



Scenario analysis using Bayesian networks: A case study in energy sector

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ABSTRACT

This paper provides a general overview of creating scenarios for energy policies using Bayesian Network (BN) models. BN is a useful tool to analyze the complex structures, which allows observation of the current structure and basic consequences of any strategic change. This research will propose a decision model that will support the researchers in forecasting and scenario analysis fields. The proposed model will be implemented in a case study for Turkey. The choice of the case is based on complexities of a renewable energy resource rich country. Turkey is a heavy energy importer discussing new investments. Domestic resources could be evaluated under different scenarios aiming the sustainability. Achievements of this study will open a new vision for the decision makers in energy sector.

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1. Introduction

Complexity of the decision making in energy sector is caused not only by multiple factors and processes [1], but also by variety of stake holders in the decision. Energy sustainability, stability and variety are considered to be vital for the economic development. Since energy is an inevitable input for all industries, the sustainable supply of energy resources becomes a necessary part of the national economical strategies. Availability of energy resources at reasonable cost and utilizing without causing negative social effects are essential strategies [2].

The high importance of energy investments cause preparation of future plans to be based on scenarios by using the alternative variables influential in decision. As Hobbs [3] stated scenario-based decision making crosses many domains and multiple perspectives. It is observed in literature survey that, until very recently, statistical methods were used to create scenarios [4]. Fluctuations in factor values and uncertainties cause fuzzy and stochastic analysis [5–7]. Knowledge systems are recently used in energy investment scenarios [8–10]. Furthermore, Bayes Networks are used mostly in risk analysis and classification [11–13].

The objective of this paper is analyzing the unstable and complex structure of energy sector by running an expert survey to find out the dependencies among effective factors and creating scenarios based on their opinions. This will give an opportunity to create scenarios independent of politics by using Casual Maps (CM) for analyzing the opinion poll and Bayes Network (BN) to create scenarios. The case application will be done in Turkey, a fossil energy

importer country with unstable economic structure, where energy policies are deemed to be redesigned.

Sustainable development of Turkish energy sector needs a change in the present energy production and consumption patterns. Investment is to be done in diversified energy resources and environmental concern is to be included in energy strategies [14]. The only alternative resource is recommended to be natural gas which has been growing rapidly [15]. Unfortunately this alternative caused the increase in import dependency [14]. Whereas, Turkey has an appropriate geographical location and weather conditions for extensive usage of renewable energy sources including hydropower, biomass, geothermal, solar and wind energy [16]. However, despite the reactions, nuclear energy is considered as a solution by Turkish government [17]. The case study in this research is constructed to respond the question of interactions of different factors effecting the renewable energy and nuclear energy investments. Hence, this study will contribute to knowledge system studies as well as decision makers in energy sector.

In Sections 2 and 3 of this paper, Causal Maps (CM) and Bayesian Networks (BN) were explained and the choice of these tools is examined. In Section 4, CM and BN of Turkish energy sector was modelled and investment alternatives were examined under different economic and policy scenarios. Finally, concluding remarks and suggestions for further studies were given in the last section.

2. Causal maps

Predictions of future events have an important role in decision making process. In forecasting, the main assumption is that the future will be much like the past. This causes a detailed analysis and clarification of the past in order to make accurate predictions [18].

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The increasing uncertainty in the 21st century creates problems to capture the dynamic structure of events. Designing a graph, which represents causal relationships between events, is a way of arranging a circumstance for reasoning under uncertainty [19]. In the last few years, Causal Maps (CM) have been widely used to construct a framework and represent major factors, knowledge and conditions that influence decision making [20].

Causal Map (CM) is a visual representation of thinking about a subject. CMs are formed by nodes and arrows which imply believed causality. CM takes shape through interviews or through the analysis and coding of documents, so they represent the beliefs, values and expertise of decision makers relevant to the issue in hand [21].

CMs have three major parts: causal concept, causal connection and causal value. A causal concept represented by a node can be an attribute, issue, factor or variable. Causal connection is presented by an arrow and shows the direction of the connection. It depicts a cause–effect relation between two concepts. The concept at the tail of an arrow is taken to cause the concept at the head of the arrow. A causal connection can be either positive or negative. Positive causal connection implies the positive correlation between two variables connected by the arrow, when the variable at the tail of the arrow increases the variable at the head of the arrow increases. In the same way, the negative causal connection refers to negative correlation. Causal value is the strength of the causal connection. There are many different techniques used for determining the causal value. The technique used for finding the causal values of a certain CM is specified by the aim of the analysis [22]. CMs can provide us to look at the problem more extensively than other decision tools which consider causal relations, such as regression. CM has been widely used in international relations, administrative science, political science, sociology, policy analysis, organizational behaviour and management science [20,21,23,24].

3. Bayesian networks

CMs are more illustrative than other analysis tools as regression and structural equation. Hence, they can supply missing information and details and bring the priorities and key factors into focus [21,23]. However there are some reasons to draw inferences inefficiently with causal maps. First reason is the inadequacy of modelling uncertainty. All variables have the same level of certainty in CMs. Problems with uncertain variables may have incomplete information or vaguely defined variables which are experienced to make inference. Second reason is the static representation of a problem. CMs cannot clarify the influence of changes on decision variables. There is a variety of methods used to make inferences from cognitive maps in literature; matrix algebra and network analytic methods, system dynamics, neural networks and BNs [20] are just some of them. These methods are valuable when the necessary data is available historically and the statistics can be run. Miao et al. [25,26], and Salmeron [27] have used a new approach of fuzzy cognitive map in order to model complicated and heterogeneous problems. They used fuzzy numbers to refer weights and concepts in cognitive map. The drawback of fuzzy cognitive map is being static in modelling the problem. Main advantage of BN is having a dynamic approach that is unavoidable to analyze the complex and unstable systems [21].

Bayesian networks are directed acyclic graph (DAG) which means there are no cycles. If there is a link between A and B ($A \rightarrow B$), we say that B is a child of A and A is a parent of B . In Bayesian networks, a link from node A to node B does not always imply causality. It implies a direct influence of A over B and the probability of B is conditioned on the value of A [2]. DAG represents the construction of causal dependence between nodes and gives the

qualitative reasoning in BN. Conditional Probabilistic Table (CPT) constitutes the quantitative part of BN with conditional probabilities of nodes. BN relies on the chain rule which is about the joint probability distribution of each variable. According to the chain rule, the marginal and conditional probabilities can be computed for each node of the network. Suppose that we have variables X_1, \dots, X_d , the joint probability of X_i is then:

$$P(X_1, \dots, X_d) = \prod_{i=1}^d P(X_i | \text{parents}(X_i)).$$

When evidence received from external sources about possible states of a variable or a set of variables, the marginal and conditional probabilities of the variables can be computed by marginalizing over the joint. If some evidence is given over some variables, the probability of incident of some events is calculated as following:

$$P(U|e) = \frac{P(U, e)}{P(e)},$$

where U is the universe of variables X_1, \dots, X_d [21].

BN has several advantages for making inferences. First, it is an effective method for data with missing values. Second, it enables us to look at the problem in a wide frame by presenting causal relations. Third, it combines the probabilistic and causal semantics so has an advantage to integrate the human knowledge and data. BN is a useful tool for modelling the uncertainty [22].

Recent studies have used CMs to provide qualitative interpretation of various decision problems. Qualitative techniques used to analyze CMs are useful in simple maps with few variables. When the map has a lot of variables and it is complex to analyze, there is a need to use a quantitative method to make inferences from CM. Bayesian Network (BN) is an artificial intelligence method which uses CM to make inferences for decision making [22].

BN helps to understand the problem structure graphical representation as well as breaking down the problem of representing the joint distribution of many variables into groups [28]. BNs can be used for several different purposes [29], including classification [30] clustering, forecasting [31,32], abductive reasoning (finding the diagnostic inference) and decision making. This paper focuses on decision making problem in energy sector. The literature covers various studies that use BN as a decision support tool in different areas. Trucco et al. [33] developed a BN modelling to analyze the risk factors in maritime transportation. Gupta and Kim [34] proposed an integrated model which combines BN and structural equation modelling to decision making in customer management. Aktas et al. [35] used BN to develop a decision support system for healthcare management. Ulengin et al. [36] proposed a decision support model based on BN for transportation policy decisions. Lauria and Duchessi [37] created a BN based decision support system to what-if analysis about information technology implementations. Şahin et al. [24] used BN to analyze the structure of inflation in Turkey. Fenton and Neil [38] developed a hybrid approach which consists of BN and analytic hierarchical process with application to a safety assessment that was being used by a major transportation organization. Nadkarni and Shenoy [22] described the BN as a tool for making inferences from causal maps and constructed a BN for a product development decision. The results of BNs are visual, illustrative and easy to interpret for decision makers.

4. Case: Turkey

4.1. Energy policies in Turkey

Energy generation, stability and efficiency are vital problems for developing countries. Extensive usage of fossil fuel by industries has caused considerable environmental problems. These problems which affect human health and welfare unfavourably can be

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