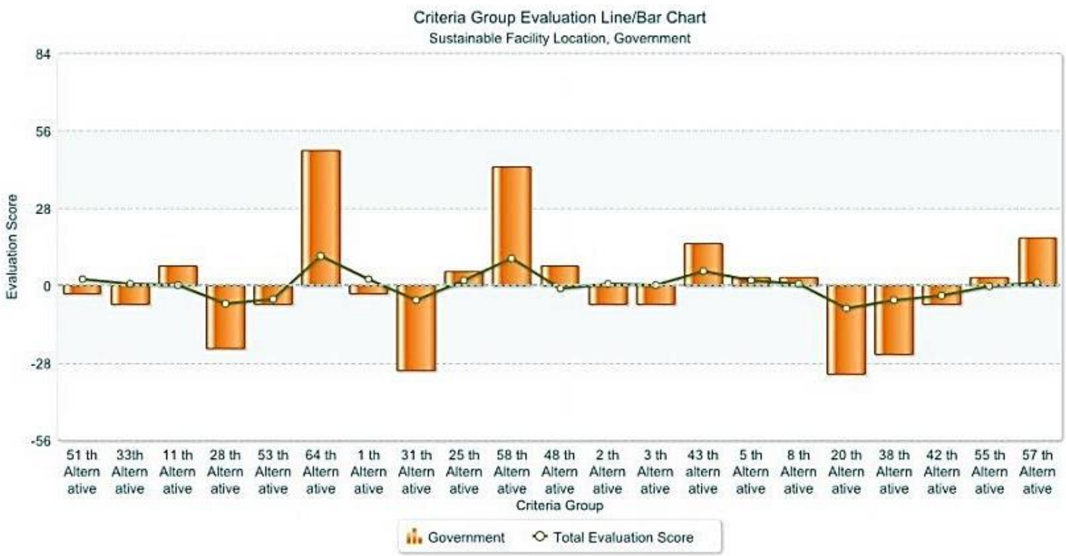

Figure B.7. Criteria evaluation radar chart: NGO

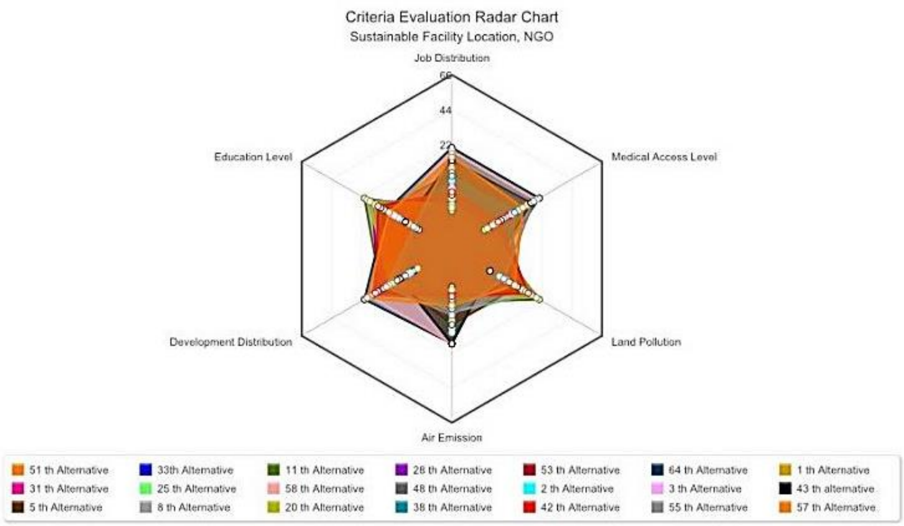

Figure B.8. Criteria group evaluation chart: NGO

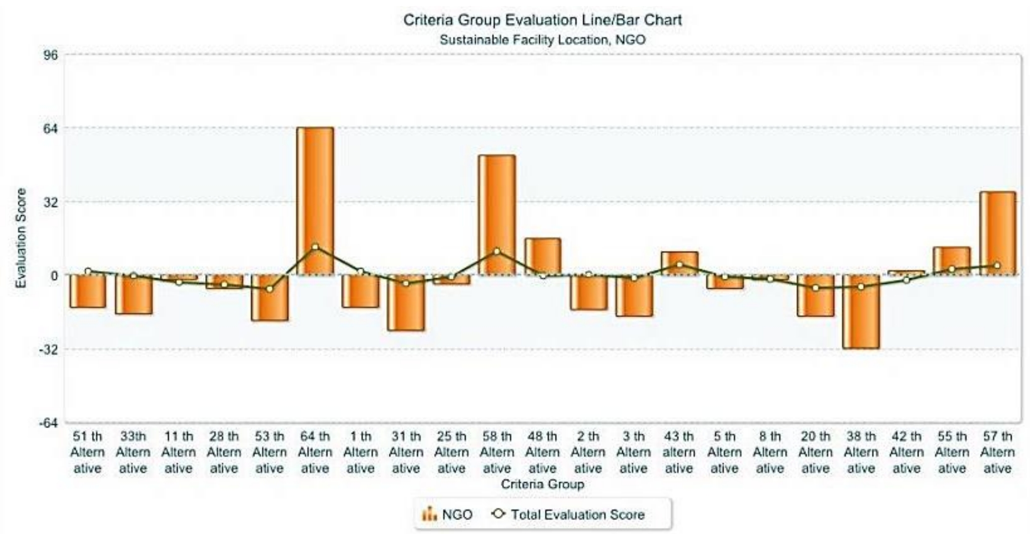

Figure B.9. Criteria evaluation radar chart: Employee

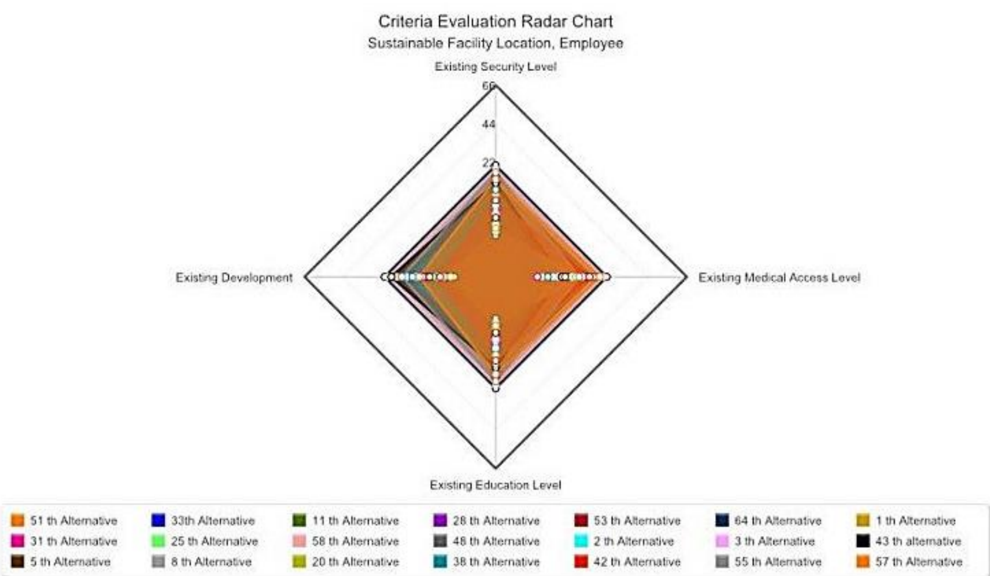

Figure B.10. Criteria group evaluation chart: Employee

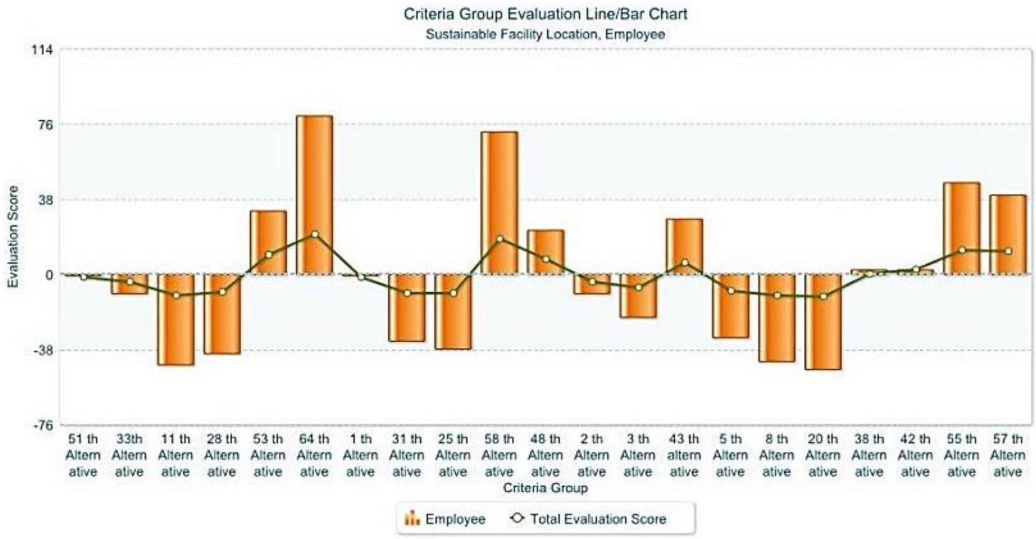

Figure B.11. Criteria evaluation radar chart: Local people

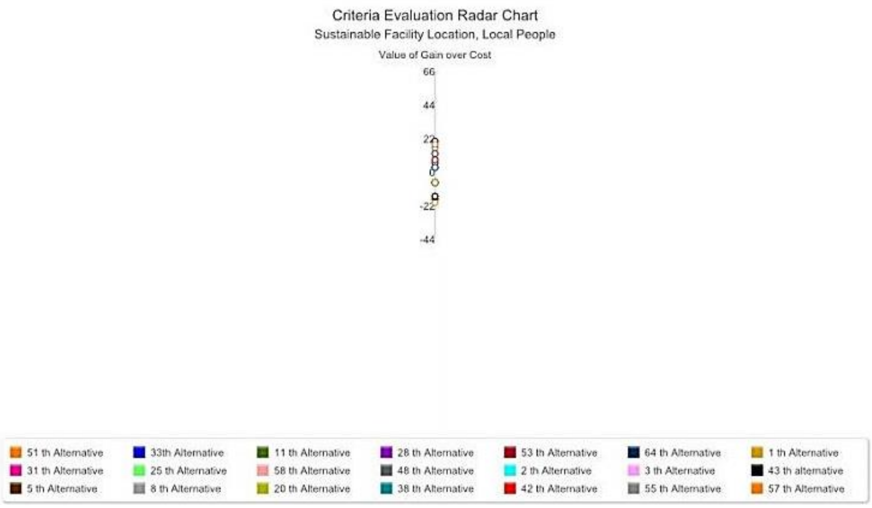

Figure B.12. Criteria group evaluation chart: Local people

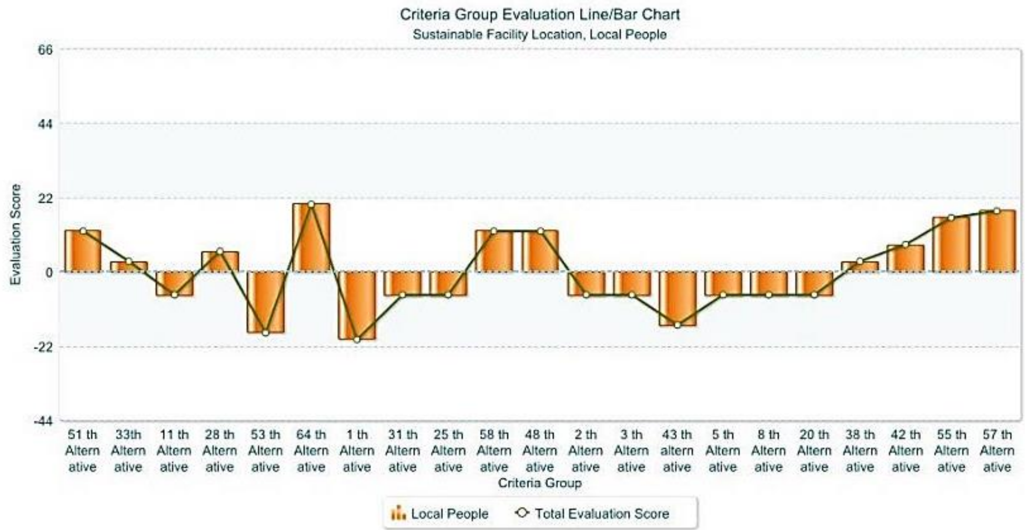

Figure B.13. Criteria evaluation radar chart: Stakeholder

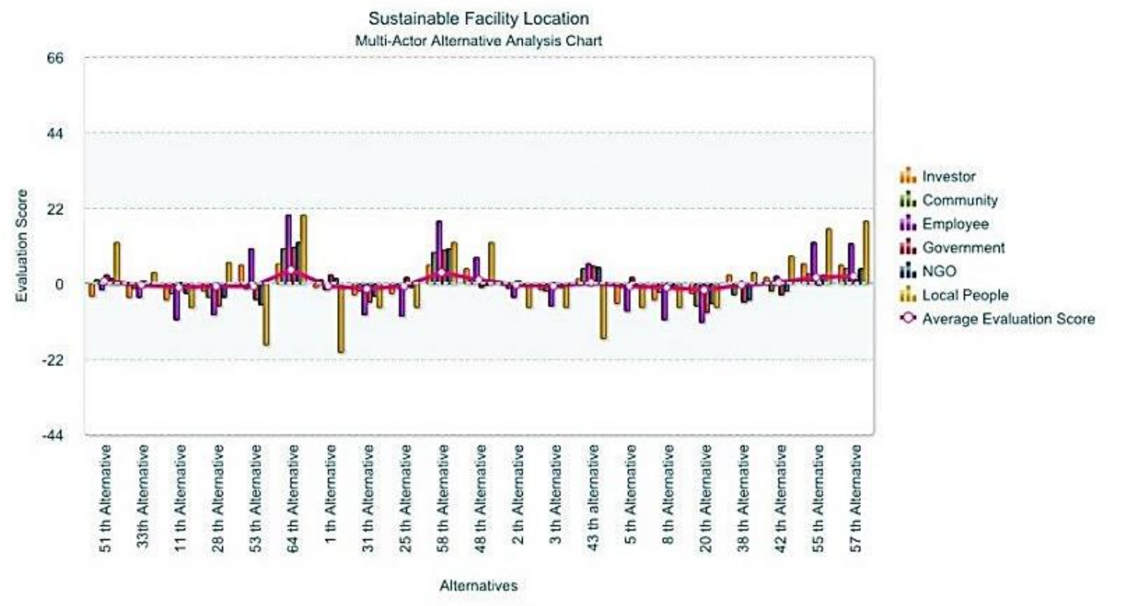

Figure B.14. Criteria group evaluation chart: Stakeholder