Electrical Power and Energy Systems 44 (2013) 897–907

Contents lists available at SciVerse ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

The integrated framework for analysis of electricity supply chain using an integrated SWOT-fuzzy TOPSIS methodology combined with AHP: The case of Turkey

Esra Bas *

Department of Industrial Engineering, Technical University, Macka 34367, Istanbul, Turkey

ARTICLE INFO

Article history:
Received 18 January 2012
Received in revised form 14 August 2012
Accepted 19 August 2012
Available online 27 September 2012

Keywords:
Electricity supply chain
Advanced planning
SWOT
Fuzzy TOPSIS
AHP

ABSTRACT

This paper proposes an integrated framework for analysis of an electricity supply chain using an integrated SWOT-fuzzy TOPSIS methodology combined with Analytic Hierarchy Process (AHP). The paper is divided into two main sections. In the first main section, the integrated framework comprising a qualitative framework and a quantitative framework is presented. In the qualitative framework, a general structure and so-called advanced planning framework are developed for an electricity supply chain based on the literature review in supply chain management (SCM). Then, a quantitative Strengths–Weaknesses–Opportunities–Threats (SWOT) framework is used to formulate a strategy plan based on the elements from the proposed qualitative framework. Since a qualitative SWOT analysis can be insufficient to formulate an action plan, an integrated SWOT-fuzzy TOPSIS methodology combined with AHP is proposed to prioritize the defined SWOT factors and to formulate a strategy plan with top priorities. In the second main section, the integrated framework is illustrated with the case of electricity supply chain in Turkey.

1. Introduction

SCM is a value chain management from the supplier of a supplier to the customer of a customer of a company with the aim of attaining an overall value. A rich literature is available in SCM [1–5]. A holistic view to end-to-end processes is the core value of the SCM concept enhancing overall optimization rather than sub-optimization of processes.

An electricity supply chain is a significant supply chain incorporating the processes from the primary fuel sourcing to electricity consumption. Since, electricity is a highly perishable commodity, a holistic view of processes with proper supply chain design becomes particularly invaluable to avoid any electricity losses. Considerable research has been conducted in the electricity supply chain. Bayod-Rujula [6] examined the consideration of a large number of distributed small generators in an electricity supply chain and presented innovative concepts such as microgrids and virtual utilities. Bouffard and Kirschen [7] explored the current state of research on centralized and distributed electricity systems and discussed the future of a hybrid system integrating the advantages of both systems. Forgionne and Guo [8] proposed optimal production and inventory policies for a centralized supply chain and adapted the policies to the electric utility supply chain. Gutiérrez-Alcaraz and Sheblé [9] proposed a dynamic game-theoretic model by using discrete event system simulation to consider the interactions among different players in an electricity supply chain. Odenberger and Johnsson [10] investigated the role of CO_2 capture and storage technologies for CO_2 emission reduction in an electricity supply chain. Peças Lopes et al. [11] discussed the key issues and challenges with respect to the integration of distributed generation to an electricity supply chain. Slingerland [12] examined the relationship between energy conservation and organization of an electricity supply chain by analyzing three case studies of energy conservation. Zhijun and Kuby [13] proposed a model for simultaneous consideration of supply side and demand side investments in an electricity supply chain. As evident from the examples, although the literature in the electricity supply chain is considerably rich, most papers focused on a few issues of the supply chain and there is a lack of an integrated framework considering different dimensions of an electricity supply chain.

The contribution of this paper is threefold. As a significant supply chain, an electricity supply chain could benefit from the concepts introduced in SCM literature. With this regard, as a first contribution, a *qualitative framework* is proposed for a better understanding of an overall view of an electricity supply chain and its elements by adapting the concepts defined in SCM literature. In this framework, the general structure of an electricity supply chain is defined and so-called advanced planning framework defined in SCM literature is adapted to the electricity supply chain. Advanced planning is a hierarchical and modular-based planning approach to design a whole supply chain for different planning

* Tel.: +90 212 293 13 00/2664 202; fax: +90 212 240 72 60.
E-mail address: atace@itu.edu.tr

0142-0615/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijepes.2012.08.045

horizon. Stadtler and Kilger [14] provided the general concept and modules of advanced planning and illustrated the advanced planning projects with case studies. Typical modules of an advanced planning framework are strategic network planning at long-term level, master planning at midterm level and production planning and scheduling at short-term level [15]. In an advanced planning system (APS), all modules are integrated with each other by an input or feedback relationship. The motivation for proposing advanced planning approach for an electricity supply chain is that this approach systematically covers different planning levels in an electricity supply chain and has a potential of integrating a wide variety of conceptual models and mathematical approaches introduced in electricity supply chain literature. Although the literature is rich in mathematical approaches and conceptual models proposed for different sections of electricity supply chain, it is not systematic and integrated, and advanced planning approach is aimed at addressing this gap in the literature.

The second contribution of the paper is that it proposes a *quantitative framework* for development of a strategy plan for an electricity supply chain. In this framework, SWOT factors are derived from the elements of the proposed qualitative framework. SWOT analysis is a structured approach to evaluate an organization with respect to its internal and external environment. By identifying factors in a SWOT matrix, action plans can be developed to augment strengths, eliminate or minimize weaknesses, exploit opportunities and identify threats. However, a qualitative SWOT matrix can be insufficient in many cases with no prioritization of SWOT factors. With this regard, the so-called quantified SWOT analysis has been proposed in the literature. The first quantified SWOT methodology, so-called A'WOT, included AHP integration and has been proposed by Kurttila et al. [16]. Other papers also appeared to illustrate A-WOT applications [17–19]. As an extension to SWOT-AHP integration, Yüksel and Dagdeviren [20] proposed Analytic Network Process (ANP) to be integrated with SWOT analysis. Other quantified SWOT techniques have also been proposed with or without uncertainty considerations [21–23]. However, the application of quantified SWOT methodology in energy planning has been relatively scarce [24]. The literature in integrated SWOT-TOPSIS methodology has also been very limited [25]. In this paper, an integrated SWOT-fuzzy TOPSIS methodology combined with AHP is proposed to structure and prioritize the SWOT factors for an electricity supply chain. AHP approach is used for determining the relative importance of factors within each SWOT group as well as the relative importance of factors across SWOT groups, while fuzzy TOPSIS is used for evaluating an electricity supply chain with respect to SWOT factors.

The third contribution of the paper is that the proposed qualitative framework and quantitative framework are illustrated with the case of electricity supply chain in Turkey. The current state of electricity supply chain in Turkey is outlined and a strategy plan is developed following the steps given in the qualitative and quantitative framework.

The paper has been organized as follows: In Section 2, the integrated framework proposed in the paper is outlined and detailed. In Section 3, the electricity supply chain in Turkey is evaluated with respect to the proposed methodology given in Section 2. Finally, in Section 4, conclusions and potentials for next research are discussed.

2. The integrated framework proposed in the paper

The integrated framework proposed in this paper is outlined in Fig. 1. Based on the literature review in SCM concepts and conceptual models, a general structure and advanced planning framework are developed for an electricity supply chain. Then, key factors are defined from the general structure and advanced planning framework as SWOT factors and these SWOT factors are incorporated into the integrated SWOT-fuzzy TOPSIS methodology combined with AHP for formulating a strategy plan.

2.1. Developing a general structure for an electricity supply chain

Based on the literature review in SCM, an electricity supply chain can be defined as a cross-company approach that incorporates the upstream and downstream integration of the processes and coordination of the electricity, information and financial flows from the supplier of the supplier to the customer of the customer of a company with the aim of maximizing overall value to all society (adapted from [2,26,27]). Overall value to all society can be attained by maximizing system reliability measures including adequacy and security of electricity supply, while minimizing total costs including an adverse effect to the environment (adapted from [28]). In system reliability measures, adequacy of supply refers to the ability of a system to supply electricity under normal conditions, while security of supply refers to the dynamic response of the system to unexpected events [28]. The general structure of an electricity supply chain comprises different elements, which will be detailed in the next subsections:

2.1.1. The overall long-term strategy of an electricity supply chain

The overall long-term strategy of an electricity supply chain can be defined as maximizing system reliability measures, while minimizing total costs across the supply chain.

2.1.2. Core processes in an electricity supply chain

The core processes in an electricity supply chain are primary fuel sourcing, electricity generation, electricity transmission, electricity distribution and electricity consumption [29]. The adaptation of the well-known Supply Chain Operations Reference (SCOR) model to electricity supply chain is provided in Fig. 2. During the transmission process, the electricity is drawn by transmission grids operating at a very high voltage, while during the distribution process, the electricity is distributed by regional grids operating at a low voltage [29]. The electricity consumption process includes also retailing process [29].

2.1.3. Internal environment of an electricity supply chain

The internal environment of an electricity supply chain represents the environment within companies or between the companies. Strengths and weaknesses with respect to internal

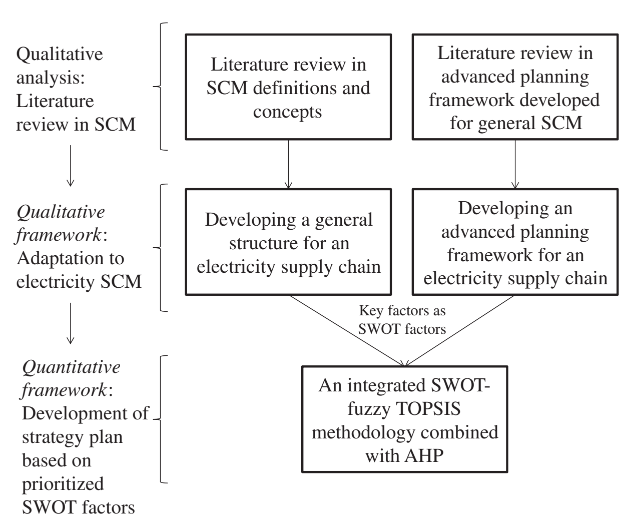

Fig. 1. The integrated framework proposed in the paper.

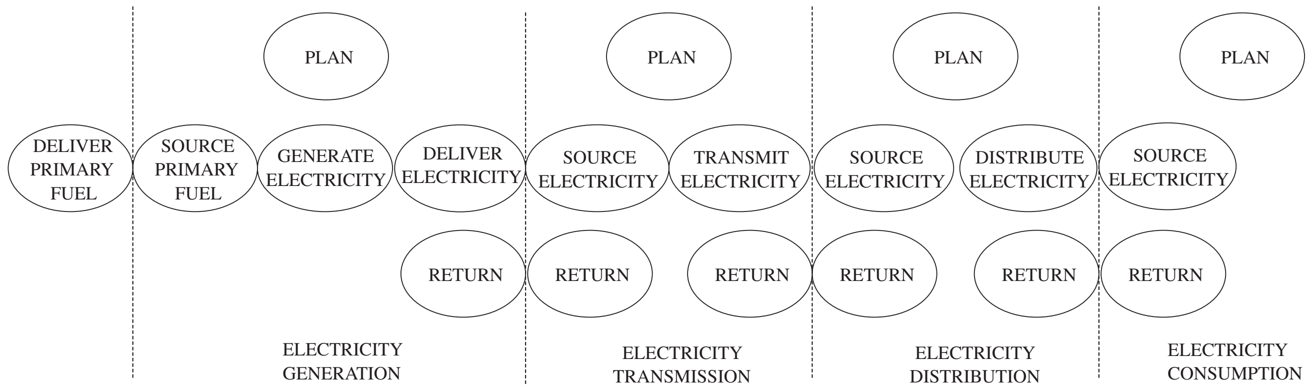

Fig. 2. SCOR-model for an electricity supply chain (adapted from [30]).

environmental factors should be evaluated. Some examples of strengths may be experiences of state-owned companies in the supply chain, commitment to environmental responsibility and some examples of weaknesses may be cultural conflicts and deficiencies in information systems and process capabilities.

2.1.4. External environment of an electricity supply chain

An electricity supply chain is particularly influenced by external factors such as economical, political, social, technological and natural environment at national and international levels. Opportunities and threats as a result of interaction with the external environment should be evaluated. Some examples of opportunities may be growing electricity demand, diversity of primary fuel sources and some examples of threats may be public resistance against transmission-line network investments and a shortage of primary fuel sources [31,32].

2.1.5. Horizontal structure of an electricity supply chain

As adapted from Lambert et al. [33], the horizontal structure of an electricity supply chain is characterized by the number of tiers in an electricity supply chain, where each tier is represented by a core process as illustrated in Fig. 2.

2.1.6. Vertical structure of an electricity supply chain

As adapted from Lambert et al. [33], the vertical structure of an electricity supply chain is characterized by the number of companies within a tier. As an example, the vertical structure of the electricity generation process can be short with a few companies, the electricity distribution process can be long with many regional state-owned and private companies and the electricity transmission process can be very short with one or two companies [29].

2.1.7. Integration of processes, coordination of flows and collaboration in an electricity supply chain

According to the literature review in SCM, the *integration of processes* in a supply chain is defined as the electronic linkage of the processes for data exchange. Internal integration is the integration of processes within a company, while external integration is the integration of processes between the companies in a supply chain [34]. A rich literature is available in horizontal and vertical market integration of electricity supply chains [35–38]. However, the definitions are different from the definition given in SCM literature. As an example, Cournot definition of an integrated electricity market is “an entire territory of which the parts are so united by the relations of unrestricted commerce that prices take the same level throughout with ease and rapidity” [39,40]. In this paper, by adapting from the SCM literature, vertical market integration in an electricity supply chain will be defined as the integration of generation, transmission, distribution and retailing companies into one company and horizontal market integration will be defined as the integration of companies within a tier into one company [41].

Based on the literature review in SCM, coordination of flows can be defined as the design of electricity, information and financial flows across the supply chain with interdependency consideration for overall optimization (adapted from [42]). There is also a considerable literature in coordination mechanisms for an electricity supply chain. Some topics covered are coordination of use of reserve capacities, coordination of adequacy policies and coordination of neighboring electricity transmission companies [43–46]. However, in this paper, coordination of all electricity, information and financial flows will be considered across the electricity supply chain for a synchronization of processes.

Based on the literature review in SCM, collaboration can be defined as the mutual design, planning, implementation and monitoring of the integrated processes in a cross-company environment [34]. Since electricity cannot be stored in a large amount, collaborative planning is crucial for all planning tasks to avoid any energy losses resulting from information distortion.

2.1.8. Role model for an electricity supply chain

A role model includes the assignment of roles and responsibilities to different players of a supply chain. A role model proposed for an electricity supply chain is provided in Fig. 3. In this model, independent service providers and government are also considered as well as the players performing core processes.

In Fig. 3, *design of overall supply chain strategy* represents the definition of long-term overall strategy of the electricity supply chain. *Overall supply chain design* is the long-term supply chain design with respect to factors such as horizontal structure, vertical structure and integration, coordination and collaboration mechanisms. *Regulatory-based supply chain design* is supply chain design with respect to regulations including their definition, update and enforcement rules. An *energy hub* is a center for managing energy reserve capacities and coordinating energy flows across the supply chain. An *information hub* is a center of information storage responsible for real-time transmission of information across the supply chain. *Task-based supply chain design* is supply chain design with respect to the advanced planning tasks and their implementation. *Performing supply chain operations* is performing the respective energy, information and financial flows by considering the overall supply chain strategy.

2.2. Developing an advanced planning framework for an electricity supply chain

Advanced planning is a modular planning approach with hierarchies of long-term, midterm and short-term planning horizon

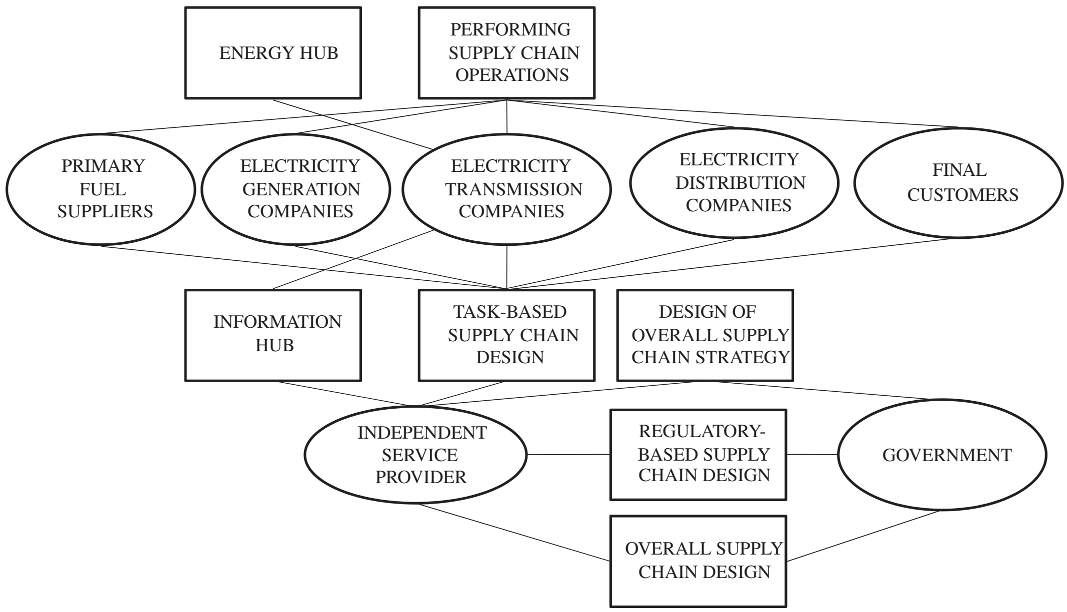

Fig. 3. A role model proposed for an electricity supply chain.

levels [15,47]. The adaptation of the advanced planning framework to an electricity supply chain is provided in Fig. 4.

In this framework, each planning module is connected with each other horizontally or vertically. Long-term planning module of *strategic network design* impacts the strategic position of the electricity supply chain in the long run, while *load forecasting*, the midterm planning task of *supply network planning*, short-term and real-time planning task of *supply and demand balancing* determine the supply chain performance with respect to system reliability measures and total costs.

An advanced planning framework comprises an *integrated information system* and *advanced planning modules*, which will be detailed in the next subsections:

2.2.1. Integrated information system

An integrated information system for an electricity supply chain is proposed to include an enterprise resource planning (ERP) system, a geographic information system (GIS), a remote sensing system and a repository for real-time data. An ERP system connects all basic internal processes such as financial, manufacturing, inventory and supply, sales and delivery and human resources management [48]. Weng [49] provided the definition of Calkins and Tomlinson [50] for GIS as "an integrated software package specifically designed for use with geographic data that performs a comprehensive range of data handling tasks such as data input, storage, retrieval, and output". A GIS has potentials in advanced planning tasks of an electricity supply chain such as strategic network design and load forecasting [51–54]. Weng [49] defined a remote sensing system as a "science and technology of acquiring information about the earth's surface and atmosphere using sensors onboard airborne such as aircraft or balloons or spaceborne such as satellites and space shuttles' platforms". A remote sensing system has also potentials in strategic network design and load forecasting tasks [55,56]. A repository for real-time data is a data warehouse for real-time data such as real-time electricity consumption, weather conditions and real-time voltage levels.

The integration of the systems is invaluable for data exchange between systems. Although the integration of remote sensing

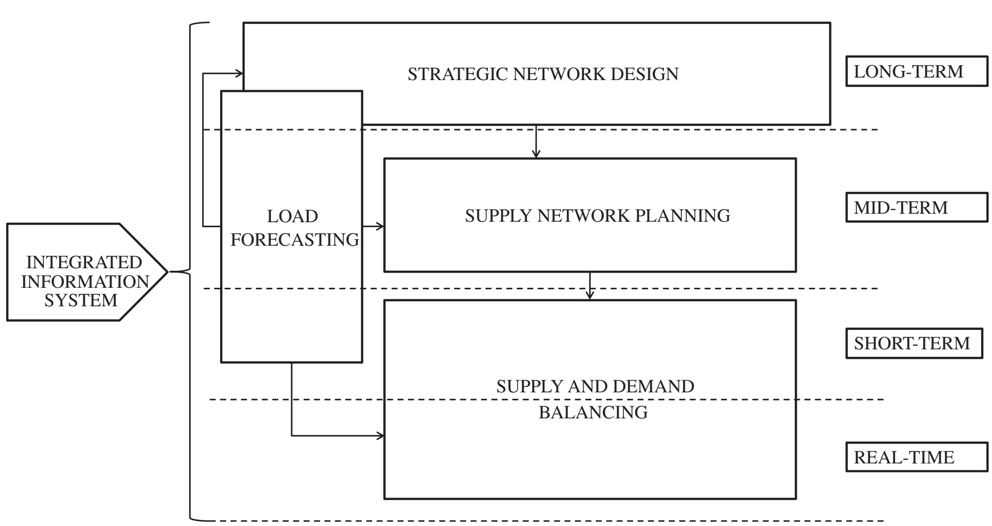

Fig. 4. Advanced planning framework adapted to an electricity supply chain (adapted from [15]).

system and GIS is already possible [49,57], the integration of all systems may not be feasible because of possible incompatibilities in different data structures.

2.2.2. Advanced planning modules for an electricity supply chain

2.2.2.1. Strategic network design. Strategic network design of an electricity supply chain characterizes the long-term optimum network design of generation facilities, transmission-line and distribution networks with respect to their optimal numbers, locations, capacities, route of electricity and synchronized timing of their investments (adapted from [58]). The basic inputs for strategic network design are long-term load forecasting results, horizontal and vertical structure, distribution of state-owned and private companies, national and international fuel sources, generation capacities, load capacities of transmission-line and distribution networks and technical, environmental, social and residential constraints. The objective can be defined as minimization of total costs while maximization of system reliability. Mixed-integer linear programming, mixed-integer nonlinear programming, what-if analysis and expert-based systems have been proposed in the literature for optimum network design in an electricity supply chain [58–64].

2.2.2.2. Load forecasting. The basic inputs for load forecasting are demographic and economic factors in the long-term and in the midterm planning horizon; seasonal input variables, weather forecast variables and historical load data for the short-term planning horizon. Long-term planning tasks such as strategic network design and short-term planning tasks such as supply and demand balancing depend on the load forecasting results. Thus, a large body of research has been devoted to the topic and several techniques including simulation, what-if analysis, statistical forecasting, expert systems and heuristics have been proposed in the literature to improve load forecasting accuracy. Some examples of expert-based system and heuristics applications in load forecasting are neural network, fuzzy modeling and ant colony optimization [65–76].

2.2.2.3. Supply network planning. Analogous to master planning module in an APS system provided in [77], the aim of supply network planning in an electricity supply chain is to determine how much electricity to generate in which generation facilities and in which time periods by using which fuel sources from which primary fuel suppliers, how much electricity to transmit and distribute through which transmission and distribution routes to which customers in which time periods and to determine generation and transmission reserve capacity. The basic inputs from the supply side are national and international fuel sources, generation capacities, load capacities of transmission-line and distribution networks, technical and environmental constraints; while the basic inputs from the demand side are midterm load forecasting results with industry, geography and fuel source dimensions.

2.2.2.4. Supply and demand balancing. The balance between supply and demand is defined as "satisfaction of foreseeable demands of consumers to use electricity without the need to enforce measures to reduce consumption" [78]. The main objective of supply and demand balancing is to synchronize supply and demand by using some market mechanisms such that supply and demand imbalance will be minimized. Batlle and Rodilla [79] made a critical assessment for securing electricity supply and provided two strategies "do-nothing" and "do something on behalf of demand", then classified the latter into price-based approaches and quantity-based approaches. Price-based approaches entail "capacity payment" made to generation companies in addition to the income; while in quantity-based approaches, the regulator buys the electricity for security of supply [79]. Müller and Rammerstorfer [80] provided a literature review of supply and demand balancing including design of auction mechanisms. Frunt et al. [81] discussed primary, secondary and tertiary control mechanisms. Primary control is supply and demand balancing within a very short-time period where all control areas are balanced by using reserve capacities. In secondary control, only the areas that cause the imbalance will be balanced. Tertiary control is used when reserve capacities are needed permanently [81].

2.3. An integrated SWOT-fuzzy TOPSIS methodology combined with AHP for strategy formulation

In this section, the key factors from the qualitative framework given in Sections 2.1 and 2.2 will be defined as SWOT factors to be incorporated into the integrated SWOT-fuzzy TOPSIS methodology combined with AHP. The reason for using a quantified SWOT methodology is that it provides prioritized SWOT factors so that the limited resources can be allocated to the SWOT factors with top priorities. Since evaluation parameters are mostly expressed as linguistic variables, fuzzy set theory is a proper approach. Before proceeding with the methodology, the preliminaries for fuzzy set theory relevant to the proposed methodology will be provided.

2.3.1. Preliminaries

Definition 1. A fuzzy set $\tilde{A} = (a_1, a_2, a_3, a_4)$ is a trapezoidal fuzzy number on R if its membership function can be represented as

$$\mu_{\tilde{A}} = \begin{cases} \frac{x-a_1}{a_2-a_1} & a_1 \leqslant x \leqslant a_2 \\ 1 & a_2 \leqslant x \leqslant a_3 \\ \frac{x-a_4}{a_3-a_4} & a_3 \leqslant x \leqslant a_4 \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

where a_1, a_2, a_3, a_4 are real numbers [82].

Definition 2. The multiplication of a fuzzy number $\tilde{A} = (a_1, a_2, a_3, a_4)$ with a scalar $k \geqslant 0$ is defined as

$$k \otimes \tilde{A} = (ka_1, ka_2, ka_3, ka_4) \tag{2}$$

Definition 3. Let $\tilde{A}_i = (a_{i1}, a_{i2}, a_{i3}, a_{i4})$ be a trapezoidal fuzzy number for $i \in I$. Then, the normalized fuzzy number of each $\tilde{A}_i$ is defined as

$$\tilde{R}_i = \left(\frac{a_{i1}}{\max\limits_{i \in I}\{a_{i4}\}}, \frac{a_{i2}}{\max\limits_{i \in I}\{a_{i4}\}}, \frac{a_{i3}}{\max\limits_{i \in I}\{a_{i4}\}}, \frac{a_{i4}}{\max\limits_{i \in I}\{a_{i4}\}} \right) \tag{3}$$

if the criterion is a profit criterion or

$$\tilde{R}_i = \left(\frac{\min\limits_{i \in I}\{a_{i1}\}}{a_{i4}}, \frac{\min\limits_{i \in I}\{a_{i1}\}}{a_{i3}}, \frac{\min\limits_{i \in I}\{a_{i1}\}}{a_{i2}}, \frac{\min\limits_{i \in I}\{a_{i1}\}}{a_{i1}} \right) \tag{4}$$

if the criterion is a cost criterion [83].

Definition 4. The $D_{p,q}$ distance between trapezoidal fuzzy numbers $\tilde{A} = (a_1, a_2, a_3, a_4)$ and $\tilde{B} = (b_1, b_2, b_3, b_4)$ can be defined for $p = 2$ and $q = 1/2$ as follows [84]:

$$D_{2,\frac{1}{2}}(\tilde{A}, \tilde{B}) = \sqrt{\frac{1}{6}\left[\begin{array}{c} (a_1-b_1)^2 + (a_2-b_2)^2 + (a_3-b_3)^2 + (a_4-b_4)^2 + \\ (a_1-b_1)(a_2-b_2) + (a_2-b_2)(a_3-b_3) + (a_3-b_3)(a_4-b_4) \end{array} \right]} \tag{5}$$

Definition 5. A linguistic variable is a variable in linguistic terms [85]. Several representations of linguistic variables are possible. An example is given in Table 1.

2.3.2. An integrated SWOT-fuzzy TOPSIS methodology combined with AHP

The steps of the integrated SWOT-fuzzy TOPSIS methodology combined with AHP are provided as follows (adapted from [16,83]):

- *Step 1. Identifying SWOT factors*: Define the set of factors to be considered for each of four SWOT groups as *S, W, O, T* with $i \in S, W, O, T$.
- *Step 2. AHP within each SWOT group*: Construct pairwise comparison matrix for comparing the relative importance of factors within each SWOT group with respect to the objective "overall long-term strategy of supply chain" and obtain the relative importance weight vectors for each SWOT group as W_S, W_W, W_O, W_T.
- *Step 3. AHP across SWOT groups*: Construct pairwise comparison matrix for comparing the relative importance of SWOT groups with respect to "overall long-term strategy of supply chain" and obtain relative importance weight vector W_G with entries w_S, w_w, w_O, w_T.
- *Step 4. Final relative importance weights of SWOT factors*: Obtain final relative importance weight vector W_F with $w_i \in W_F$ and entries $W_{SF}, W_{WF}, W_{OF}, W_{TF}$, where $W_{SF} = W_S w_S$; $W_{WF} = W_W\ w_w$; $W_{OF} = W_O w_O$; $W_{TF} = W_T w_T$.
- *Step 5. Evaluation vector*: Obtain evaluation vector $\tilde{E}$ by evaluating the electricity supply chain for each SWOT factor $i \in S, W, O, T$ with linguistic variable $\tilde{e}_i = (e_{i1}, e_{i2}, e_{i3}, e_{i4})$.
- *Step 6. Normalized linguistic variable*: Obtain normalized linguistic variable
- $\tilde{n}_i = \left(\frac{e_{i1}}{\max_i \{e_{i4}\}}, \frac{e_{i2}}{\max_i \{e_{i4}\}}, \frac{e_{i3}}{\max_i \{e_{i4}\}}, \frac{e_{i4}}{\max_i \{e_{i4}\}}\right)$ if $i \in S, W, O, T$ is evaluated with respect to a profit criterion or $\tilde{n}_i = \left(\frac{\min_i \{e_{i1}\}}{e_{i4}}, \frac{\min_i \{e_{i1}\}}{e_{i3}}, \frac{\min_i \{e_{i1}\}}{e_{i2}}, \frac{\min_i \{e_{i1}\}}{e_{i1}}\right)$ if $i \in S, W, O, T$ is evaluated with respect to a cost criterion.
- *Step 7. Weighted normalized linguistic variable*: Obtain a weighted evaluation of electricity supply chain with respect to each SWOT factor *i* as $\tilde{n}_i^w = \tilde{n}_i * w_i$ by using Eq. (2).
- *Step 8. Distance to positive ideal normalized weighted linguistic variable*: Calculate the distance of $\tilde{n}_i^w$ to positive ideal normalized weighted linguistic variable $\tilde{n}_i^p = w_i \otimes (1, 1, 1, 1)$ as d_i^+ by using Eq. (5) for each $i \in S, W, O, T$.
- *Step 9. Distance to negative ideal normalized linguistic variable*: Calculate the distance of $\tilde{n}_i^w$ to negative ideal normalized linguistic variable $(0, 0, 0, 0)$ as d_i^- by using Eq. (5) for each $i \in S, W, O, T$.
- *Step 10. Closeness coefficient*: Calculate closeness coefficient $CC_i = \frac{d_i^-}{d_i^+ + d_i^-}$ for each $i \in S, W, O, T$.
- *Step 11. Strategy formulation*: Formulate a strategy plan including SWOT factors with top priorities to increase strengths, eliminate or minimize weaknesses, exploit opportunities and prepare for threats based on the results of *Step 4* and *Step 10*.

Table 1
An example of a set of linguistic variables (adapted from [86]).

Linguistic variable	Trapezoidal fuzzy number
Extremely poor (EP)	(0,0,1,2)
Very poor (VP)	(1,2,3,4)
Poor (P)	(2,3,4,5)
Medium poor (MP)	(3,4,5,6)
Fair (F)	(4,5,6,7)
Medium good (MG)	(5,6,7,8)
Good (G)	(6,7,8,9)
Very good (VG)	(7,8,9,10)
Extremely good (EG)	(8,9,10,10)

According to the proposed methodology, the SWOT factors should be determined for *Step 1*. The key factors assigned to *Strengths* and *Weaknesses* are overall long-term strategy, internal environment, horizontal structure, vertical structure, integration of processes, coordination of flows and collaboration, role distribution and advanced planning modules. The key factors assigned to *Opportunities* and *Threats* are external environment including economical, political, social, natural, technological environment and advanced planning modules.

Some basic features of AHP will be provided with respect to *AHP within each SWOT group* based on Winston [87]. Accordingly, the SWOT factors within a group are evaluated in pairwise comparison matrix, by using the AHP importance scale given in Table 2 with 2, 4, 6 and 8 as intermediate values. It should be noted that upper and lower triangles of a pairwise comparison matrix are reciprocal to each other. Then, each column of the pairwise comparison matrix is normalized by dividing each entry of the column by the sum of the entries in that column. The arithmetic average of the entries in each row of the normalized matrix gives the approximate relative importance weight for each SWOT factor within a SWOT group. The consistency of the results should also be checked and consistency index (CI) should not exceed 0.1 [87]. For details of AHP, the reader is referred to [87,88].

Kurttila et al. [16] proposed *AHP across SWOT groups* to involve one representative factor from each SWOT group with the highest relative importance score. In this paper, this approach will be followed.

3. The analysis of electricity supply chain in Turkey

The analysis of the electricity supply chain in Turkey will be based on some regulations and strategy reports issued by the Turkish government and an independent report by Deloitte [89]. If there is no regulation or report with respect to an element given in Sections 2.1 and 2.2, then that element is not included in the analysis. Overall value to all society has been defined as maximizing the security of electricity supply and use of national primary fuel sources, while providing cost-effective electricity with minimum adverse effect to the natural environment [90].

3.1. Developing the general structure of the electricity supply chain in Turkey

The general structure of the electricity supply chain in Turkey is given in Fig. 5, where key players and basic electricity flows are illustrated.

3.1.1. The overall long-term strategy of the electricity supply chain in Turkey

Overall value to all society can be interpreted as the overall long-term strategy of the electricity supply chain in Turkey.

3.1.2. Horizontal structure

The horizontal structure is short as illustrated in Fig. 5. The Energy Market Regulatory Authority is a department of the Republic of Turkey Ministry of Energy and Natural Resources and acts as an independent department responsible for the regulation of the electricity supply chain in Turkey [91]. The electricity distribution is partly two-tiered, since TETAS and other wholesale companies

Table 2
AHP importance scale [88].

AHP importance scale
1 – Equally important
3 – Moderately more important
5 – Strongly more important
7 – Very strongly more important
9 – Extremely more important

purchase electricity in a large amount to sell to corporate customers and to distribution companies through TEIAS, to supply and demand balancing market and to cross-border companies [92].

3.1.3. Vertical structure

The vertical structure of electricity generation tier is long with "one state-owned company, EÜAS, their subsidiaries, affiliates, partnerships, the companies having Build–Operate–Transfer (BOT), Build–Operate–Own (BOO) and Transfer of Operation Rights (TOOR) contracts, other private generation companies and autoproducers" [93]. The electricity transmission tier is represented by a single state-owned transmission company, TEIAS. The vertical structure of electricity distribution tier is relatively long with 12 affiliates of TEDAS in the process of privatization, eight privatized companies of TEDAS and one private company [93].

3.1.4. Integration of processes, coordination of flows and collaboration levels in a supply chain

No overall integration across the supply chain has been reported. Instead, the integration of information systems has been reported as a strategy [90,94]. Supply and demand balancing mechanism, so-called Balancing and Settlement system, can be interpreted as a measure for coordination of electricity flows in Turkey and will be discussed shortly in Section 3.2.4.

3.1.5. Role model for electricity supply chain in Turkey

The governmental body responsible for energy is the Republic of Turkey Ministry of Energy and Natural Resources. To the best of our knowledge, there is no independent service provider who is responsible for all tasks given in Fig. 3. However, Energy Market Regulatory Authority acts as an independent regulator of the electricity market for overall value to all society [91]. TEIAS is responsible for task-based supply chain design, for regulating operations such as regulating Balancing and Settlement market and load dispatching and frequency control [93,94]. All other players are primarily responsible for performing supply chain operations and providing data to TEIAS for task-based supply chain design.

3.2. Developing an advanced planning framework for electricity supply chain in Turkey

Some regulations are available in Turkey for the implementation of some advanced planning tasks in the electricity supply chain. In this section, the current status will be provided.

3.2.1. Integrated information system

Integration of information systems is one of the strategies of the Republic of Turkey Ministry of Energy and Natural Resources. As an example, an integrated information system for generation companies has been reported as a strategy [90]. The integration of TEIAS SCADA/Energy Management System (EMS) with the systems of generation and distribution companies has also been reported as a future project [94].

3.2.2. Load forecasting

According to Regulation for Load Forecasting [95], each regional electricity distribution company is responsible for annual regional load forecasting for a 10-year period by considering high load, low load and base case scenarios. Then, single reports accompanied with data set are sent to Energy Market Regulatory Authority for review with respect to some factors such as assumptions, mathematical model, validation of results, forecasting of parameters and updatability of the model [95]. If the whole review is successful, then load forecasting results are sent to TEIAS by the distribution companies for compilation. Although there is no optimization technique provided in this regulation, according to the report by Deloitte [89], Model for Analysis of Energy Demand (MAED) scenario-based simulation technique is used by the Republic of Turkey Ministry of Energy and Natural Resources.

3.2.3. Supply network planning

Although there is no regulation or report for supply network planning, some strategies from [96] can be adapted to the framework provided in Section 2.2.2.3. As the basic inputs from the supply side, the factors such as priority to national primary fuel sources and renewable energies, diversification of fuel sources, climatic and environmental constraints and wholesale activities of TETAS can be incorporated into the framework [96].

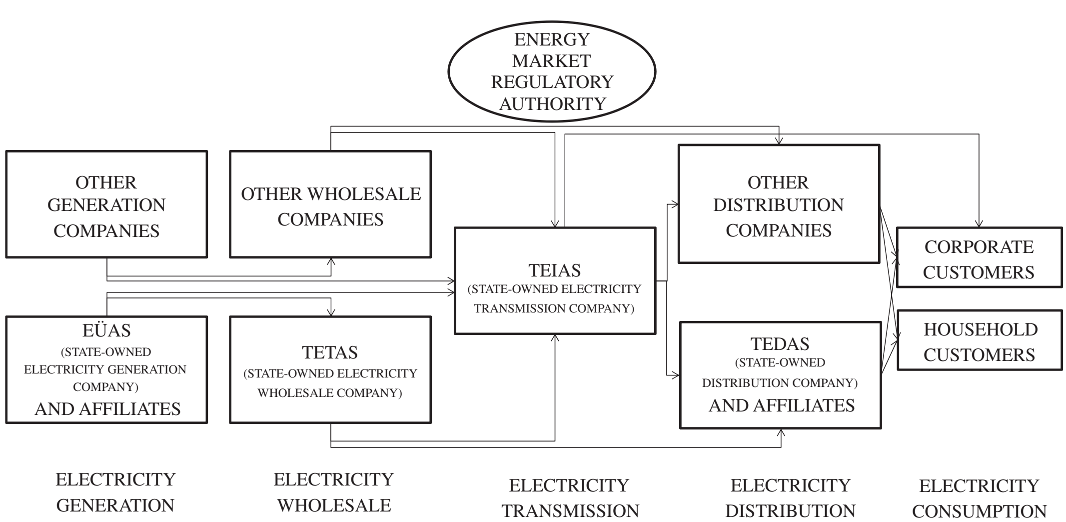

Fig. 5. The general structure of electricity supply chain in Turkey.

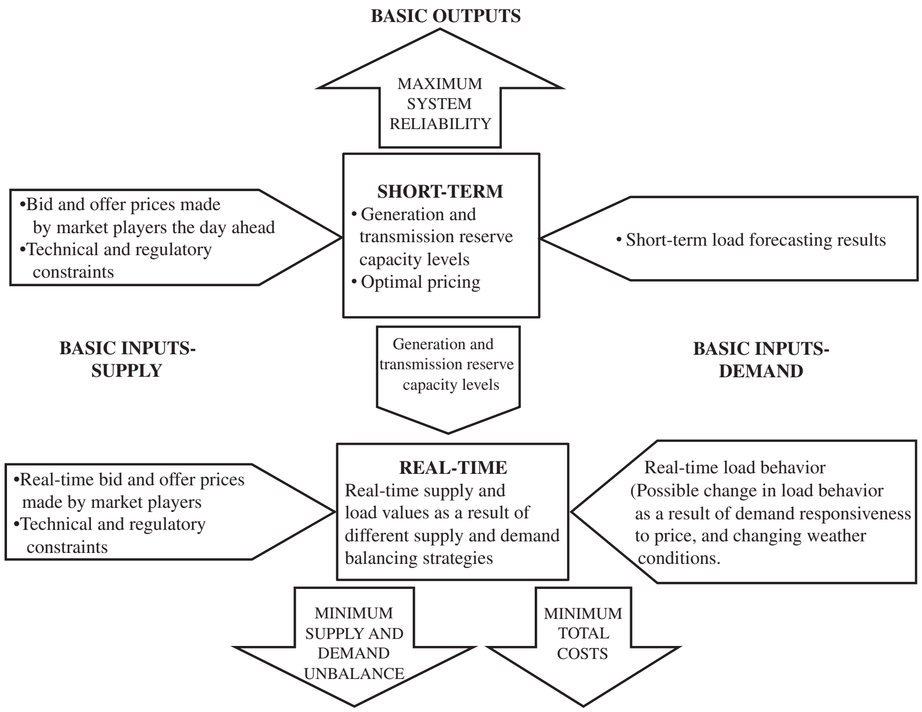

Fig. 6. Balancing and settlement system in Turkey (adapted from [97,98]).

Table 3
SWOT factors considered for the case of Turkey (some factors adapted from [89,90]).

Strengths
S1: Overall long-term strategy: Long-term commitment to security of electricity supply
S2: Internal environment: Commitment to technological adaptation
Weaknesses
W1: Internal environment: Possible cultural conflicts between state-owned and private companies
W2: Internal environment: Financial problems
W3: Advanced planning: Problems in data retrieval from information systems and deficiencies in data integration between systems
W4: Advanced planning: Lack of variety of load forecasting techniques and long information flows
W5: Advanced planning: Synchronization problems in investments
W6: Role distribution: Unclear definition of roles and responsibilities
Opportunities
O1: External environment: Abundance and diversity of national primary fuel sources
O2: External environment: Restructuring of energy markets and competitive market environment
O3: External environment: Growing demand
O4: External environment: Geo-strategic position of Turkey
Threats
T1: External environment: Density of residential areas and public resistance to investments
T2: External environment: Level of dependence on international primary fuel sources
T3: External environment: Inconsistencies in regional political environment

3.2.4. Supply and demand balancing

Supply and demand balancing is achieved by so-called "Balancing and Settlement System" in Turkey. Regulation of Balancing and Settlement System in Electricity Market [97] provided the regulatory details of the system, Camadan and Erten [93] and Erdogdu [98] reviewed and discussed the system. The basic system is illustrated in Fig. 6. Erdogdu [98] provided the mechanism of the system such that "Bid and offer prices are submitted for each settlement period (daytime, peak, night, twice a month). Until 14:30 every day, they are also required to present physical notifications covering the 24 h period between 00:00 and 24:00 h before the day physical notifications are made. Then bids and offers are evaluated by TEIAS. Bids and offers accepted by TEIAS are transformed into loading and deloading instructions and issued to the relevant players". For details of discussions of the system, the reader is referred to [93,98].

3.3. An integrated SWOT-fuzzy TOPSIS methodology combined with AHP for strategy formulation: The case of Turkey

The steps of the methodology given in Section 2.3.2 will be illustrated for the case of Turkey.

- *Step 1.* Identifying SWOT factors. Celiktas and Kocar [99] conducted a SWOT analysis to evaluate Turkish renewable energies by considering policy, market, technology and social dimensions. In Table 3, a set of SWOT factors are given for the electricity supply chain in Turkey.

Table 4
Final relative importance weights, closeness coefficients of SWOT factors and ranking orders.

SWOT factor	W_F	W_F ranking order	CC_i	CC_i ranking order
S1	0.4020	1	0.548260	3
S2	0.0804	4	0.548260	3
W1	0.0286	9	0.548260	3
W2	0.0429	7	0.451740	4
W3	0.0078	13	0.451740	4
W4	0.0061	14	0.548260	3
W5	0.0590	5	0.451740	4
W6	0.0132	11	0.548260	3
O1	0.0122	12	0.548260	3
O2	0.0241	10	0.828302	1
O3	0.0052	15	0.644356	2
O4	0.0468	6	0.828302	1
T1	0.1580	2	0.355644	5
T2	0.0840	3	0.355644	5
T3	0.0298	8	0.261204	6

Table A1
AHP within "Strengths" group.

	S1	S2	W_S
S1	1.00	5.00	0.8333
S2	0.20	1.00	0.1667
		CI	0.0000

- *Step 2.* AHP within each SWOT group. The objective is defined as "maximizing the security of electricity supply". The results of AHP within each SWOT group are provided in Tables A1–A4. As an example for Table A1, the following question is asked: "Which of the following is more important, S1 or S2, and how much with respect to maximizing the security of electricity supply?". The same question is also relevant for each pairwise comparison within other SWOT groups.
- *Step 3.* AHP across SWOT groups. The SWOT factors with the highest relative importance weights are selected from each SWOT group for AHP across SWOT groups and the results are given in Table A5.
- *Step 4.* Final relative importance weights of SWOT factors. The final relative importance weights of SWOT factors are given in the second column of Table 4. According to the results, "S1: Overall long-term strategy: Long-term commitment to security of electricity supply" has the highest relative importance weight with 0.4020, and "T1: External environment: Density of residential areas and public resistance to investments", "T2: External environment: Level of dependence on international primary fuel sources" and "S2: Commitment to technological adaptation" have the second, third and fourth highest weights with 0.1580, 0.0840 and 0.0804, respectively.
- *Step 5.* Evaluation vector. The evaluation vector is provided in Table A6. Each SWOT factor is evaluated by using the set of linguistic variables given in Table 1.
- *Steps 6–10.* Fuzzy TOPSIS methodology to prioritize the evaluated SWOT factors.As a result of Steps 6–10, closeness coefficients of SWOT factors are obtained and given in the fourth column of Table 4. The SWOT factor with a closeness coefficient of 1 represents an ideal SWOT factor. "O2: External environment: Restructuring of energy markets and competitive market environment" and "O4: External environment: Geo-strategic position of Turkey" have the highest closeness coefficient value of 0.828302.
- *Step 11.* Strategy formulation. The ranking orders of SWOT factors are given in the third and fifth column of Table 4 with respect to the relative importance weights and closeness coefficients of SWOT factors. The improvement potentials are available for SWOT factors with high relative importance weights, but relatively low closeness coefficient values. As an example, the SWOT factors with ranking order up to 9 with respect to the relative importance weights can be considered in strategy formulation. In case of a corresponding ranking order greater than or equal to 3 with

Table A2
AHP within "Weaknesses" group.

	W1	W2	W3	W4	W5	W6	W_W
W1	1.00	0.50	5.00	5.00	0.50	2.00	0.1815
W2	2.00	1.00	7.00	7.00	0.50	3.00	0.2726
W3	0.20	0.143	1.00	2.00	0.143	0.50	0.0492
W4	0.20	0.143	0.50	1.00	0.143	0.50	0.0386
W5	2.00	2.00	7.00	7.00	1.00	5.00	0.3744
W6	0.50	0.33	2.00	2.00	0.20	1.00	0.0836
						CI	0.0204

Table A3
AHP within "Opportunities" group.

	O1	O2	O3	O4	W_O
O1	1.00	0.50	3.00	0.20	0.1378
O2	2.00	1.00	5.00	0.50	0.2735
O3	0.33	0.20	1.00	0.143	0.0585
O4	5.00	2.00	7.00	1.00	0.5302
				CI	0.0186

Table A4
AHP within "Threats" group.

	T1	T2	T3	W_T
T1	1.00	2.00	5.00	0.5813
T2	0.50	1.00	3.00	0.3092
T3	0.20	0.33	1.00	0.1096
			CI	0.0032

Table A5
AHP across SWOT groups.

	S1	W5	O4	T1	W_G
S1	1.00	3.00	5.00	2.00	0.4824
W5	0.33	1.00	2.00	0.50	0.1575
O4	0.20	0.50	1.00	0.33	0.0883
T1	0.50	2.00	3.00	1.00	0.2718
				CI	0.0054

Table A6
Evaluation vector.

SWOT factor	$\tilde{E}$
S1	(4,5,6,7)
S2	(4,5,6,7)
W1	(4,5,6,7)
W2	(3,4,5,6)
W3	(3,4,5,6)
W4	(4,5,6,7)
W5	(3,4,5,6)
W6	(4,5,6,7)
O1	(4,5,6,7)
O2	(7,8,9,10)
O3	(5,6,7,8)
O4	(7,8,9,10)
T1	(2,3,4,5)
T2	(2,3,4,5)
T3	(1,2,3,4)

respect to closeness coefficient, the inclusion of that SWOT factor in strategy formulation is suggested.

Accordingly, some measures to augment strengths "S1: Overall long-term strategy: Long term commitment to security of electricity supply", "S2: Internal environment: Commitment to technological adaptation" and to eliminate or minimize weaknesses "W1: Internal environment: Possible cultural conflicts between state-owned and private companies", "W2: Internal environment: Financial problems", "W5: Advanced planning: Synchronization problems in investment" should be conducted. Moreover, some measures to be prepared for threats "T1: External environment: Density of residential areas and public resistance to investments", "T2: External environment: Level of dependence on international primary fuel sources" and "T3: External environment: Inconsistency in regional political environment" should be introduced.

4. Conclusions

An electricity supply chain is a significant supply chain with electricity as a perishable product. In this paper, an integrated framework is proposed to analyze an electricity supply chain. In this study, a holistic view to electricity supply chain is aimed to understand the interdependencies of processes. This is already the main motivation of SCM approach for any industry. However, in an electricity supply chain, since the product is a highly perishable product and cannot be easily stored in a large amount, the significance of synchronized processes will be more crucial. Thus, the investigation of the potentials of the concepts defined in SCM literature is significant for an electricity supply chain. In the proposed framework, although some dimensions of the general structure such as core processes and horizontal structure will not be case-specific, other dimensions will be case-specific and can help analyzers gain a structured view regarding the specific case. The adaptation of the advanced planning framework to electricity supply chain is contributory for showing the interdependencies of the planning tasks for different horizon and a need for coordination among these tasks. An integrated SWOT-fuzzy TOPSIS methodology combined with AHP provides structured and prioritized SWOT factors to identify strengths, weakness, opportunities and threats with their ranking orders. Based on the defined priority levels, an electricity supply chain strategy can be formulated. To illustrate the methodology, the integrated framework is applied to electricity supply chain in Turkey and the integrated SWOT-fuzzy TOPSIS methodology is illustrated with a sample set of SWOT factors. As a next research, a more detailed SWOT analysis can be recommended for the case of Turkey.

Appendix A

See Tables A1–A6.

References

[1] Burgess K, Singh PJ, Koroglu R. Supply chain management: a structured literature review and implications for future research. Int J Operat Prod Manage 2006;26:70729.
[2] Chopra S, Meindl P. Supply chain management: strategy, planning, and operation. 4th ed. Boston: Pearson; 2010.
[3] Giunipero LC, Hooker RE, Joseph-Matthews S, Yoon TE, Brudvig S. A decade of SCM literature: past, present and future implications. J Suppl Chain Manage 2008;44:66–86.
[4] Simchi-Levi D, Kaminsky P, Simchi-Levi E. Designing and managing the supply chain: concepts, strategies and case studies. 2nd ed. New York: Mc-Graw Hill Higher Education; 2003.
[5] Soni G, Kodali R. A critical analysis of supply chain management content in empirical research. Bus Process Manage J 2011;17:238–66.
[6] Bayod-Rújula AA. Future development of the electricity systems with distributed generation. Energy 2009;34:377–83.
[7] Bouffard F, Kirschen DS. Centralised and distributed electricity systems. Energy Policy 2008;36:4504–8.
[8] Forgionne G, Guo Z. Internal supply chain coordination in the electric utility industry. Eur J Oper Res 2009;196:619–27.
[9] Gutiérrez-Alcaraz G, Sheblé GB. Modeling energy market dynamics using discrete event system simulation. Energy 2009;34:1467–76.
[10] Odenberger M, Johnsson F. The role of CCS in the European electricity supply system. Energy Procedia 2009;1:4273–80.
[11] Peças Lopes JA, Hatziargyriou N, Mutale J, Djapic P, Jenkins N. Integrating distributed generation into electric power systems: a review of drivers, challenges and opportunities. Electr Power Syst Res 2007;77:1189–203.
[12] Slingerland S. Energy conservation and organization of electricity supply in the Netherlands. Energy Policy 1997;25:193–203.
[13] Zhijun X, Kuby M. Supply-side–demand-side optimization and cost-environment tradeoffs for China's coal and electricity system. Energy Policy 1997;25:313–26.
[14] Stadtler H, Kilger C, editors. Supply chain management and advanced planning: concepts, models, software, and case studies. Berlin Heidelberg: Springer-Verlag; 2008.
[15] Meyr H, Wagner M, Rohde J. Structure of advanced planning systems. In: Stadtler H, Kilger C, editors. Supply chain management and advanced planning: concepts models software and case studies. Berlin Heidelberg: Springer-Verlag; 2008. p. 109–15.
[16] Kurttila M, Pesonen M, Kangas J, Kajanus M. Utilizing the analytic hierarchy process (AHP) in SWOT analysis—a hybrid method and its application to a forest-certification case. Forest Policy Econ 2000;1:41–52.
[17] Shrestha RK, Alavalapati JRR, Kalmbacher RS. Exploring the potential for silvopasture adoption in south-central Florida: an application of SWOT–AHP method. Agric Syst 2004;81:185–99.
[18] Kajanus M, Kangas J, Kurttila M. The use of value focused thinking and the A'WOT hybrid method in tourism management. Tourism Manage 2004;25:499–506.
[19] Shinno H, Yoshioka H, Marpaung S, Hachiga S. Quantitative SWOT analysis on global competitiveness of machine tool industry. J Eng Des 2006;17:251–8.
[20] Yüksel İ, Dagdeviren M. Using the analytic network process (ANP) in a SWOT analysis—a case study for a textile firm. Inf Sci 2007;177:3364–82.
[21] Chang HH, Huang WC. Application of a quantification SWOT analytical method. Math Comput Model 2006;43:158–69.
[22] Lee KL, Lin SC. A fuzzy quantified SWOT procedure for environmental evaluation of an international distribution center. Inf Sci 2008;178:531–49.
[23] Gao CY, Peng DH. Consolidating SWOT analysis with nonhomogeneous uncertain preference information. Knowl-Based Syst 2011;24:796–808.
[24] Dwivedi P, Alavalapati JRR. Stakeholders' perceptions on forest biomass-based bioenergy development in the southern US. Energy Policy 2009;37:1999–2007.
[25] Celik M, Cebi S, Kahraman C, Er ID. Application of axiomatic design and TOPSIS methodologies under fuzzy environment for proposing competitive strategies on Turkish container ports in maritime transportation network. Expert Syst Appl 2009;36:4541–57.
[26] Baumgarten H. Terminologie der logistik: Terminologie der logistik und die hierarchische einordnung in das unternehmen. In: Baumgarten H, Wiendahl HP, Zentes J, editors. Logistik-management: strategien-konzepte-praxisbeispiele. Berlin: Springer-Verlag; 2002. p. 1–15.
[27] Bowersox DJ, Closs DJ, Cooper MB. Supply chain logistics management. 3rd ed. Boston: McGraw-Hill/Irwin; 2010.
[28] McCarthy RW, Ogden JM, Sperling D. Assessing reliability in energy supply systems. Energy Policy 2007;35:2151–62.
[29] Beggs C. Utility companies and energy supply. Energy Manage Conserv 2002;22–36.
[30] Supply Chain Council. Supply chain operations reference (SCOR) model. Overview-Version 10.0. <http://supply-chain.org/f/SCOR-Overview-Web.pdf>.
[31] Buijs P, Bekaert D, Cole S, Hertem DV, Belmans R. Transmission investment problems in Europe: going beyond standard solutions. Energy Policy 2011;39:1794–801.
[32] Gerlach LP. Public reaction to electricity transmission lines. Encycl Energy 2004:145–67.
[33] Lambert DM, Cooper MC, Pagh JD. Supply chain management: implementation issues and research opportunities. Int J Logist Manage 1998;9:1–19.
[34] Baumgarten H, Beyer I, Stommel H. Planungs- und steuerungsaufgaben in industriellen Versorgungsnetzwerken. In: Wolf-Kluthausen H, editor. Jahrbuch logistik. Korschenbroich: Free beratung GmbH; 2004. p. 64–70.
[35] Creti A, Fumagalli E, Fumagalli E. Integration of electricity markets in Europe: relevant issues for Italy. Energy Policy 2010;38:6966–76.
[36] Finon D, Romano E. Electricity market integration: redistribution effect versus resource reallocation. Energy Policy 2009;37:2977–85.
[37] Niesten E. Network investments and the integration of distributed generation: regulatory recommendations for the Dutch electricity industry. Energy Policy 2010;38:4355–62.
[38] Pineau PO. Electricity sector integration in West Africa. Energy Policy 2008;36:210–23.

[39] Federico G. Market integration and market efficiency: the case of 19th century Italy. Explor Econ Hist 2007;44:293–316.
[40] Spiller PT, Huang CJ. On the extent of the market: wholesale gasoline in the Northern United States. J Ind Econ 1986;35:131–45.
[41] Tennbakk B. Power trade and competition in Northern Europe. Energy Policy 2000;28:857–66.
[42] Kuhn A, Hellingrath B. Supply chain management: Optimierte zusammenarbeit in der wertschöpfungskette. Berlin et al.: Springer-Verlag; 2002. 2002.
[43] Cepeda M, Saguan M, Finon D, Pignon V. Generation adequacy and transmission interconnection in regional electricity markets. Energy Policy 2009;37:5612–22.
[44] He X, Delarue E, D'haeseleer W, Glachant JM. A novel business model for aggregating the values of electricity storage. Energy Policy 2011;39:1575–85.
[45] Rious V, Glachant JM, Perez Y, Dessante P. The diversity of design of TSOs. Energy Policy 2008;36:3323–32.
[46] Roques FA. Market design for generation adequacy: healing causes rather than symptoms. Utilities Policy 2008;16:171–83.
[47] Fleischmann B, Meyr H, Wagner M. Advanced planning. In: Stadtler H, Kilger C, editors. Supply chain management and advanced planning: concepts, models, software, and case studies. Berlin Heidelberg: Springer-Verlag; 2008. p. 81–106.
[48] Davenport TH. Putting the enterprise into the enterprise system. Harvard Bus Rev 1998;76:121–31.
[49] Weng Q. Remote sensing and GIS integration: theories, methods, and applications. United States of America: The McGraw-Hill Companies; 2010.
[50] Calkins HW, Tomlinson RF. Geographic information systems, methods and equipment for land use planning. Ottawa: International Geographical Union, Commission of Geographical Data Sensing and Processing and U.S. Geological Survey; 1977.
[51] Carrión JA, Estrella AE, Dols FA, Toro MZ, Rodríguez M, Ridao AR. Environmental decision-support systems for evaluating the carrying capacity of land areas: optimal site selection for grid-connected photovoltaic power plants. Renew Sustain Energy Rev 2008;12:2358–80.
[52] Heiple S, Sailor DJ. Using building energy simulation and geospatial modeling techniques to determine high resolution building sector energy consumption profiles. Energy Build 2008;40:1426–36.
[53] Prest R, Daniell T, Ostendorf B. Using GIS to evaluate the impact of exclusion zones on the connection cost of wave energy to the electricity grid. Energy Policy 2007;35:4516–28.
[54] Vajjhala SP, Fischbeck PS. Quantifying siting difficulty: a case study of US transmission line siting. Energy Policy 2007;35:650–71.
[55] Doll CNH, Pachauri S. Estimating rural populations without access to electricity in developing countries through night-time light satellite imagery. Energy Policy 2010;38:5661–70.
[56] Zvoleff A, Kocaman AS, Huh WT, Modi V. The impact of geography on energy infrastructure costs. Energy Policy 2009;37:4066–78.
[57] Mesev V. Integration of GIS and remote sensing. England: John Wiley & Sons, Ltd.; 2007.
[58] Costa AM, França PM, Filho CL. Two-level network design with intermediate facilities: an application to electrical distribution systems. Omega 2011;39:3–13.
[59] Lise W. Towards a higher share of distributed generation in Turkey. Energy Policy 2009;37:4320–8.
[60] Lu W, Bompard E, Napoli R, Jiang X. Heuristic procedures for transmission planning in competitive electricity markets. Electr Power Syst Res 2007;77:1337–48.
[61] Sadegheih A. Optimization of network planning by the novel hybrid algorithms of intelligent optimization techniques. Energy 2009;34:1539–51.
[62] Sadegheih A, Drake PR. System network planning expansion using mathematical programming, genetic algorithms and tabu search. Energy Convers Manage 2008;49:1557–66.
[63] Soontornrangson W, Evans DG, Fuller RJ, Stewart DF. Scenario planning for electricity supply. Energy Policy 2003;31:1647–59.
[64] Yang N, Wen F. A chance constrained programming approach to transmission system expansion planning. Electr Power Syst Res 2005;75:171–7.
[65] Azadeh A, Ghaderi SF, Sohrabkhani S. A simulated-based neural network algorithm for forecasting electrical energy consumption in Iran. Energy Policy 2008;36:2637–44.
[66] Dash PK, Liew AC, Rahman S, Dash S. Fuzzy and neuro-fuzzy computing models for electric load forecasting. Eng Appl Artif Intell 1995;8:423–33.
[67] Hamzaçebi C. Forecasting of Turkey's net electricity energy consumption on sectoral bases. Energy Policy 2007;35:2009–16.
[68] Hong WC. Application of chaotic ant swarm optimization in electric load forecasting. Energy Policy 2010;38:5830–9.
[69] Mamlook R, Badran O, Abdulhadi E. A fuzzy inference model for short-term load forecasting. Energy Policy 2009;37:1239–48.
[70] Mastorocostas PA, Theocharis JB, Kiartzis SJ, Bakirtzis AG. A hybrid fuzzy modeling method for short-term load forecasting. Math Comput Simul 2000;51:221–32.
[71] Murat YS, Ceylan H. Use of artificial neural networks for transport energy demand modeling. Energy Policy 2006;34:3165–72.
[72] Niu D, Wang Y, Wu DD. Power load forecasting using support vector machine and ant colony optimization. Expert Syst Appl 2010;37:2531–9.
[73] Ranaweera DK, Hubele NF, Karady GG. Fuzzy logic for short term load forecasting. Int J Electr Power Energy Syst 1996;18:215–22.
[74] Xiao Z, Ye SJ, Zhong B, Sun CX. BP neural network with rough set for short term load forecasting. Expert Syst Appl 2009;36:273–9.
[75] Yalcinoz T, Eminoglu U. Short term and medium term power distribution load forecasting by neural networks. Energy Convers Manage 2005;46:1393–405.
[76] Hahn H, Meyer-Nieberg S, Pickl S. Electric load forecasting methods: tools for decision making. Eur J Oper Res 2009;199:902–7.
[77] Rohde J, Wagner M. Master planning. In: Stadtler H, Kilger C, editors. Supply chain management and advanced planning: concepts, models, software, and case studies. Berlin Heidelberg: Springer-Verlag; 2008. p. 161–80.
[78] EC. Commission of the European Communities. Directive 2005/ 89/EC of the European Parliament and of the Council of 18 January 2006 concerning measures to safeguard security of electricity supply and infrastructure investment. Official Journal of the European Union, L 33, pp. 22–27.
[79] Batlle C, Rodilla P. A critical assessment of the different approaches aimed to secure electricity generation supply. Energy Policy 2010;38:7169–79.
[80] Müller G, Rammerstorfer M. A theoretical analysis of procurement auctions for tertiary control in Germany. Energy Policy 2008;36:2620–7.
[81] Frunt J, Kling WL, van den Bosch PPJ. Classification and quantification of reserve requirements for balancing. Electr Power Syst Res 2010;80:1528–34.
[82] Chou SY, Chang YH, Shen CY. A fuzzy simple additive weighting system under group decision-making for facility location selection with objective/subjective attributes. Eur J Oper Res 2008;189:132–45.
[83] Chen CT. Extensions of the TOPSIS for group decision-making under fuzzy environment. Fuzzy Sets Syst 2000;114:1–9.
[84] Mahdavi I, Mahdavi-Amiri N, Heidarzade A, Nourifar R. Designing a model of fuzzy TOPSIS in multiple criteria decision making. Appl Math Comput 2008;206:607–17.
[85] Lee KH. First course on fuzzy theory and applications. Berlin Heidelberg: Springer-Verlag; 2005.
[86] Li DF. Compromise ratio method for fuzzy multi-attribute group decision making. Appl Soft Comput 2007;7:807–17.
[87] Winston WL. Operations research applications and algorithms. 4th ed. Canada: Thomson Brooks/Cole; 2004.
[88] Saaty TL, Vargas LG. Models, methods, concepts & applications of the analytic hierarchy process. Norwell: Kluwer Academic Publishers; 2001.
[89] Deloitte. Turkish electricity market 2010–2011. Expectations and developments. <http://www.deloitte.com/assets/Dcom-Turkey/Local%20Assets/Documents/turkey-tr_er_ElektrikEPiyasasi2010_090710.pdf> [accessed 12.08.12, in Turkish].
[90] Republic of Turkey Ministery of Energy and Natural Resources 2009. Strategic plan 2010–2014. <http://www.enerji.gov.tr/tr/dokuman/ETKB_2010_2014_Stratejik_Plani_Taslak.pdf> [accessed 12.08.12, in Turkish].
[91] EMRA. About Energy Market Regulatory Authority. <http://www.epdk.gov.tr/index.php/epdk-hakkinda> [accessed 12.08.12, in Turkish].
[92] TETAS. Activities report. <http://www.tetas.gov.tr/Uploads/2010%20faaliyet%20raporu.pdf>[accessed 12.08.12, in Turkish].
[93] Camadan E, Erten IE. An evaluation of the transitional Turkish electricity balancing and settlement market: lessons for the future. Renew Sustain Energy Rev 2011;15:1325–34.
[94] TEIAS. Strategic plan 2011–2015. <http://www.teias.gov.tr/Dosyalar/TEIAS_Strtj_2011.pdf>. [accessed 12.08.12, in Turkish].
[95] Regulation for load forecasting 2006. <http://www.mevzuat.gov.tr/Metin.Aspx?MevzuatKod=7.5.10084&MevzuatIliski=0&sourceXmlSearch=elektrikenerjisitaleptahminleri> [accessed 12.08.12, in Turkish].
[96] State Planning Organization 2009. Strategy report for electricity market and security of electricity supply. <http://www.enerji.gov.tr/yayinlar_raporlar/Arz_Guvenligi_Strateji_Belgesi.pdf> [accessed 12.08.12, in Turkish].
[97] Regulation for balancing and settlement system in electricity market. <http://www.mevzuat.adalet.gov.tr/html/28315.html> [accessed 12.08.12, in Turkish].
[98] Erdogdu E. A paper on the unsettled question of Turkish electricity market: balancing and settlement system (Part I). Appl Energy 2010;87:251–8.
[99] Celiktas MS, Kocar G. A quadratic helix approach to evaluate the Turkish renewable energies. Energy Policy 2009;37:4959–65.