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Towards Sustainable Facility Location – A Literature Review

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Abstract

Facility location methods play a crucial role in specifying the optimum location options for various types of facilities. A question that arises is what makes a facility location decision a sustainable one? Facility location, also known as location analysis, is a known concept in the literature, but sustainable facility location is not. This requires appropriately defining the concept and framing the problem in order to address the relevant issues. Facility location models in the existing literature do not effectively include all the requirements of sustainable development. This paper serves as a discussion of the current literature concerning the sustainability aspects of the location problem. The aim is to conduct a comprehensive literature review to identify the characteristics of the sustainable facility location problem and propose a framework for classification of sustainability characteristics. The study shows that the location literature has steadily progressed toward considering not only economic but also social and environmental criteria in location decisions; but that many steps remain to be taken toward developing location models that integrate all three aspects of sustainability into decision making. The main motivation for the current study is to provide a foundation from which issues of sustainable development can be built into facility location and siting models.

Keywords: facility location, sustainability, sustainable facility location, location problem, facility siting models, site suitability analysis

1. Introduction

Location decision makers have traditionally focused on the economic aspects of locating facilities, but given the growing interest in sustainable development, location decisions frequently also include environmental and social consequences. When compared to past practice, not only industry and government but also the general public are demanding more complex facilities that also meet social and environmental goals. As a result, an increasing number of requirements need to be satisfied in the location decision process. Facility location, also known as location analysis, is a well-known concept in the literature but sustainable facility location is not. This work attempts to define the concept and frame the problem in order to address the issue.

This research has been done by conducting a thorough literature review on the sustainability aspects of the facility location problem and specifying potential areas of significance for further research into the issue of sustainable facility location. Sustainability characteristics can subsequently be employed in developing location models to demonstrate how decisions can be made to ensure or improve the economic, environmental and social sustainability of a facility through its location.

In March 2012, potentially relevant papers were retrieved among peer-reviewed research articles from multiple online databases such as Compendex, Web of Knowledge, and Google Scholar using an iterative approach. The first group of papers was retrieved using the keywords: “Facility Location”, “Location Theory”, and “Location Problem”, “Location Analysis”, in combination with “Social”, “Environmental”, and “Sustainability”. This then led to additional search keywords such as “Site Suitability Analysis” and “Land Suitability Analysis”. Finally, search results were improved by back-referencing citations in the identified papers. Therefore, only the location literature that included environmental, social, and/or sustainability issues have been included.

In this paper, sustainable facility location models are defined as facility location and siting models that include requirements for sustainable development. As an example, take the case of finding an appropriate location for a refinery. Many risk factors are involved, and a sound decision cannot be made unless all aspects of sustainable development, i.e. economic, environmental and social, are investigated, recognized and analyzed.

The intention here is not to undermine previously proposed location models but to suggest that the trends of location theories need to shift toward addressing not only some but all the requirements of real-world problems. In other words, the traditional approach in location theories needs to be augmented by holistically including aspects of sustainable development.

It is worth noting that sustainable facility location is not sought only for noxious facilities but can and should be used for all types of facilities. Traditionally, in location modeling, social or environmental criteria have been considered to be influential mostly in noxious facility location such as nuclear power plants or incinerators (See Barda et al., 1990; Gros, 1975; Muntzing, 1976). However, according to Barda et al. 1990, "locational decisions concerning implantation of power stations require to take into consideration several qualitative or quantitative criteria of economic, technological or social nature" (p. 332).

In alignment with the paradigm shift toward locating facilities sustainably, the need to take a holistic approach encompassing all three pillars of sustainable development, i.e., economic, environmental and social aspects, is greater and more justified than ever before. Inclusion of all three main pillars of sustainability for finding the appropriate location for all types of facilities including "desirable" facilities is recommended.

1.1 Facility Location

The study of facility decisions has a long history in the literature. A typical facility location problem involves optimal placement of facilities by minimizing the costs associated with or maximizing the desirability gained by the placement. Moreover, certain in-reciprocal-relationship points, mostly in the form of supply and demand points, are involved in these kinds of decision making problems. Locating warehouses, distribution points, and manufacturing sites are classic examples. Other terms such as location analysis, site suitability analysis and land use suitability analysis are also terms used for location studies in which proper placement is the whole or a major component.

Planners recognize the work of the geographical economist Thunen 1826 in the beginning of the nineteenth century as the inception of location theory. From the point of view of operations researchers, the inception of location theory dates back to 1929 when Alfred Weber published his book titled "Theory of the Location of Industries" (Weber, 1929). These initiatives formed the basis of descriptive and normative location theories respectively. Up to now, several researchers and authors have developed the topic, and many handbooks and scientific papers have been published on this subject. Descriptive models seek spatial socio-economic patterns that follow each placement; whereas, normative location theories aim at setting up decision making mathematical models for this purpose. The distinctions between normative and descriptive approaches to location theory have remained in place until now, since their goals are different.

The literature of facility location is rich with various types of models, algorithms and applications. Facility location models include but are not limited to locating a single facility versus multiple facilities, locating on a plane without any restriction in terms of the number of candidate points versus on a network with a limited number of points, assuming capacitated versus non-capacitated facilities, assuming deterministic versus stochastic parameters, and assuming static versus dynamic parameters.

Although operations research (OR) forms the majority of normative methods, other mathematical models have also been proposed. Examples include risk assessment, decision analysis methods, graph-theoretic and game-theoretic methods. Several review articles have been published on facility location theories providing a good summary of the development of this branch of knowledge. Comprehensive examples of these review articles include Francis et al. (1983), Brandeau and Chiu (1989), Current et al. (1990), Schilling et al. (1993), Mesa and Boffey (1996), ReVelle and Eiselt (2005), Nagy and Salhi (2007), Sahin and Sural (2007), and Farahani et al. (2010).

Drezner (1995) categorized various objective functions in three main types based on their type of influence: pushing, i.e., pushing the facilities away from undesirable points; pulling, i.e., pulling the facilities towards demand, or balancing types of objectives. As listed by Farahani et al. (2010), various objective functions have been used in the literature to address various types of requirements. Examples include minimizing the total setup cost, longest distance from the existing facilities, fixed cost, total annual operating cost, average time or distance traveled, maximum time or distance traveled, the number of facilities or maximizing service and responsiveness.

As this area of research has evolved, it has now been acknowledged that various and sometimes contradicting decision making criteria should be considered in making sound location decisions. As stated by Owens (2004), "a more complex and dynamic model of siting controversies is needed, in which land use conflicts are seen as formative in a gradual process of policy learning and change" (p. 102).

Although location theories have mostly advanced during the past forty years, most published articles in this field reflect the result of applying the accepted theoretical framework in new sorts of cases under very specific circumstances. Therefore, the current research can be regarded as a suggested approach toward finding location models that can better address real-world problems.

1.2 Sustainable Development

Scientists have continuously endeavored to theorize various frameworks to predict and demonstrate the long-term consequences of development. Sustainable development can be regarded as one of these endeavors. In this article, the terms “sustainable development” and “sustainability” have been used interchangeably. Although these two terms are used at times as synonyms and at times to express somewhat different ideas, sustainability and sustainable development as used in this article express the same concepts. Different roots can be traced for this concept based on different “strains of thought” that have been emerged as branches of the mainstream of “sustainability” (Kidd, 1992). The term “sustainability” was first used in 1972 in a book titled “Blueprint for Survival” (Goldsmith, 1972); and has evolved with the development of the topic (Kidd, 1992).

The Brundtland Report (Brundtland & Khalid, 1987), a United Nation document, has been recognized as one of the prominent publications addressing the topic. The most commonly used definition of sustainable development from the Brundtland Report is “development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs” (p. 43). Following this initial philosophical definition, the definition of sustainability has tended to shift toward a more tangible multi-dimensional characterization taking into account economic, social, and environmental factors.

Sustainable development requires consideration and scrutiny of different aspects of development in order to build a sustainable solution. As stated by Atkinson et al. (2007), “sustainable is now prefixed to numerous and disparate policy objectives” (p. 16). Glavic and Lukman (2007) indicate the focus of sustainable development as being “the evolution of human society from the responsible economic point of view, in accordance with environmental and natural processes” (p. 1884). Although there are similarities in the definitions, there are also disagreements. According to Common and Perrings (1992), “this disagreement has various sources, including differences in disciplinary perspectives, the axiomatic foundations of the dynamic models within which the concept has been explored, and the interpretation of sustainability at the policy level” (p. 7).

Sustainability has become one of the cornerstones of different disciplines, reflected by the increasing number of publications on this topic. Nonetheless, since its inception, the concept of sustainability has not had a widely agreed upon definition of its scope, metrics, and implications for the future development of a society.

In response to the question of “How can sustainability be measured?” many different indicators have been proposed; some addressing only one and some several aspects of sustainability. Decision frameworks such as life cycle impact assessment use multi-aspect indicators to reflect performance from several aspects. Although many sustainability-related questions have been put forward, and much research has been done, there are many areas where additional exploration and research is needed.

1.3 Sustainable Facility Location

In this section of the article, only the location literature having direct relevance to sustainability are been presented. In section 2, additional literature is synthesized to identify the characteristics of sustainable facility location models.

Dudukovic et al. (2005) used the term “sustainable industrial siting” in the title of their work in which they developed a suitability map and used a multi-criteria spatial decision support system (MC-SDSS) for the siting of industrial facilities. Although only a few geophysical and environmental criteria have taken into account, the taken approach is of relevance to the current article.

Tsoutsos et al. (2007) used the term “sustainable siting procedure” in the title of their work in which they proposed a sustainable siting procedure for siting a small hydroelectric plant (SHP) using the principles of sustainable spatial planning. They proposed the procedure for analyzing the environmental, economic, and social impacts of SHP’s during their installation and operation.

Farahani et al. (2010) have included the term “sustainable facility location” in the suggestions-for-future-research section of the article without any further development or description: “The most important thought that we took into consideration, is how to measure these attributes related to social and environmental objective functions. Therefore, we can think of a term like sustainable facility location” (p. 17).

The term sustainable locating method has been used by Store (2009) but with a different meaning; namely, as a tool to support the effective location of different forest uses within a forest area. This article cannot be considered in line with the focus of the current article due to the absence of demand and supply points which are the integral parts of typical facility location problems. In this article a GIS (Geographic Information System)-based method has been proposed to evaluate location candidates of different forest uses to determine the best option possible given social, environmental and economic criteria.

The existing literature of facility location does not effectively include comprehensive requirements of sustainability. The literature does include cases where, depending on the needs demonstrated under some specific circumstances, environmentally or socially conscious attributes have been introduced into the model. Locating undesirable or noxious facilities can be regarded as examples of specific circumstances where negative environmental or social impacts have been included.

For instance, Dobson (1979) has improved the automated regional screening technique by incorporating multiple criteria across a range of economic, environmental impact, and socioeconomic criteria in a power plant siting case. Location candidates have been rated based on aggregating the criteria importance weights obtained from the two nominal groups involved. The "procedure requires a geographical base file of relevant and easily accessible information, a screening algorithm for application to the stored data, and one or more sets of siting criteria for each type of land use or facility" (p. 224).

Some types of facility location problems include equity criteria. The United Nations Commission on Sustainable Development (CSD) considers equity, along with other issues such as health, welfare, social and ethical values and income distribution, to be one of the key themes under which social indicators can be categorized (The United Nations Department of Economic and Social Affairs [UNDESA], 2001).

Mumphrey et al. (1971) introduced equity to the facility location problem, which led in particular to the inclusion of equity in facility location problems in the public sector. A comprehensive review article addressing equity issue in facility location has been published by Marsh and Schilling (1994). They argued, "When the effects of that facility vary with the distance from it, differential effects within the population are experienced and, hence, inequities are likely" (p. 2).

Effects of placing facilities can be measured in different scales. A thought-provoking classification of scales has been furnished by Marsh and Schilling (1994). As shown in Table 1, the implications of locating facilities on social equity can be investigated from spatial, demographic, physical or temporal dimensions. Given that equity is one of the main themes of sustainability, the classification proposed in Table 1 might be appropriate for sustainable facility location.

Table 1. Dimensions for effects of placing facilities (Adapted from Marsh and Schilling (1994))

Dimension	Description	Examples
Spatial	- Jurisdictional boundaries or unit areas that partition a spatial surface into mutually exclusive groups. - Synonyms: areal, jurisdictional	States, counties, square kilometers, legislative districts
Demographic	- Social or human characteristics that are typically distributed over the spatial surface. - Synonyms: vertical, stratified	Population, income, ethnic group, age
Physical	- Geologic, biologic, or geographic features that may partition a spatial surface or may be distributed throughout the surface.	Land use, forest type, habitat
Temporal	- Time; any category above may also be defined over a period of time.	Years, decades, generations

Briassoulis (1995) presented a number of alternative classification schemes for facility siting criteria. In addition, common characteristics of the criteria and the factors conditioning the use of the criteria have been identified. The main focus of the article is environmental criteria.

Dehghanian and Mansour (2009) designed a sustainable recovery network, in which economic, environmental and social impacts are balanced. In this article the authors have used life cycle analysis (LCA) in order to specify the environmental impact of different end-of-life (EOL) options. Also, a three-objective mathematical programming model has been proposed in order to optimize the combination of economic, social and environmental implications. The optimization has been performed by maximizing the economic and social benefits and minimizing the negative environmental impacts. Because the authors have investigated how to incorporate social and environmental factors in multi-objective optimization models used in the lifecycle of products, this article is of great relevance to the current study.

A conceptual descriptive model for placing and evaluating sustainable industrial parks has been proposed by Fernandez and Ruiz (2009). In order to take sustainability criteria along with other basic factors into consideration, the authors have proposed the use of the analytical hierarchy process (AHP) decision making method to come up with a location solution that balances all the factors considered. In fact, AHP has been used both to breakdown complex multi-criteria evaluation problems in a hierarchical structure and to help prioritize decision-making criteria by performing pairwise comparisons of those criteria in each level of the hierarchy. By structuring the model into geographical area selection, evaluation and selection of suitable areas, and evaluation of specific zones, the authors have distinguished various geographical scales of the location problem. Having defined categories and subcategories in each of these stages, the authors have proposed a way to make sure that different aspects of the problem such as social, economic, environmental, and infrastructure are taken into account. Ultimately, for the purpose of calculating the extent to which locating decision-making criteria are fulfilled by a particular emplacement, an evaluation function based on fuzzy logic was used. Evaluation functions are applied to identify the best location option that satisfies the prioritized criteria.

Dou and Sarkis (2010) developed a framework for offshoring strategic decision models that incorporates the principals of sustainability in conjunction with facility location and supplier selection criteria. They have used the Analytical Network Process (ANP) as a tool to integrate a broad range of decision factors for offshoring and outsourcing decisions. In this work, typical economic measures have been included in the evaluation process along with social and environmental factors, which make up sustainability criteria for the decision.

Another work that incorporates the requirements of sustainability into the facility location decision is the work of Banias et al. (2010), in which, authors have used the ELECTRE III (ELimination and Choice Expressing REality) multi-criteria decision analysis method to determine the most appropriate location for a construction and demolition waste management facility. The proposed methodology can accept both quantitative and qualitative criteria to investigate environmental compliance, local acceptability, and financial viability of alternative sites; and introduce the optimum scenario accordingly.

Cattafi et al. (2011) used an integer linear programming approach for choosing the best location for a biomass power plant. The proposed method maximizes the environmental sustainability of the biomass power plant; at the same time incorporates the produced net energy and cost of the facility depending on its location. In this model, however, sustainability is defined only in terms of the net energy of the biomass system and does not include other aspects of sustainability.

A summary of the reviewed location studies is provided in Table 2; and additional discussion on various characteristics of sustainable facility location is provided hereafter. General characteristics of the location problem, i.e., Holistic Approach, Validity, Interdisciplinary Consciousness, Multiplicity, Life Cycle Consciousness, and Spatial Scale Consciousness, were highlighted as the main characteristics of sustainable facility location models. The location literature summary shown in Table 2 indicates that the literature has steadily progressed toward considering not only economic but also social and environmental criteria in location decisions. Although a range of techniques are being used for location decisions, additional development of location models that integrate all three aspects of sustainability into decision making is needed. For example, most current models typically account for impacts associated with a limited range of stages of a facility, whereas a lifecycle approach is preferred.

1.4 Location Decision Making Process

Calzonetti et al. (1987) outlined a procedure that has been used for the Maryland Power Plant Siting Program. Although certain problems in implementing the procedure have been reported, the procedure itself is worth noting. Three layers of screening, including exclusionary, discretionary, and suitability, have been utilized in the case prior to the candidate locations' comparison and analysis resulting first in narrowing down the candidates and then selecting a final location.

Berkhuizen et al. (1988) proposed conducting location and feasibility analysis at national, regional and local scales to determine the most suitable area for the location of large wind energy projects in the Netherlands.

In cases dealing with undesirable facilities, Erkut and Neuman (1989) suggested using a two-stage decision process that includes site generation to identify potential locations and site selection to select final location: "we believe this is clearly superior to a single stage approach, given the complexity of the problem" (p. 286).

Land use screening is an alternate term used by planners and geologists. Land use screening uses some techniques such as map overlays to disqualify some locations based on given criteria. Of particular relevance is the work of McHarg (1995) in investigating the nature-society relationship to identify opportunities and limitations to development at a regional scale.

Table 2. Location studies reviewed in this article

	General					Holistic Approach							Validity							Interdisciplinary Consciousness						Multi-plicity		LCA		Spatial Scale		
	Review-type article?	A location decision tool proposed?	Undesirable facility?	Multi-layer (multistage) decision making?	Sensitivity analysis conducted?	Economic aspects discussed?	Environmental aspects discussed?	Environmental suitability discussed?	Environmental impact discussed?	Social aspects discussed?	Social suitability discussed?	Social impact discussed?	Distance/ travel time included?	Distance Metric: Euclidean, Rectilinear, Network	Spatial Representation: Network, Planer	Existing facilities	Co-locating?	Dynamism over time?	Stochasticity?	Interdisciplinary approach taken?	Operations research / Optimization	Urban planning / GIS methods	Decision analysis methods	Other methods used?	Risk assessment conducted?	Multicriteria?	Simulation tools utilized?	Life Cycle approach taken?	Life Cycle Assessment (LCA) utilized?	Spatial Scale: Local, Regional, National, International	A centralized location decision proposed?	National need versus local interests discussed?
Cattafi et al. (2011)		✓	✓			✓	✓		✓				✓	N	N	✓					✓					✓		✓		R		✓
Achillas et al. (2010)		✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	N	N	✓		✓					✓			✓		✓		N		
Dou and Sarkis (2010)		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	?	N			✓		✓			✓			✓				I		
Banias et al. (2010)		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	R	N	✓							✓			✓				N		✓
Fernandez and Ruiz (2009)		✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	?	N	✓						✓	✓			✓				R		
Dehghanian and Mansour (2009)		✓	✓	✓		✓	✓		✓	✓	✓	✓	✓	N	N	✓					✓		✓			✓		✓	✓	N		
Sumathi et al. (2008)		✓	✓			✓	✓	✓	✓				✓	E	P							✓	✓			✓				R		
Lamelas et al. (2008)		✓				✓	✓	✓					✓	E	P							✓	✓			✓				R		
Noorollahi et al. (2008)		✓					✓	✓		✓		✓	✓	E	P							✓	✓			✓				L		
Queiruga et al. (2008)		✓	✓			✓	✓				✓		✓	N	N	✓										✓				R		
Tuzkaya et al. (2008)		✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	N	N								✓		✓	✓		✓		L		
Goyal and Chalapati Rao (2007)		✓					✓		✓					E	P							✓		✓						R		
Alumur and Kara (2007)		✓	✓	✓		✓	✓		✓	✓		✓	✓	N	N	✓			✓		✓				✓	✓						
Norese (2006)		✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	N	N								✓			✓				L		
Dudukovic et al. (2005)		✓		✓		✓	✓	✓	✓	✓	✓		✓	E	P					✓		✓	✓			✓				L		
Wey (2005)		✓	✓	✓		✓	✓		✓	✓		✓	✓	N	N	✓				✓	✓	✓	✓	✓		✓				R		
Owens (2004)			✓							✓		✓																				✓
Maniezzo et al. (1998)		✓	✓	✓		✓	✓		✓				✓	N	N	✓					✓				✓	✓				R		
Ulph and Valentini (1997)		✓				✓	✓		✓				✓	N	N	✓								✓		✓	✓			?		
Hokkaneh and Salminen (1997)		✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	N	N	✓							✓			✓				R	✓	
Reams and Templet (1996)			✓			✓	✓	✓	✓	✓		✓																				✓
Briassoulis (1995)	✓					✓	✓	✓	✓																							
Marsh and Schilling (1994)	✓					✓	✓			✓																						
Erkut and Moran (1991)		✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	N	N								✓			✓				L		
Barda et al. (1990)		✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	E	N	✓							✓			✓				N		
Kennedy (1990)		✓				✓				✓	✓	✓		?	N					✓		✓				✓				L		
McConnell and Schwab (1990)							✓		✓	✓				?	N									✓						N		
Erkut and Neuman (1989)	✓		✓																													
Berkhuizen et al. (1988)		✓		✓		✓	✓		✓				✓	E	P									✓		✓				N		
Merkhofer and Keeney (1987)		✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	N	N				✓				✓		✓	✓		✓		N		
Calzonetti et al. (1987)			✓	✓		✓	✓	✓	✓	✓		✓																				
Susskind (1985)			✓			✓	✓		✓													✓										✓
Dobson (1979)		✓	✓	✓		✓	✓	✓	✓	✓		✓	✓	E	P							✓	✓			✓				R		
Keeney and Nair (1977)		✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	E	N				✓				✓		✓	✓				R		
Muntzing (1976)			✓			✓	✓																									
Gros (1975)		✓	✓			✓	✓	✓	✓				✓	N	N								✓			✓				R		
Warszawski (1972)		✓				✓							✓	N	N						✓					✓				?	✓	
Mumphrey et al. (1971)			✓			✓				✓		✓					✓		✓			✓								L		

Note: "?" means not specified. Other characters represent one of the underlined options in the corresponding column, i.e., in the column "Distance Metric", E = Euclidean, R = Rectilinear, N = Network. In the column "Spatial Representation", N = Network, and P = Planer. In the column "Spatial Scale", L = Local, R = Regional, N = National, and I = International.

Briassoulis (1995) presented a criteria selection process regarding environmental concerns. The main steps proposed include problem definition, determining the impacts of stakeholders, choosing appropriate environmental concepts and constructs, filtering, choosing operational measures, and choosing the final location.

Maniezzo et al. (1998) proposed a decision support system for multi-criteria siting problems in an effort to facilitate making siting decisions. The main focus was on industrial waste management facilities. The authors have implemented a system that retrieves geographical, treatment, disposal, and waste production data first and then processes them using models such as cost, risk, transportation risk, and environmental impact.

Sumathi et al. (2008) proposed a procedure for siting landfill sites in an urban location based on a multi-criteria decision analysis (MCDA) and overlay analysis using a GIS.

The work of Tuzkaya et al. (2008) includes a proposed methodology for the undesirable facility location selection process. The work of Archillas et al. (2010) is also worth mentioning here as they presented the conceptual design of a decision support system for the optimal location of waste electrical and electronic equipment (WEEE) treatment plants.

2. Characteristics of Sustainable Facility Location Models

As mentioned before, sustainable facility location has not been characterized, framed or developed in the literature so far. The reason to introduce this new term is linked to the necessity of responding to the new challenges of a rapidly changing world by taking a more holistic and practical approach to the location problem.

Based on a rigorous review process conducted on location problems discussed in the literature, the sustainability characteristics of facility siting models are identified, and a framework within which sustainability characteristics can be classified is developed.

The following aspects have been recognized as having the greatest contribution to the sustainable facility location problem (see Figure 1).

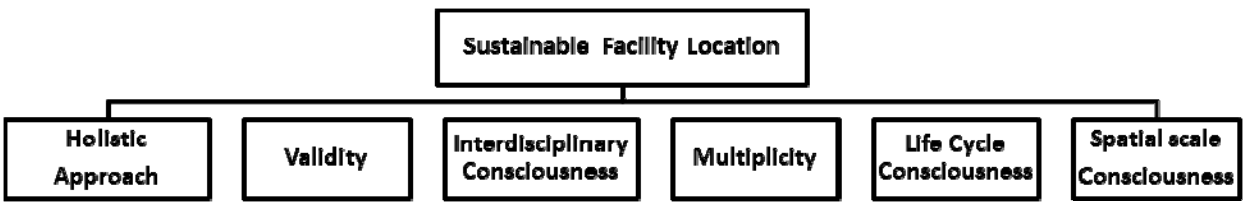

Figure 1. Sustainable facility location model characteristics

2.1 Holistic and Lifecycle Approach

No facility has a purely economic, environmental, or social impact. The collective impact, interdependencies, and interactions between these three aspects are important in all location decision making.

Two extremes that represent unrealistic types of modeling are those including only the economic dimension compared with those totally ignoring the economic dimension. Most traditional location theories are examples of the former whereas models proposed for locating undesirable facilities are examples of the latter. As Erkut and Neuman (1989) have argued, “clearly, the social and environmental concerns overpower the economic concerns for most undesirable facility location decisions. However, completely ignoring economic aspects may result in a very poor solution” (p. 287).

As indicated before, some articles from the literature of location theory have already addressed integrating economic, environmental and social criteria for selecting the best location. Examples include Keeney and Nair (1977), Dobson (1979), Merkhofer and Keeney (1987), Erkut and Moran (1991), Hokkanen and Salminen (1997), Wey (2005), and Dehghanian and Mansour (2009). These models have been proposed for noxious facilities with explicitly significant environmental or social impacts.

Location decision makers should determine significant environmental and societal factors affected by the location decision. Conducting well-performed and unbiased environmental assessment, social assessment, and risk assessment studies help modelers identify all definite and potential implications of placing facilities. It is important that the type of facility together with its specifications is assessed. Susskind (1985) proposed an even more challenging endeavor; namely, building joint fact finding investigations addressing the concerns of the different stakeholders involved: “Some of the most congenial siting processes have been those that invited all sides to commission jointly the kinds of studies they believed were needed to make a wise decision” (p. 161).

As acknowledged by Dehghanian and Mansour (2009), integrating social dimensions in operations research (OR) models have been underutilized: “The social sustainability dimension has largely been absent in OR contributions, with the exception of some areas investigating the health impacts of institutional operations” (p. 561). Since the majority of analytical location models have been developed in OR, there is an overall underrepresentation of social dimensions in facility location models.

The social dimension of the location problem can also be viewed from the social responsibility (SR) point of view. Although various definitions have been proposed for this concept, a large degree of congruity is seen among the proposed definitions (Dahlsrud, 2008). In a nutshell, SR characterizes the efforts that are being made in a socially responsible manner. In this sense, the concept of SR can be extended to the scope of the current research to specify the requirements of location decisions that are made in a socially responsible way. The launch of ISO 26000 is an effort to reach a consensus on the definition of SR and the SR issues that organizations need to deal with (see International Organization for Standardization [ISO] (2010)).

Whether a facility to be placed is noxious or not, communities are expected to respond to or be influenced by the positive or negative risks involved in the placement. “Respond” and “influences” are considered formative elements of social implications of location decisions. Reams and Templet (1988) found that political, ideological, social, demographic, physical, and economic factors are influential in communities’ responses in the case of locating incinerators.

Briassoulis (1995) emphasized the need to recognize the purpose of environmental decision making criteria. As a result, he proposed differentiating between suitability and impact in criteria, whereby, the former addresses how appropriate the local environment is for the facility, and the latter investigates how the local environment will be influenced by placing the facility (see Figure 2). A similar approach can be taken toward the social implications of economic activities. Arrows shown in Figure 2 demonstrate which aspect of the economy - environment relationship serves as a locus for developing facility siting criteria.

The critical role played by impact criteria in location decisions and their implications for sustainability have also been addressed by Lamelas et al. (2008): “The exploitation of these resources may give rise to conflicts with other land use interests {…} however, generational equity issues play also a role since these deposits represent a substantial groundwater resource that should be preserved for future generations” (p. 1674). In the work of Lamelas et al. (2008) as well as the work of Sumathi et al. (2008), the GIS land-use suitability maps and multi-criteria evaluation decision support methodologies have been utilized to address both the suitability and impact criteria throughout the land-use decision process.

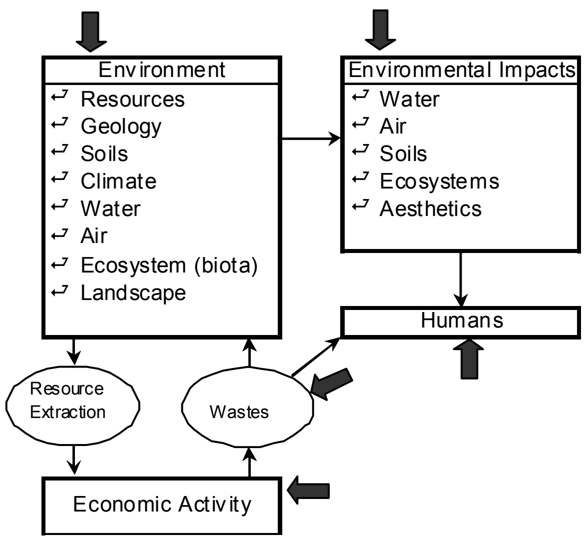

Figure 2. The economy – environment relationship with the loci for development of environmental criteria shown by arrows (Adapted from Briassoulis (1995))

As part of environmental and social studies conducted in support of location decisions, both approaches - suitability and impact - should be utilized. In other words, not only environmental and social suitability studies but also environmental and social impact studies are required. However, some scientists have focused more on the former while others on the latter. The work of Noorollahi et al. (2008) is an example of the former, whereas, examples from the latter include Merkhofer and Keeney (1987), Wey (2005), Goyal and Chalapati (2007), and Alumur and Kara (2007).

Another influential consideration to be factored in regarding the location decisions is the impact of social and environmental regulations. McConnell and Schwab (1990) have addressed this consideration by analyzing the impact of environmental and non-environmental variables deemed influential in urban location decisions. "Pollution haven hypothesis", a proposed explanation for the situation where an area due to its poorly enforced environmental regulations attracts polluting industries, can be tested when social and environmental regulations are concerned.

Every so often, new, more holistic decision making criteria are proposed such as welfare (see Bigman & Revelle, 1978), criminology (see Kennedy, 1990) and environmental equity (see Marsh & Schilling, 1994).

The main challenge of the holistic approach is how to aggregate or compare inherently different values, such as economic and social values and to determine the importance of one over the other in a given situation. Mostly, decision makers address this challenge by either defining weights or by introducing subjective expert perception into the decision model for converting different values to the same unit of comparison. Risk assessment, AHP, ELECTRE, PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) and other decision analysis techniques have been used for this process.

2.2 Validity

Many types of models have been developed to approach the location problem from different perspectives. No viable result would be obtained from any model unless a validation process indicates that the model's behavior is an adequate representation of the important aspects of the problem. Invalid modeling assumptions or oversimplifying can contribute to the failure of a location model.

As part of their critique of past research on undesirable facility location problems, Erkut and Neuman (1989) have highlighted a number of modeling flaws. Improper distance measure is an example: "For most undesirable facility problems, rectilinear distances or a tree network structure make little sense. For instance, in the case of a chemical plant, it is not realistic to model the dispersal of the pollutants using a rectilinear metric (p. 286). Another example of the recognized modeling flaws is point representation of candidate locations or demand points especially where a broad range of land could be a potential site. A further example includes improper feasible regions, such as convex regions, which overlooks geographical or jurisdictional requirements of local or national boundaries. Despite the free shape of feasible territories, such as cities, counties and states, assuming incompatible feasible shapes places the model in danger of invalidity.

A systematic approach toward the facility siting problem can ensure that all influential elements of the entire system of the facility and its surroundings are recognized, and interdependencies or interaction are reflected in the location decision model. Transportation, which is one of the transactions taking place from and to many types of facilities (see for instance Nagy & Salhi, 2007), might bring about such suitability or impact significance that cannot be ignored unless model precision is sacrificed. This consideration could cover the implications of transportation on the whole life cycle of the corresponding facility. According to Erkut and Neuman (1989), "the selected objective for the location of an undesirable facility may conflict with an objective geared towards minimizing transport accident probability. A realistic model would incorporate the location and transportation objectives" (p. 287). The work of Noorollahi et al. (2008) is a comprehensive review of location-routing models.

Another important consideration for location model validity is the issue of network connection. Proximity to raw materials, transportation networks, and demand points, and the interrelation between facilities can be investigated under the category of network connections. Interrelation between facilities can be examined from different angles such as industrial symbiosis, co-location, and hierarchal facility location. For instance, as the possibility of sharing or exchange of resources or byproducts among industrial agents can be assessed during site location studies, the concept of industrial symbiosis could be seen as a factor influencing the decision process.

When interacting facilities within a multiple-layer configuration are concerned, the concept of hierarchal facility location models can be applied. Networks of interacting medical facilities or distribution systems, within which entities are initially processed by a facility but later directed toward other facilities, are common examples in the location literature. Sahin and Sural (2007) have provided a comprehensive review of the literature of hierarchical facility location.

Interacting facilities can be viewed in the context of supply chains whose overall sustainability can be assessed as a "sustainable supply chain". Similarly, inter-sectoral linkages between firms whose locations are of interest to decision makers have been explored by Ulph and Valentini (1997). Although certain benefits are expected by co-locating firms, potential risks from either policies or other factors must be considered as well. As shown by Ulph and Valentini (1997), the implications of government-adopted environmental policies on a firms' location problem can be so sophisticated that no analytical tool but simulation would suffice as the decision making engine.

Location model validity can also be regarded from a system state point of view. Many facility location models assume that the surrounding system within which a facility is located is a stable system whose state does not change; whereas, different reactions caused by placement are possible. For instance, in a case where locating a hospital is concerned, the state of the entire system can be influenced by the population density of candidate areas, patient demand rate, portion of demand rate taken by other medical facilities (competitors), and the availability of the human resources required for the operation of the hospital. Assuming that these factors are constant during the long term and underestimating their changes due to the placement of the facility can lead to invalidity of the location model. Methods, such as discrete-event simulation or system dynamics, are capable of dealing with stochastic or dynamic situations and are appropriate tools for certain situations. Nonetheless, the dearth of simulation modeling and techniques in the location literature is tangible (see Table 2). Simulation techniques can be helpful in guiding the choice of location by developing and running models of a system to assess various location scenarios over a time period of interest. Simulation models can include all existing and proposed facilities with their corresponding attributes such as distances, demands and supplies, and impact factors.

2.3 Interdisciplinary Consciousness

Many scholars from different branches of science such as industrial engineering, operations research, urban planning, public policy, environmental science and geography have contributed to the location problem. Different approaches to the location problem can be considered to be a matter of controversy among location scientists based upon the main focus and the methods used.

As mentioned in section 0, the term sustainability is defined by different disciplines in different ways. This divergence of views should not necessarily be taken as a drawback but as an opportunity to undertake multi-dimensional analysis. As stated by Kidd (1992), "In fact, it is more productive for analysts to concentrate on precision and clarity in stating specifically what they mean by sustainability in the context of the specific problem with which they are dealing than to search for a generally accepted single definition of sustainability"(p. 24).

Regardless of the discipline in which the location problem emerges, examples of methods used involve optimization, decision analysis, risk analysis, and GIS methods. The current article proposes addressing facility location problems in light of the principles of sustainability. However, expecting the result of a location problem to be sustainable makes the problem even more complex and solving it more difficult. This requires decision makers to seek interdisciplinary solutions generated by thinking not only vertically, i.e., deeper into a single discipline, but also horizontally across disciplines. The subjects of the location problem should become more important than the methods due to the fact that methods in most cases are linked to particular disciplines but subjects are discussed beyond particular methods.

Many attempts have been made toward bridging the disciplinary divides in collectively addressing the complex problem of location analysis. The inception of hierarchal facility location problems, e.g., dealing with different types of interacting facilities within a multiple layer configuration, is an example of an attempt to create more common ground between two branches of knowledge, operations research and planning.

2.4 Multiplicity

Decision making criteria are determined by the specific type of facility to be located. The main disadvantage of single-criterion modeling is its inability to evaluate all influential aspects of the decision at the same time. As stated by Barda et al. (1990), "the monocriterion model is unable to integrate all the different aspects of the site choice problem with which we are faced" (p. 333). Although new location models have shifted more toward multi-criteria than before, single-criteria location models are still being proposed (see for example Goyal & Chalapati (2007)).

Different methods have been proposed for multi-criteria location problems. Decision analysis methods such as

ELECTRE (see Barda et al., 1990; Norese, 2006), PROMETHEE (see Queiruga et al., 2008), ANP (Analytic Network Process) (see Tuzkaya et al., 2008) and AHP (see Erkut & Moran, 1991) are some of the examples. Several useful review articles of the existing multi-criteria problem have been published (see for instance Current et al., 1990; Farahani et al., 2010).

Although numerous facility siting models have been proposed in the literature, many of them are applicable only under very specific circumstances. This problem is the main challenge for adopting facility location decisions. Moreover, different objectives are in play in different situations; and the tradeoff between different objectives is not easily explored. This challenge has been acknowledged in the literature particularly for locating undesirable facilities to the extent that the underutilization of multiobjective models has been criticized. As Erkut and Neuman (1989) argued, "we believe multiobjective decision making tools are underutilized in the undesirable facility location literature. The multiple constituency, multiobjective nature of the problem severely limits the usefulness of single objective models."(p. 287).

As noted before, sustainability indicators are an integral part of sustainable development efforts. The process of determining the most appropriate sustainability indicators is considered to be inevitable in all location decision making cases; otherwise, the difference among varying location decisions cannot be quantified and evaluated against the overall sustainability objective.

Although recognizing the most appropriate criteria to be embedded in the sustainable facility location problem is not the focus of the current study, the process by which the decision criteria are extracted is of great importance and will be addressed later in the current article.

2.5 Life Cycle Consciousness

Sustainability cannot be achieved unless an inclusive view of impacts from the placement of a facility is used. The whole lifecycle of facilities needs to be investigated. For instance, in the case of locating an industrial plant, the development and construction stages in addition to the plant operation have to be considered.

Briassoulis (1995) presented several classification schemes for environmental criteria used in facility siting decisions. These indicators can also be utilized for the purpose of Environmental Impact Assessment (EIA). Temporal scale, varying from short and medium to long-term, is introduced to demonstrate the importance of time for environmental impact. With regard to the long-term view of sustainability, valid models are likely to have long time scales covering a reasonable lifecycle for facility siting models. For a review of the application of alternative environmental assessment methods and criteria to planning and building construction, see Thabrew et al. (2009) and Thabrew and Ries (2009).

Life cycle implications of siting a facility can be evaluated in the context of environmental equity as well. Sacrificing the long-term consequences of siting noxious facilities against short-term economic gains for example might occur unless decision makers regard environmental equity. Poor or minority groups might accept placement of a noxious facility in their area only because of temporal economic incentives – a decision which is considered to be in contradiction with sustainable development principles because of the lack of regard for its long-term impacts on future generations. As Reams and Templet (1996) noted, this sacrifice exacerbates environmental inequity because of the greater vulnerability of these groups to temporal gains: "Political powerlessness, lack of economic resources, vulnerability to short-term economic incentives, racially segregated housing patterns, and possible differential patterns of enforcement are complicated, interrelated phenomena that do not lend themselves to quick and easy solutions to environmental inequity" (p. 317).

2.6 Spatial Scale Consciousness

The spatial scale considered in the facility location problem can make a difference in the result. Examples of spatial scales include local, regional, subnational, national, and international. The decision result obtained from a location problem solved considering only a local domain is not necessarily the same as the one considering a national or global domain. As a result, assuming different spatial scales can bring about a different set of economic, social and environmental dimensions. Rarely are impacts solely regional or national. Therefore, on the one hand, decisions about the spatial scale to be considered during the location decision making process should be well thought out. On the other hand, the implications of local, regional, subnational, national, and international policies should be investigated since these policies can attract or repel certain facilities. Selecting the proper spatial scale for a location problem can be influenced by factors such as the level of decision making, availability of resources, existing policies and regulations, the boundaries of jurisdictional control, and the strategic orientation of decision makers.

Warszawski (1972) has supported countrywide or regional planning units in order to make centralized location decisions and perform production and capacity planning of industrial plants in the construction industry. The author has proposed centralized planning as “the only way to cope with the shortage of labor and growing demand for housing” (p. 209). In this article, industrial plants represent prefabrication plants that provide building components for housing projects. The centralized process of decision making has been proposed to make sure a wide range of options are investigated to find the best option possible. It is worth noting that problem-specific circumstances are the conditions that determine whether location decisions can be made on a centralized or decentralized basis.

Ulph and Valentini (1997) explored how relatively severe and restrictive environmental policies can expose domestic producers to a competitive disadvantage and influence the circumstances to the extent that relocation options might make more sense for them. This article also investigates the implications of eco-dumping as a compromising decision made due to poorly enforced environmental regulations.

Decisions concerning spatial scales need to be made carefully particularly when national need versus local interests is concerned. Owens (2004) highlighted the criticality of the spatial scale at which controversial location decisions, in particular those that are nationally needed but locally resisted, are made: “Salvation lies in adopting a clear strategic framework at the national level, which will cascade down to the local level where individual projects must be accommodated” (p. 105).

Similarly, Wong et al. (2010), as part of their suggestions for sustainable development of the construction industry in Hong Kong, recommended establishing a centralized strategic planning unit responsible for giving strategic directions and making macro-level coordinating decisions. The need to properly select construction sites has been highlighted as part of the first strategic direction, formulating an industry-specific long term vision and policy: “A long term vision for positioning Hong Kong’s construction industry is lacking at the outset according to many of the industry practitioners consulted” (p. 259).

3. Discussion

As part of the location decision making process, one way to analyze the suitability and impact of environmental and social criteria simultaneously is to reevaluate the positive and negative risks imposed in each situation. In fact, risk analysis studies are able to address both suitability and impact issues since the former can be regarded as in a category of positive risks while the latter can be seen in a group of negative risks. Subsequently, this point of view has been utilized to model the interrelationship and interactions among economic, environmental, and social factors that are in equilibrium.

Building upon the work of Briassoulis (1995) in which the social implications of economic activities have not been developed, a more general model representing the interrelationship between economic activities, environment, and society is proposed (see Figure 3). The previously-mentioned differentiation between suitability and impact is utilized to build a more general model in which examples of negative and positive risks imposed by economic activities are identified. These risks can be economic, environmental, or social risks. Positive risks represent opportunities surrounding suitability issues while negative risks represent threats imposed by impacts.

Some of the listed factors can be considered as a positive, negative, or both a positive or negative risk depending on the situation. For example, a criterion such as closeness to population centers might be considered as an opportunity (positive risk) for siting a commodity distribution center, whereas the same criterion might be considered as a threat (negative risk) for locating an obnoxious facility. Figure 3 has been drawn such that economic criteria are surrounded by social criteria; and both are surrounded by environmental criteria to illustrate the potential contribution of environmental sustainability to social development and economic growth.

Note that the arrows in this figure represent reciprocal cause and effect relationships between linked elements. The main message of the modeled relationships is the interrelatedness and interactions among economic, environmental and social variables, which makes the behavior of the entire system dynamic and complex. The main challenge for location decision makers is how to sustain the viability of the entire system by maximizing positive risk yet minimizing negative risks.

All location decision making processes start with defining the problem which allows preliminary risk analysis studies to be conducted. Referred to section 0, with regard to the capabilities of risk analysis studies to address suitability and impact issues, it is proposed here that risk analysis studies are incorporated in a location decision making framework not as a replacement but as part of a more comprehensive approach. Conducting suitability analysis together with environmental and social impact studies is expected to be performed during risk studies. Based on the results of the preliminary risk analysis, the appropriate spatial scale for the location problem is chosen, potential sites are recognized, and exclusionary screening is conducted. In this stage, the investigation is assumed to be preliminary.

A more detailed risk analysis is used to identify all threats and opportunities involved in tackling the problem. Subsequently, performance measures are specified based on the definition adopted for sustainability for the location decision. Various problem-specific objectives and criteria are then selected and embedded in the decision model. Model validation and verification is carried out prior to discretionary screening, which is executed by applying a decision model.

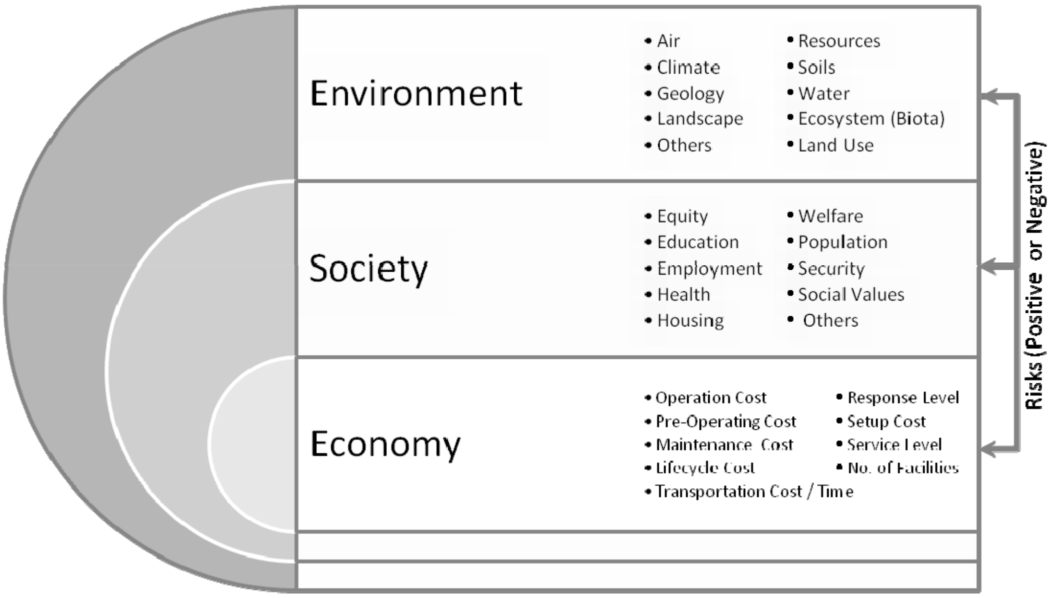

Figure 3. Economy – Environment – Society inter-relationship

Upon the use of the decision model for discretionary analysis, sensitivity analysis is undertaken. Sensitivity analysis refers to a range of techniques that can be employed to determine how sensitive the result of the location model is to changes in the input data or assumptions. Finally, taking into account all decision making factors, the feasibility - suitability analysis will ensure the decision makers that the project will be implementable. Any overarching concerns are investigated and the final location decision is made or reevaluated if needed.

4. Conclusion

Research in outlining the characteristics of sustainable facility location needs to be augmented. In this article a comprehensive look at these characteristics has been provided. These characteristics can help in design, selection, and implementation of location methods that are appropriate to address the challenging requirements of sustainability standards.

Although the existing location literature has steadily progressed toward considering not only economic but also social and environmental criteria in location decisions, instances of direct reference to sustainable development in location problems are rare. Despite the dearth of direct reference to the sustainable facility location concept, a rigorous interdisciplinary review process was conducted to select those publications that have the most relevance and contribution to the expanding knowledge in this field. The current research will provide future researchers with new insights into the concept of sustainable facility location and help foster further developments.

The aim of this paper has not been to propose a decision model or sustainability criteria for the location problem. Instead, the aim is to summarize potential areas of interest by conducting a literature review on a selected list of references that have dealt with one or more of the environmental, social, or sustainability aspects of the location problem.

Many steps remain to be taken toward developing location models that integrate all three aspects of sustainable development into decision making. Sustainable development will remain out of reach unless all types of decisions including location decisions are made based on a thorough understanding of all possible economic, environmental, and social outcomes.

References

Achillas, C., Vlachokostas, C., & Banias, G. (2010). Decision support system for the optimal location of electrical and electronic waste treatment plants: A case study in Greece. *Waste Management, 30*(5), 870-879. http://dx.doi.org/10.1016/j.wasman.2009.11.029

Alumur, S., & Kara, B. Y. (2007). A new model for the hazardous waste location-routing problem. *Computers & Operations Research, 34*(5), 1406-1423. http://dx.doi.org/10.1016/j.cor.2005.06.012

Atkinson, G., Dietz, S., & Neumayer, E. (2007). Handbook of sustainable development. Edward Elgar Publishing.

Banias, G., Achillas, C., Vlachokostas, C., Moussiopoulos, N., & Tarsenis, S. (2010). Assessing multiple criteria for the optimal location of a construction and demolition waste management facility. *Building and Environment, 45*(10), 2317-2326. http://dx.doi.org/10.1016/j.buildenv.2010.04.016

Barda, O. H., Dupuis, J., & Lencioni, P. (1990). Multicriteria location of thermal power plants. *European Journal of Operational Research, 45*(2-3), 332-346. http://dx.doi.org/10.1016/0377-2217(90)90197-J

Berkhuizen, J., de Vries, E., & Slob, A. (1988). Siting procedure for large wind energy projects. *Journal of Wind Engineering and Industrial Aerodynamics, 27*(1-3), 191-198. http://dx.doi.org/10.1016/0167-6105(88)90035-9

Bigman, D., & ReVelle, C. (1978). The theory of welfare considerations in public facility location problems. *Geographical Analysis, 10*(3), 229-240. http://dx.doi.org/10.1111/j.1538-4632.1978.tb00652.x

Brandeau, M. L., & Chiu, S. S. (1989). An overview of representative problems in location research. *Management Science*, 645-674. http://dx.doi.org/10.1287/mnsc.35.6.645

Briassoulis, H. (1995). Environmental criteria in industrial facility siting decisions: An analysis. *Environmental Management, 19*(2), 297-311. http://dx.doi.org/10.1007/BF02471998

Brundtland, G. H., & Khalid, M. (1987). *Our common future: The world commission on environment and development*. Oxford, GB: Oxford University Press.

Calzonetti, F. J., Sayre, G. G., & Spooner, D. (1987). A reassessment of site suitability analysis for power plant siting: A Maryland example. *Applied Geography, 7*(3), 223-241. http://dx.doi.org/10.1016/0143-6228(87)90035-X

Cattafi, M., Gavanelli, M., Milano, M., & Cagnoli, P. (2011). Sustainable biomass power plant location in the Italianemilia-romagna region. *ACM Transactions on Intelligent Systems and Technology, 2*(4).

Common, M., & Perrings, C. (1992). Towards an ecological economics of sustainability. *Ecological Economics, 6*(1), 7-34. http://dx.doi.org/10.1016/0921-8009(92)90036-R

Current, J., Min, H., & Schilling, D. (1990). Multiobjective analysis of facility location decisions. *European Journal of Operational Research, 49*(3), 295-307. http://dx.doi.org/10.1016/0377-2217(90)90401-V

Dahlsrud, A. (2008). How corporate social responsibility is defined: An analysis of 37 definitions. *Corporate Social Responsibility and Environmental Management, 15*(1), 1-13. http://dx.doi.org/10.1002/csr.132

Dehghanian, F., & Mansour, S. (2009). Designing sustainable recovery network of end-of-life products using genetic algorithm. *Resources, Conservation and Recycling, 53*(10), 559-570. http://dx.doi.org/10.1016/j.resconrec.2009.04.007

Dobson, J. E. (1979). A regional screening procedure for land use suitability analysis. *Geographical Review, 69*(2), 224-234. http://dx.doi.org/10.2307/214965

Dou, Y., & Sarkis, J. (2010). A joint location and outsourcing sustainability analysis for a strategic offshoring decision. *International Journal of Production Research, 48*(2), 567-592. http://dx.doi.org/10.1080/00207540903175145

Drezner, Z. (1995). *Objectives in location problems*. In Facility location: a survey of applications and methods (pp. 151-180) Springer.

Dudukovic, J., Stanojevic, M., & Vranes, S. (2005). Decision aid for sustainable industrial siting. EUROCON 2005. *The International Conference on Computer as a Tool, 2*, 1085-1088. http://dx.doi.org/10.1109/EURCON.2005.1630139

Erkut, E., & Moran, S. R. (1991). Locating obnoxious facilities in the public sector: An application of the analytic hierarchy process to municipal landfill siting decisions. *Socio-Economic Planning Sciences, 25*(2), 89-102. http://dx.doi.org/10.1016/0038-0121(91)90007-E

Erkut, E., & Neuman, S. (1989). Analytical models for locating undesirable facilities. *European Journal of Operational Research, 40*(3), 275-291. http://dx.doi.org/10.1016/0377-2217(89)90420-7

Farahani, R. Z., SteadieSeifi, M., & Asgari, N. (2010). Multiple criteria facility location problems: A survey. *Applied Mathematical Modelling, 34*(7), 1689-1709. http://dx.doi.org/10.1016/j.apm.2009.10.005

Fernandez, I., & Ruiz, M. C. (2009). Descriptive model and evaluation system to locate sustainable industrial areas. *Journal of Cleaner Production, 17*(1), 87-100. http://dx.doi.org/10.1016/j.jclepro.2008.02.011

Francis, R. L., McGinnis, L. F., & White, J. (1983). Locational analysis. *European Journal Operational Resarch, 12*(3), 220-252. http://dx.doi.org/10.1016/0377-2217(83)90194-7

Glavic, P., & Lukman, R. (2007). Review of sustainability terms and their definitions. *Journal of Cleaner Production, 15*(18), 1875-1885. http://dx.doi.org/10.1016/j.jclepro.2006.12.006

Goldsmith, E. (1972). Blueprint for survival. Houghton Mifflin Boston, MA.

Goyal, S. K., & ChalapatiRao, C. V. (2007). Air assimilative capacity-based environment friendly siting of new industries: A case study of Kochi region, India. *Journal of Environmental Management, 84*(4), 473-483. http://dx.doi.org/10.1016/j.jenvman.2006.06.020

Gros, J. (1975). Power plant siting: A paretian environmental approach. *Nuclear Engineering and Design, 34*(2), 281-292. http://dx.doi.org/10.1016/0029-5493(75)90125-9

Hokkanen, J., & Salminen, P. (1997). Locating a waste treatment facility by multicriteria analysis. *Journal of Multi-Criteria Decision Analysis, 6*(3), 175-184. http://dx.doi.org/10.1002/(SICI)1099-1360(199705)6:3<175::AID-MCDA150>3.3.CO;2-R

International Organization for Standardization. (2010). Guidance on social responsibility.

Keeney, R. L., & Nair, K. (1977). Nuclear siting using decision analysis. *Energy Policy, 5*(3), 223-231. http://dx.doi.org/10.1016/0301-4215(77)90038-6

Kennedy, D. B. (1990). Facility site selection and analysis through environmental criminology. *Journal of Criminal Justice, 18*(3), 239-252. http://dx.doi.org/10.1016/0047-2352(90)90004-U

Kidd, C. V. (1992). The evolution of sustainability. *Journal of Agricultural and Environmental Ethics, 5*(1), 1-26. http://dx.doi.org/10.1007/BF01965413

Lamelas, M., Marinoni, O., Hoppe, A., & de La Riva, J. (2008). Suitability analysis for sand and gravel extraction site location in the context of a sustainable development in the surroundings of Zaragoza (Spain). *Environmental Geology, 55*(8), 1673-1686. http://dx.doi.org/10.1007/s00254-007-1116-9

Maniezzo, V., Mendes, I., & Paruccini, M. (1998). Decision support for siting problems. *Decision Support Systems, 23*(3), 273-284. http://dx.doi.org/10.1016/S0167-9236(98)00042-6

Marsh, M. T., & Schilling, D. A. (1994). Equity measurement in facility location analysis: A review and framework. *European Journal of Operational Research, 74*(1), 1-17. http://dx.doi.org/10.1016/0377-2217(94)90200-3

McConnell, V. D., & Schwab, R. M. (1990). The impact of environmental regulation on industry location decisions: The motor vehicle industry. *Land Economics, 66*(1), 67-81. http://dx.doi.org/10.2307/3146684

McHarg, I. L. (1995). Design with nature. Turtleback Books.

Merkhofer, M. W., & Keeney, R. L. (1987). A multiattribute utility analysis of alternative sites for the disposal of nuclear waste. *Risk Analysis, 7*(2), 173-194. http://dx.doi.org/10.1111/j.1539-6924.1987.tb00981.x

Mesa, J. A., & Brian Boffey, T. (1996). A review of extensive facility location in networks. *European Journal of Operational Research, 95*(3), 592-603. http://dx.doi.org/10.1016/0377-2217(95)00321-5

Mumphrey, A. J., Seley, J. E., & Wolpert, J. (1971). A decision model for locating controversial facilities. *Journal of the American Planning Association, 37*(6), 397-402. http://dx.doi.org/10.1080/01944367108977389

Muntzing, M. (1976). Siting and environment: Towards an effective nuclear siting policy. *Energy Policy, 4*(1), 3-11.

Nagy, G., & Salhi, S. (2007). Location-routing: Issues, models and methods. *European Journal of Operational*

Research, 177(2), 649-672. http://dx.doi.org/10.1016/j.ejor.2006.04.004

Noorollahi, Y., Itoi, R., Fujii, H., & Tanaka, T. (2008). GIS integration model for geothermal exploration and well siting. *Geothermics, 37*(2), 107-131. http://dx.doi.org/10.1016/j.geothermics.2007.12.001

Norese, M. F. (2006). ELECTRE III as a support for participatory decision-making on the localization of waste-treatment plants. *Land Use Policy, 23*(1), 76-85. http://dx.doi.org/10.1016/j.landusepol.2004.08.009

Owens, S. (2004). Siting, sustainable development and social priorities. *Journal of Risk Research, 7*(2), 101-114. http://dx.doi.org/10.1080/1366987042000158686

Queiruga, D., Walther, G., Gonzalez-Benito, J., & Spengler, T. (2008). Evaluation of sites for the location of WEEE recycling plants in Spain. *Waste Management, 28*(1), 181-190. http://dx.doi.org/10.1016/j.wasman.2006.11.001

Reams, M. A., & Templet, P. H. (1996). Political and environmental equity issues related to municipal waste incineration siting. *Journal of Hazardous Materials, 47*(1), 313-323. http://dx.doi.org/10.1016/0304-3894(95)00119-0

ReVelle, C. S., & Eiselt, H. A. (2005). Location analysis: A synthesis and survey. *European Journal of Operational Research, 165*(1), 1-19. http://dx.doi.org/10.1016/j.ejor.2003.11.032

Sahin, G., & Sural, H. (2007). A review of hierarchical facility location models. *Computers & Operations Research, 34*(8), 2310-2331. http://dx.doi.org/10.1016/j.cor.2005.09.005

Schilling, D. A., Jayaraman, V., & Barkhi, R. (1993). A review of covering problems in facility location. *Location Science, 1*(1), 25-55.

Store, R. (2009). Sustainable locating of different forest uses. *Land Use Policy, 26*(3), 610-618. http://dx.doi.org/10.1016/j.landusepol.2008.08.013

Sumathi, V., Natesan, U., & Sarkar, C. (2008). GIS-based approach for optimized siting of municipal solid waste landfill. *Waste Management, 28*(11), 2146-2160. http://dx.doi.org/10.1016/j.wasman.2007.09.032

Susskind, L. E. (1985). The siting puzzle: Balancing economic and environmental gains and losses. *Environmental Impact Assessment Review, 5*(2), 157-163. http://dx.doi.org/10.1016/0195-9255(85)90040-X

Thabrew, L., & Ries, R. (2009). Application of life cycle thinking in multidisciplinary multistakeholder contexts for cross-sectoral planning and implementation of sustainable development projects. *Integrated Environmental Assessment and Management, 5*(3), 445-460. http://dx.doi.org/10.1897/IEAM_2008-064.1

Thabrew, L., Wiek, A., & Ries, R. (2009). Environmental decision making in multi-stakeholder contexts: Applicability of life cycle thinking in development planning and implementation. *Journal of Cleaner Production, 17*(1), 67-76. http://dx.doi.org/10.1016/j.jclepro.2008.03.008

Thunen, J. H. (1826). Der isoliertestaat in beziehung auf land wirtschaft und national okonomie (the isolated state in relation to agriculture and political economy). *Fischer, Jena, 182*(1).

Tsoutsos, T., Maria, E., & Mathioudakis, V. (2007). Sustainable siting procedure of small hydroelectric plants: The Greek experience. *Energy Policy, 35*(5), 2946-2959. http://dx.doi.org/10.1016/j.enpol.2006.10.015

Tung, Y., & Hathhorn, W. E. (1988). Probability distribution for critical do location in streams. *Ecological Modeling, 42*(1), 45-60. http://dx.doi.org/10.1016/0304-3800(88)90091-9

Tuzkaya, G., Onut, S., Tuzkaya, U. R., & Gulsun, B. (2008). An analytic network process approach for locating undesirable facilities: An example from Istanbul, Turkey. *Journal of Environmental Management, 88*(4), 970-983. http://dx.doi.org/10.1016/j.jenvman.2007.05.004

Ulph, A., & Valentini, L. (1997). Plant location and strategic environmental policy with inter-sectoral linkages. *Resource and Energy Economics, 19*(4), 363-383. http://dx.doi.org/10.1016/S0928-7655(97)00017-1

The United Nations Department of Economic and Social Affairs [UNDESA]. (2001). Indicators of sustainable development: Guidelines and methodologies. United Nations. Retrieved from http://www.un.org/esa/sustdev/publications/indisd-mg2001.pdf

Warszawski, A. (1972). Planning of location and capacity of industrial plants in the construction industry. *Building Science, 7*(4), 209-214. http://dx.doi.org/10.1016/0007-3628(72)90001-1

Weber, A. (1929). Theory of the location of industries. University of Chicago Press.

Wey, W. M. (2005). An integrated expert system/operations research approach for the optimization of waste incinerator siting problems. *Knowledge-Based Systems, 18*(6), 267-278. http://dx.doi.org/10.1016/j.knosys.2005.03.004

Wong, J. M. W., Thomas Ng, S., & Chan, A. P. C. (2010). Strategic planning for the sustainable development of the construction industry in HongKong. *Habitat International, 34*(2), 256-263. http://dx.doi.org/10.1016/j.habitatint.2009.10.002

Nomenclature

AHP	Analytical Hierarchy Process
ANP	Analytic Network Process
CSD	United Nations Commission on Sustainable Development
EIA	Environmental Impact Assessment
ELECTRE	ELimination and Choice Expressing REality
EOL	End-Of-Life
GIS	Geographic Information System
ISO	International Organization for Standardization
LCA	Life Cycle Analysis
MCDA	Multi-Criteria Decision Analysis
MC-SDSS	Multi-Criteria Spatial Decision Support System
OR	Operations Research
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluation
SHP	Small Hydroelectric Plant
SR	Social Responsibility
UNDESA	United Nations Department of Economic and Social Affairs
WEEE	Waste Electrical and Electronic Equipment