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LEAN ENERGY EFFICIENCY: SCENARIO ANALYSIS OF A REFRIGERATOR PLANT APPLICATION

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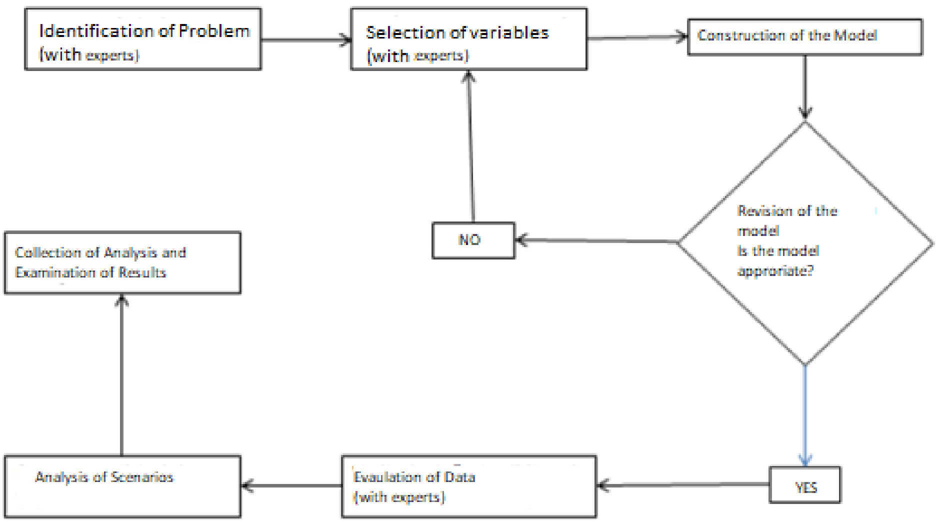
Highlights

- This study aimed to reveal the emerging techniques for energy efficiency management and to promote the implementation of value stream mapping (VSM) to increase the efficiency of flexible operations.
- The relevance of energy consumption in a production process was demonstrated by applying a specific value stream map to appliance manufacturing.
- The main objectives of this study were to determine the energy bottlenecks for a sample refrigerator production plant and construct strategies to eliminate them, as support for future decisions to be taken by the management.

Graphical Abstract (Optional)



Flowchart of the proposed method.

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ABSTRACT: Energy concern is increasing in the manufacturing companies implementing the most recent technologies. Energy is a major input for many industries and therefore, within the definition of Industry 4.0 new energy efficiency strategies are defined. Energy flexible processes and waste-to-energy are well-known strategies since they are easily implemented in any manufacturing site. Reduction in energy consumption is also facilitated by the preventive maintenance and renewal of the technologies using energy resources. This study aims to apply a lean production method Value Stream Maps (VSM) on energy consumption levels of the processes to evaluate the decision of technology and/or process change. Processes which use energy excessively when compared with the industry average, will be considered as a bottleneck. Using the value stream maps for energy use is accepted as "Lean Energy Efficiency". Parameters determined by the preparation of these maps will be enriched by interdependencies determined using the Bayesian Belief Network, which will support finding the priorities among the new efficiency activities. This technique will facilitate the decision of repair or buy through priority scenarios showing the possibility of a decision in each scenario. The combination of the Lean Energy Efficiency Method and the Bayesian Belief Network Method will assist the decision-makers in developing more informed and knowledge-based strategies. The case study is realized in a refrigerator factory handling the energy consumption of different departments. Consequently, these findings could be used as a roadmap for the technology renewal investment decisions made by the firm.

Keywords: *Bayesian network, Lean energy efficiency, Value stream mapping*

1. INTRODUCTION

Energy demand and consumption are rapidly increasing together with technological developments. Industries are surveying energy consumption and seeking the safest manner of supplying energy. Energy is the basic input for many profitable manufacturing sites. Consequently, because of the desire to reduce production costs and to receive green certification, the number of lean energy efficiency applications is increasing. The two terms "energy efficiency" (EE) and "lean manufacturing" are combined in the new term "lean energy efficiency" (LEE), defined as energy used in the most efficient way to reduce energy consumption per unit product [1].

Energy consumption in the EU-28 according to the sector is listed as transport 33.9%, industry 25,3 %, residential 24.7%, commercial and public services 14.53%, agriculture, forestry and fishing 2.43%, and others 0.3% in 2018. Hence, industrial sectors with heavy energy use in manufacturing need to apply energy-saving policies [2]. Most governments are implementing energy efficiency policies to fight against climate change, to balance payments and improve the competitive edge.

To create momentum for the decrease in energy consumption by the manufacturing sites, the Environmental Protection Agency (EPA) has introduced a series of energy efficiency guidelines. These industry-specific guides, currently available for 14 manufacturing industries, report that the top five metal products and machinery industries are responsible for 92% of industrial pollutants. Since refrigerator

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production belongs to both the metal and machinery sectors, it is listed among the promoted industries [3]. Since machine parts have erosion and corrosion, both the energy consumption and the waste increase. The production losses caused by old machine parts can be removed by using lean production tools [4]. Hence, the implementation of lean energy efficiency can avoid the increase in energy consumption.

The Turkish government follows the global approaches and supports efficiency strategies for industrial energy consumption [5]. One of the objectives is to take preventive action and promote the usage of clean energy resources. Other objectives of the program include ensuring the rational use of energy resources, promoting the diversification of energy resources, and introducing the usage of electricity and hydrogen in transportation. Moreover, it involves a credit system designed for use in financing resource efficiency and energy investments for potential investors such as industrial organizations, commercial entrepreneurs, or residence owners. The fact that the manufacturing sector has been at the top of the energy-consumption lists [6], clearly demonstrates the importance of energy projects in manufacturing. It is also well known in this sector that energy has always constituted an important percentage of operational costs. The manufacturing companies therefore look for the direct and indirect benefits created by EE.

Lean production is implemented by completing operations in the shortest time and by reducing waste, thereby increasing efficiency and quality, reducing costs, and providing flexible operations for companies. Energy is one of the most important resources in the production process; hence, companies need the concept of lean energy efficiency. Lean energy efficiency (LEE) is a lead for lean production. Here, the main target is to reduce the energy consumed per unit of product. In the production process, there are clear links between energy use and waste, such as the use of electricity to heat, cool, and light underutilized inventory spaces [7].

When the literature on lean energy is examined [8-13], no study focusing on the lean energy efficiency scenario has been encountered, especially in refrigerator manufacturing. The most recent study that can be mentioned on the subject is Verma et al. (2021) [14]. Verma et al. (2021) emphasized that sustainable value stream mapping (VSM) is an evolving research theme. In order to organize how sustainable VSM can be applied to lean energy, it aimed to reduce non-value-added processes in energy consumption with the Lean-Energy-Six Sigma Value Stream Mapping model.

This study aims to reveal the emerging techniques for energy efficiency management and to promote the implementation of value stream mapping (VSM) to increase the efficiency of flexible operations. The relevance of energy consumption in a production process is demonstrated by applying a specific value stream map to appliance manufacturing. The main objectives of this study are to determine the energy bottlenecks for a sample refrigerator production plant and construct strategies to eliminate them, as support for future decisions to be taken by the management. Energy shortages in refrigerator production facilities may be caused by factors such as inefficient use of resources or insufficient availability. In such facilities, power outages can result from inefficient operation of equipment or from the use of energy-inefficient equipment. For example, old or technologically outdated production equipment may consume more energy. Inadequate maintenance and inadequate working conditions can also prevent the efficient use of energy resources. Additionally, HVAC (Heating, Ventilation, and Air Conditioning) systems are major energy consumers in refrigerator manufacturing plants. Power outages can occur due to incorrect sizing of HVAC systems, the use of low-efficiency equipment, or ineffective control of systems. Unnecessary energy consumption based on heating or cooling needs can lead to wastage of energy resources. In addition, energy shortages can result from ineffective energy management practices or inadequate implementation of energy-saving measures in operational processes. For example, unnecessary energy consumption during working hours or not implementing energy-saving methods can contribute to power cuts. Addressing these energy deficiencies includes developing energy efficiency scenarios, monitoring and analysing energy consumption, using energy-efficient equipment, adopting low-energy lighting systems, using effective HVAC systems and implementing energy-saving measures in operational processes.

The Bayesian Belief Network method is applied to determine the interrelation among the criteria that will be handed as a result of the Lean Energy Efficiency application so that the decision of investment or maintenance could be given by applying the probabilities. Alternative scenarios are created by implementing the Bayesian Belief Network in Netica software, where applying the LEE possibilities according to the probabilities achieved, will change the decision of investment. Bayesian Belief network created according to the preferences of the decision-makers will eliminate the uncertainties caused by subjectivity. This method will assist decision-makers by showing the causal relationship among the LEE parameters and estimating the probabilities of investment accordingly.

In the next section of the study, more information is given on LEE. In the third section, VSM and Bayesian network methods are explained. The fourth section is reserved for the implementation of the methods and discussion of the results followed by a scenario analysis. In the last section, concluding remarks and recommendations are given.

2. MATERIAL AND METHODS

2.1. Lean Approach and Lean Energy Efficiency (LEE)

The lean manufacturing concept is generally associated with Toyota, a Japanese automotive company. In the 1950s, Taiichi Ohno designed a new system based on eliminating unnecessary activities, eliminating waste, and improving efficiency [15]. The lean manufacturing concept was first written up and published in 1990 by Womack et al. [16]. Statistical data published in North America in 2006 showed that Toyota had reached the top of the list of automotive manufacturers, demonstrating the company's significant progress in lean manufacturing. The manufacturing establishments will intensely focus on both service and lean manufacturing at the same time [17]. Lean manufacturing is defined in various ways, including: "An important concept that increases productivity and quality, reduces costs, and provides flexible operation for firms" [18], "a concept that ensures the continuous increase of the system efficiency and aims to eliminate waste " [19], "the production of the item requested by the customer at the most affordable price, in the shortest time, and by reducing waste" [20], "an important parameter that provides a competitive advantage over other organizations" [21], and "production of the item requested by the customer using all elements most properly, with the fewest resources, with the least error, without waste, and by eliminating all functions that do not add value in production"[22]. Thus, lean manufacturing is a concept related to all the parameters in the production system and supply chain management. In the business model of a circular economy, the suppliers employ a technician to superintend the repair operations of improper goods to make them reusable with the help of lean tools [4]. The main values of lean manufacturing are 'must' parameters. These can be summarized as flexibility, elimination of faults, optimization, process control, and effective usage of the workforce [23].

In lean manufacturing, there are five main principles involving the processes between customer demand and the delivery of the product [24] (Fig. 1). The first is 'Value' as identified by the end customer. The demand of the customer is a requisite. The value is produced according to customer demand. The second, the 'Value Stream' principle, is defined as the operations necessary to produce the items. The third one is the 'Flow', the formation of the production for the needed quantity in the required time. 'Pull' is the production of items just at the time the customer needs them. The last principle, 'Perfection', seeks the perfect product. One of the goals is to minimize the amount in stock because, in lean manufacturing, these items are seen as waste (Fig. 1).

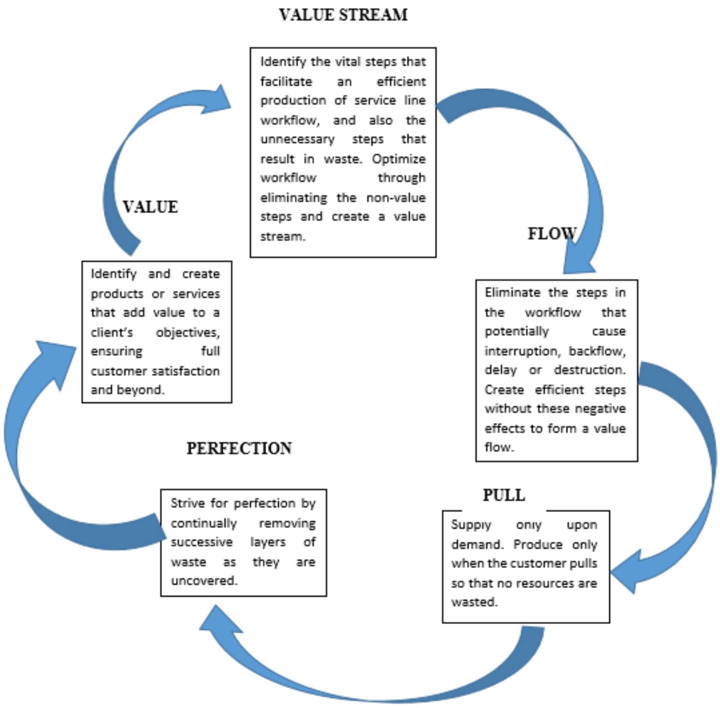

Figure 1. Basic principles of lean manufacturing [25]

Applying lean manufacturing concepts to energy efficiency created the lean energy (LE) concept [26]. The basic goal is to reduce the energy consumption per unit produced by identifying the maximum energy-consuming points and energy bottlenecks and finding the optimal solution by using energy efficiency methods.

In a worldwide survey, studies performed to improve energy efficiency have included methods such as applying various motor driver speeds, reusing scrap heat, using higher-efficiency electric motors, and reducing pressure to reduce losses from compressor leaks [27]. Examples of the benefits of these approaches can be found in [28].

In 2011, the Turkish government introduced a regulation to raise energy efficiency. This regulation, prepared under the leadership of the Ministry of Energy and Natural Resources, serves as an example for boosting EE in the industrial sector [29]. The projects to promote EE carried out by industries have mainly involved steam, boilers, and thermal operations [30], a detailed literature review was performed for this study. The basic relation between lean energy and manufacturing is EE [31]. Kiss proposed the Kaizen principles as an ideal tool for preventing energy losses [32]. In a study on work standardization, Deming's PDCA circle, and 5S were introduced as important tools for saving energy. Gogula et al. simultaneously applied the pull system, cellular manufacturing, poka-yoke, work standardization, visual control, and workload balancing methods to reduce the energy bills in a valve regulator production facility [33]. In the study performed by Rivas Duarte et al., the interrelations of energy consumption and manufacturing operations were successfully demonstrated by employing methods depending on lean manufacturing principles [34]. The main objective of LE can be defined as reducing the energy bills of production by controlling the energy stream to prevent unnecessary energy consumption in the production processes. Value stream maps (VSMs) are used to improve the search for energy efficiency at various types of production plants. In their 2008 study, Fraizer et al. determined that VSMs could be used to determine the energy consumption characteristics of production processes [35]. In another study, an easy and quick technique was proposed to analyze the flow of material and energy [36].

2.2. Value Stream Mapping

Value stream mapping (VSM) is a dynamic and customer-focused method that plays an important role in eliminating production system waste. The flow of information is shown by using certain symbols to produce the desired product and service. All the necessary and unnecessary activities are visualized during the processes. The concept of VSM is one of the indispensable parameters of production.

The process of VSM consists mainly of four steps: gathering the data, presenting the status map, applying VSM tools, and preparing the future status map [37]. In the first step of VSM, answers are sought to questions in terms of customer demands, information flow, and material flow. After gathering the required information, the present status map can be prepared. At this step, the customer demands, the process flow, the information flow, and the material flow are mapped respectively. By using tools like process mapping, pairing, and a value-added time profile, the end status is then formed, and the VSM is carried out. The VSM is analyzed in detail, and the bottlenecks and improvement potentials are determined. The prescribed future status map is prepared together with the improvement potentials. The result of the study by Dağ and Kara (2020) shows that the VSM application can be considered an important starting point in terms of simplifying the operation of the enterprise [38].

To use VSM for EE projects (E-VSM), some studies must be carried out within the firm. These include a lean analysis, an energy survey for E-VSM, and scenario studies for a Bayesian network. The E-VSM is a graphical method that shows energy consumption and indicates the potential energy-saving points in each process of the production line [26].

In one study, Shadid et al. combined total productive maintenance, process mapping, and VSM for use in EE projects [39]. The value-adding and non-adding operations are defined after the application of the process map. These outcomes are useful for reducing energy consumption. In another study, Rivas introduced a practical process mapping methodology that combined energy management with VSM [34]. The methodology, based on lean manufacturing principles, was applied to industrial use cases and was shown to successfully illustrate the relationship between energy usage and production activities for a particular value stream.

The present study presents an E-VSM perspective combined with Bayesian networks that enables bottlenecks to be depicted and potential results to be analyzed in future scenarios.

2.3. Bayesian Networks

In this study, future-study scenarios were implemented using Bayesian networks (BNs). Around the 1960s, statisticians realized that graphical models were the best and easiest way to analyze statistical conditions involving uncertainties and probabilities [40]. In recent years, artificial intelligence and expert probability systems have been used, especially to solve the problems of various industries in an integrated structure. Nowadays, BNs are frequently used for surveys on data mining and for artificial intelligence-oriented solutions.

Some features of BNs are found to be very useful for solving problems involving the analysis and management of real data. Deterministic modeling is very effective when there is not enough data or the control mechanisms are insufficient [41]. When the amount of data is insufficient for sampling, the BN technique for estimation when used together with analytical decision-making tools can be helpful for decision-makers [42]. The interdependent associations between variables are found presuming they have conditional probability distribution employing the cause and result effects of existing variables in the parameter learning of the Bayesian belief network [43].

A Bayesian probability approach provides the chance for inference where there is no past data, or when the data contain uncertainties. If event A has occurred and there is no uncertainty, then P(A) = 1. However, if event A is in the future and involves uncertainty, expert advice is necessary to determine the probability of the occurrence of A. In light of this expert advice, some assumptions can be made, as seen in the form of Equation (1).

$$A = \{a1, a2, a3,....,an\} \tag{1}$$

Here, a1 and a2 represent the variables of event A. When all the variables are evaluated in a common denominator, the result is $\sum p(a_i)$ = 1. This implies that the probability of event A is related to the probability of the occurrence of its variables. In general, the expression P(A|B) means that with the probability of occurrence of event A, event B has already happened. The expression P(A|B,K) is derived at the point where the basic logic of the Bayesian approach and networks are taken into account. This means that K represents all of the variables of A [44]. The mathematical expression of the Bayesian rule is seen in Equation (2) below.

$$P(A|B) = \frac{P(A,B)}{P(B)} \quad (2)$$

P(A): Probability of occurrence of event A
P(B): Probability of occurrence of event B
P(A|B): Event B has already happened and the probability of occurrence of event A.

In Equation (2), two different events can be represented as A and B, with P representing the probability.

The Bayesian Belief Network (BBN) facilitates understanding the causal relations among the parameters or activities by using a graphical representation [45]. The literature covers several studies that apply BBNs as decision-support tools in different areas. One detailed evaluation showed the use of BBNs in the industry for risk and reliability analyses, health and mechanical diagnoses, and financial risk management [46]. One of these studies was performed by Neil et al. [47] and involved the modelling of real decision-making problems and situations including uncertainties. All the potential results and the analyses of interactions between all variables were revealed to the experts and decision-makers. Aktaş et al. used a BBN in a proposed decision-support system in the healthcare field [48]. Gupta and Kim developed an integrated model combining BBNs and structural equation modelling for decision-making in customer management [49]. Dereli used a BBN to evaluate the risks from factors that negatively affected the efficiency of a supply chain [50]. Çınar and Kayakutlu proposed an overview of building scenarios for energy policies using BBN models [51]. In the study of Jones et al., a BBN model was applied to a maintenance and inspection department. That study aimed to construct a BBN model whereby various parameters were responsible for the failure rate of the system. One study was able to apply BBNs to a delay-time analysis. The BBN modelling allowed certain influencing events that affected the parameters to be used in determining the failure rate of a system under consideration [52]. As demonstrated by these studies, the outcomes of BBNs are graphical, descriptive, and easy to understand for decision-makers [26].

A BBN has been used in this study to facilitate the technology investment decisions during the implementation of the energy efficiency strategies. By using this method the investment decision will be tested by different priorities of energy efficiency activities. Since the achievement will allow observing the activity priorities with the smallest probability of investment based on the beliefs of a group of decision-makers, economic benefits will be protected during energy efficiency investments.

2.4. Proposed Model and Application

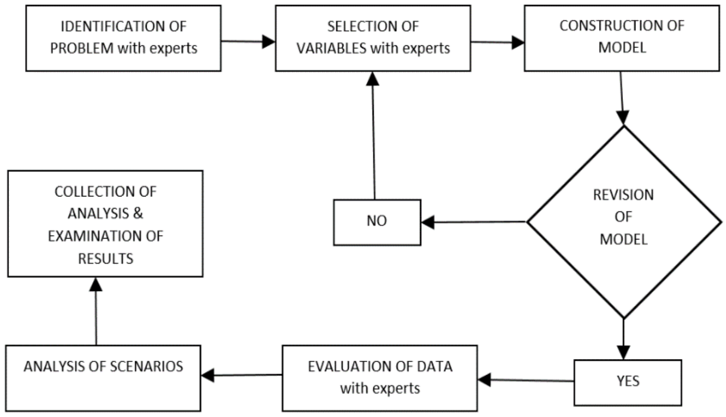

Figure 2. Bayesian network process used in the study

First, to evaluate the current energy situation, meetings were conducted with experts who defined energy efficiency conditions in the factory by taking energy, production, manufacturing, and maintenance dynamics into account. Because of the many fields that had been included, the results were more realistic. Next, the energy consumption of the factory was analyzed. This enabled the processes that were consuming more energy to be identified. This information was combined using E-VSM. Moreover, the combined information enabled the bottlenecks of the factory to be determined from an energy point of view. After the resources of the factory had been evaluated and the bottlenecks determined, alternative solutions for the bottlenecks were set.

In order to understand the relations between these three stages of the process, a relation matrix was formed and evaluated by the experts. After forming the model, a three-step survey was administered to the experts to determine the probability values. The first step was to evaluate factory resources in terms of probability values, the second was to evaluate factory resources and alternative solutions at the same time, and the last step was to evaluate alternative solutions and bottlenecks at the same time. After collecting all probability values, using NETICA software, these values were applied to a BN. This software enabled the determination of the probability values of the bottlenecks within the context of acquiring the solution. After receiving the results for the current energy status of the factory, scenarios were developed to determine the future status.

A flowchart showing the Bayesian network used in the study is presented in Figure 2. Re-evaluations may be required in some parts of this generation process. At this point, a cyclic structure can be seen, and the same operations can be repeated. When constructing the optimal model, the process is turned back and the same operations are executed again [53].

3. RESULTS AND DISCUSSION

3.1. Energy Value Stream Mapping

VSM is implemented for the manufacturing processes in a refrigerator production plant. The manufacturing process in the plant consists of three steps: preproduction, assembly, and packaging. A sketch of the process is shown in Figure 3.

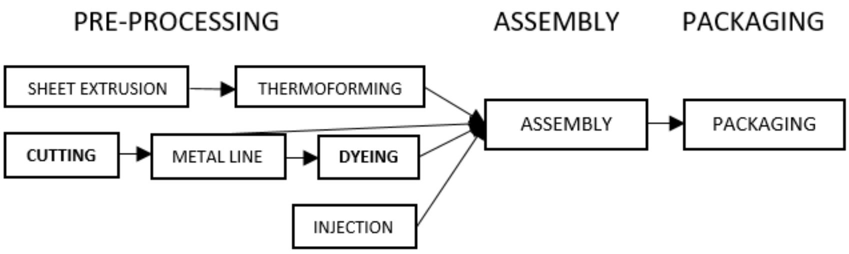

Figure 3. Plant manufacturing process

VSM for the manufacturing processes already existed in the plant. We used the existing maps to structure energy value maps (E-VSM) on the three groups of processes. In this way, energy bottlenecks are specified. The map given in Figure 4 shows a section of the energy value stream map of the current processes of the plant. The main processes and the job allocations to the departments can be seen on this map. In Figure 5 E-VSM of the factory is shown. On this map, the high-energy-consuming areas are coloured with red and the lower-energy-consuming areas are coloured with light red or orange. The 'High' and 'Medium' notes at the bottom of the map represent the general evaluation of energy consumption in the related departments. These measures are determined by comparing the plant values with the local industry average. High means higher than the industry average, Medium means very close or similar to the industry average and Low means lower than the industry averages. Obviously, points determined as 'High' are the potential energy bottlenecks in the factory's basic focus.

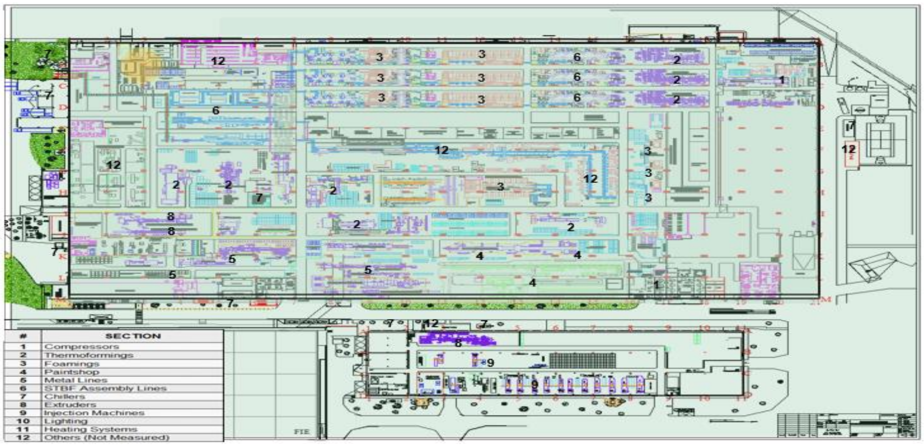

Figure 4. Section of plant value stream map

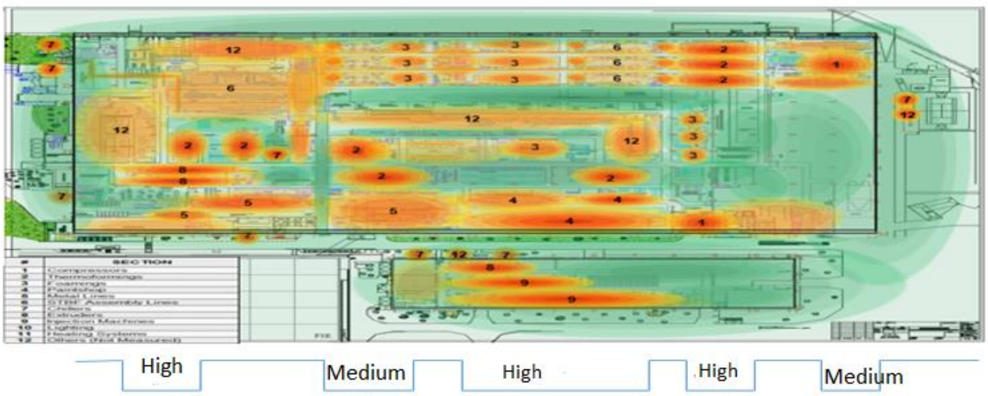

Figure 5. Plant energy value stream map

Considering the expert recommendations and the annual energy consumption, the energy bottlenecks of the factory were identified as the Machine Injection, Thermoforming, and Painting Departments.

3.2. Establishing the Bayesian Network Model

Bayesian Belief Network will be used to model future activities to dissolve the bottlenecks defined by using the VSM. However, the investment or activity decisions are very much affected by the resources of the plant and BBN will be defined according to those resources based on the preferences of the decision makers of the Plant. The resource variables obtained via expert recommendations and the literature survey are listed in Table 1. The alternatives for dissolving the bottlenecks are also presented in the same table as solution alternatives.

Table 1. Resource variables and alternative solutions for the firm

RESOURCE VARIABLES	Definition
Budget	Budget is one of the most important parameters as a resource variable. In many cases, it directly affects the decision to be made. It allows the company to evaluate whether an investment should be made or not.
Total Production	If more products are produced, more energy is consumed, and thus, annual period planning affects consumption.
Equipment	The industry needs a great deal of equipment to produce the requested products. The number of equipment items varies depending on the planning. Therefore, the amount of equipment has been chosen as a resource variable.
Quality	Quality is not considered directly as a resource, yet, it is one of the most important resource variables. In particular, the case plant has quality as the top priority of a German branch. The quality standards are above the industry limits That is why quality is chosen as the fourth source variable.
Market Share	The position of the company in the market affects many operations. Changes in the market share affect energy consumption at the factory.
Number of employees	The number of employees in the enterprise is an important resource for the company. Many employees are needed to continue production in the best possible way.
SOLUTION ALTERNATIVES	**Definition**
Investment in New Energy-Efficient Machinery	To solve the consumption problem, the purchase of new energy-efficient machinery is proposed, which will certainly reduce energy consumption by using the most recent technology, thereby reducing consumption in the related bottlenecks.
Change to Energy-Efficient Processes	An energy-efficient process is proposed to replace the current on-going process. Here the focus is on process modification to realize the predicted reduced consumption.
Energy-Efficient Automation / Usage of Robots	Plans are made to purchase energy-efficient automation/robot systems to be used during production in the factory. In this way, it is predicted that consumption will be reduced.
Energy-Efficiency Projects	Energy efficiency projects at the factory will be studied and carried out in an appropriate process.
Increase in Energy Efficiency of Machines	Energy efficiency studies will be carried out on the machines owned by the company to reduce consumption.
Energy Efficiency Conscious Employees	As part of the planned reduction of energy use efforts will be made to raise the energy efficiency awareness of the employees. Energy-efficiency training is to be carried out in the company.

The initial structure, in which the determined variables are arranged in accordance with the BBN structure, is given in Figure 6. At the top of the structure, the business resources are seen, in the middle, the solution alternatives, and at the bottom, the bottlenecks. A dual evaluation was performed using a BBN model. The business resources were evaluated with solution alternatives creating alternative solutions for the bottlenecks which structured the scenarios. The relation matrix is used to evaluate the cause and result relations, and then the BBN model is designed according to the opinions of the experts.

This section includes the business resource variables analysed by the experts. When evaluating each variable, the present status of the factory is conceptualised. After the evaluation of the relation matrix, the final structure of the model is loaded in NETICA software as shown in Figure 7. The questionnaire to determine the probabilities is given to the decision-makers.

Figure 6. Variable Relations

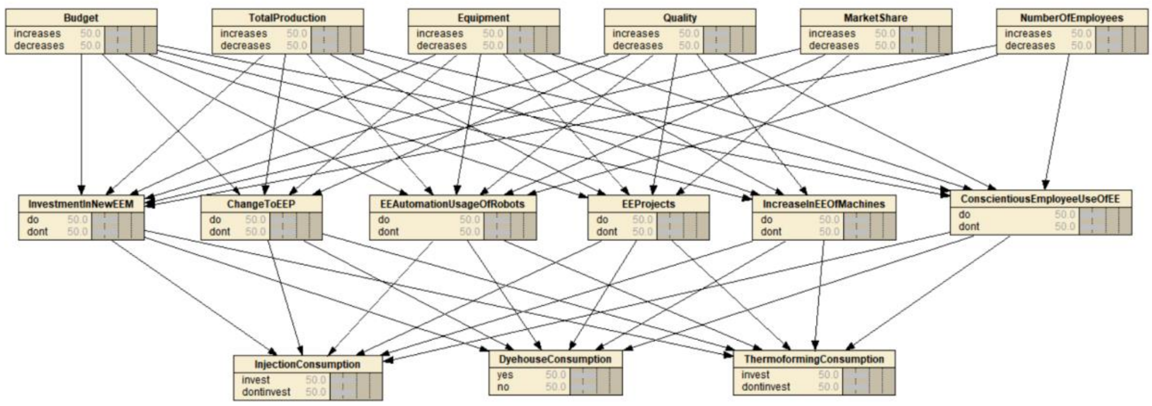

Figure 7. BBN Model in NETICA

The decision-makers gave two alternatives for all the resource variables as increasing or decreasing, with equal probabilities. The values of the alternative solutions are also evaluated by the decision makers as do and do not with different probabilities. For example, in the budget/purchasing section, there is an investment for a new energy-efficient machine, for which there were more than two probability combinations, including alternatives for the budget ('increases' and 'decreases') and for purchasing the energy-efficient new machine ('do' and 'do not'). For instance, Budget Decrease with investment becomes 100%.

Although the resources budget, production volume, equipment, and quality concepts are evaluated under the alternative solutions, the market share and the number of employees are evaluated independently as process change and the increase in the number of EE machines. The market share was not related to EE-trained personnel as a resource, and the personnel number was not related to EE projects. All of the alternative solutions were affecting the three bottlenecks determined by the application of the E-VSM.

3.3. Scenario Analysis

Once the BBN model is structured, three basic scenarios are designed: the 'as-is' case changing nothing in the current situation, 'the worst' case, and 'the best' case. These scenarios will allow observing the future indication of activities of using all the resources or not. The general evaluation results in further investment strategies for EE improvement.

The impacts of the three EE scenarios on investment are explored. The first scenario is stable, based on the current conditions. The second scenario is optimistic, where all resource variables were evaluated as 100% in the positive direction. The third and last scenario was reserved for a pessimistic condition where all resource variables are evaluated as 100% in the negative direction. Figures 8, 9, and 10 show the results obtained for the current situation, the optimistic, and the pessimistic scenarios.

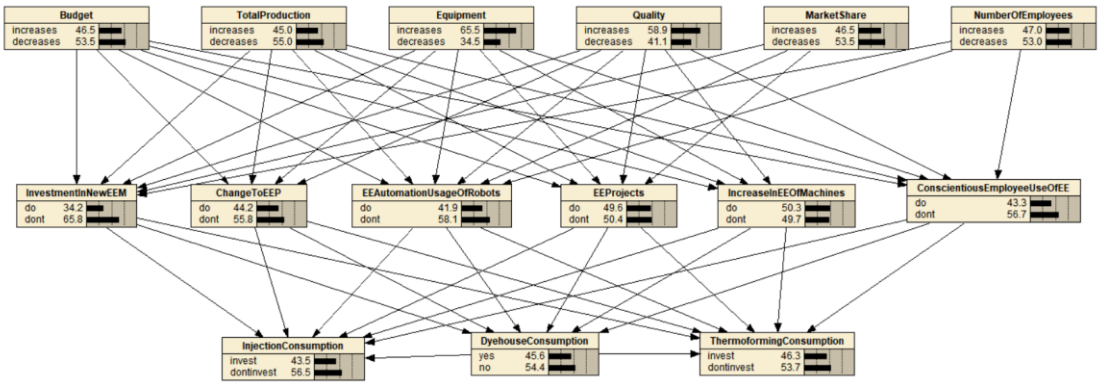

Figure 8. As-Is Scenario in NETICA

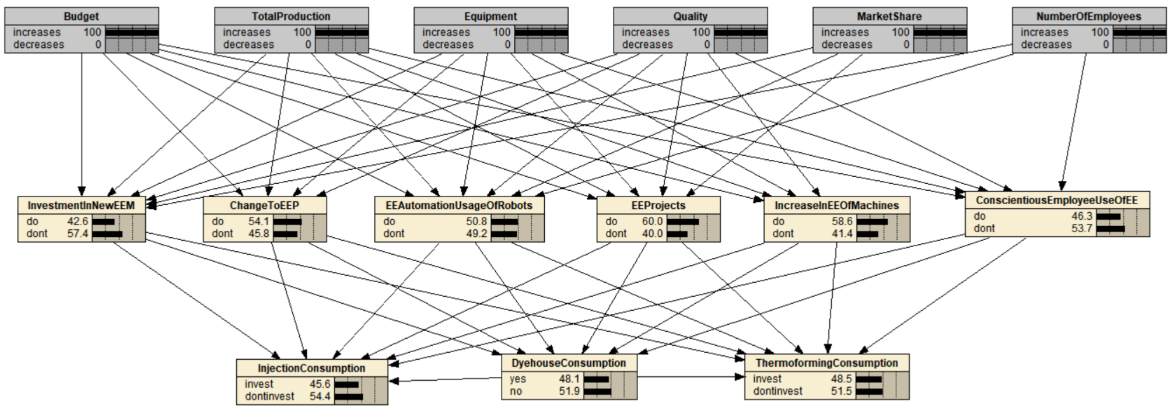

Figure 9. Best Case Scenario in NETICA

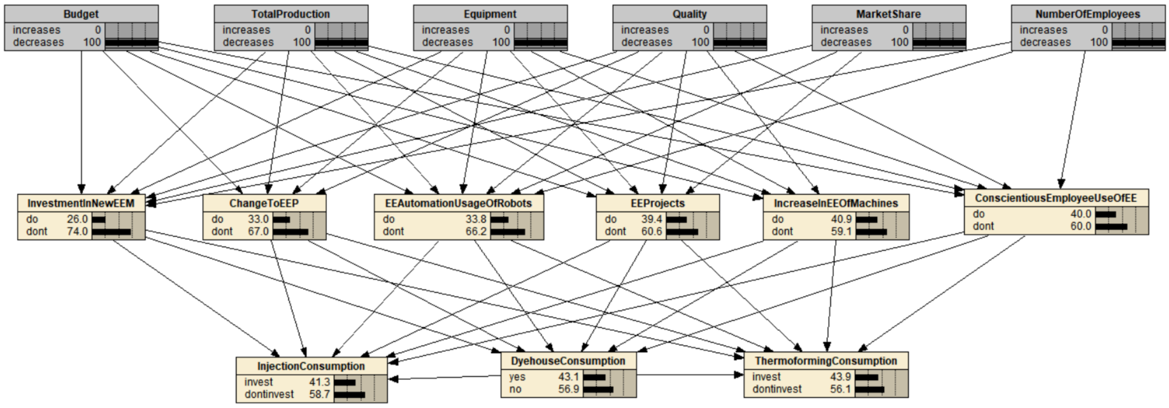

Figure 10. Worst Case scenario in NETICA

When the current situation scenario is evaluated, energy efficiency projects are preferred to be considered as future activities. The best ('optimistic') scenario shows that the EE process could be changed by investing in energy-efficient automation or robots, and by increasing the number of EE machines (Fig. 9). The worst ('pessimistic') scenario is kind of about doing nothing, so no efficiency improvement can be observed (Fig. 10). This application shows that if energy efficiency strategies are given full priority, then new investments in energy-efficient technologies are unavoidable. If budget is concerned to have the first priority, then no energy efficiency can be expected. Hence, as a German company, this case cannot afford the alternative "don't invest" in energy-efficient technologies (based on the scenarios – see, Figures 7 to 9).

In the white goods sector, this could mean addressing inefficiencies in the manufacturing process that hinder energy efficiency and lean production goals. Investment scenario analysis helps prioritize which bottlenecks to address, based on their impact on energy efficiency and overall production performance. Moreover, investment scenario analysis assists in aligning short-term investments with long-term objectives. It allows companies to plan for continuous improvement in energy efficiency and lean production, ensuring sustainability and competitiveness in the white goods sector.

4. CONCLUSIONS AND DISCUSSION

The energy efficiency improvement of an electronic home equipment producer is analysed in three steps. First, a Lean Manufacturing technique, Value Stream Mapping is implemented in end-to-end processes of manufacturing and the bottlenecks in terms of energy use are determined. In the second step, a basic framework has been designed for energy consumption policies with the focus of providing solutions. The Bayesian method facilitates the links among the variables by giving the impact probabilities. Hence in the third and last step, a refrigerator plant with high energy consumption is analysed referring to the energy expert beliefs in the factory. The current energy status of the plant is determined considering the company resources. Yet, only three departments of bottlenecks are considered in this study giving more space to the detailed processes of each department as part of the future studies. In the three chosen departments company's resources are evaluated to support the decision to repair existing equipment or invest in replacement with the improved technologies. Budget, Production, Equipment, Quality, Market Share and Number of Employees are the resources evaluated to design the Bayesian Map given in Figure 7.

After designing the conditions for the current energy status of the manufacturing site, scenarios are developed to determine future strategies. In addition to the current energy evaluation, the best and the worst scenarios are developed. In the best scenario, it was assumed that all of the factory resources were maximal in terms of probability values. With this scenario, we achieved an increasing reduction in the electricity budget flow over the years. As is, the scenario reflects the current situation, hence, gives no differences. However, in the worst scenario, it is assumed that all of the factory resources are minimal in terms of probability values. With this scenario, investments are increased. After evaluating the current energy status and the best and the worst scenarios, the bottlenecks that are identified by VSM are focused to realise investment. This is because the current scenario and the worst-case scenario were both aiming for the repair of the current equipment which led to increasing energy costs. In the Optimistic scenario, the investment in new technologies is foreseen to solve the bottleneck. It is observed that the probability of investing in thermoforming machines is more effective than that of investing in injection machines. Investment in the thermoforming machines is to given priority (Figure 11).

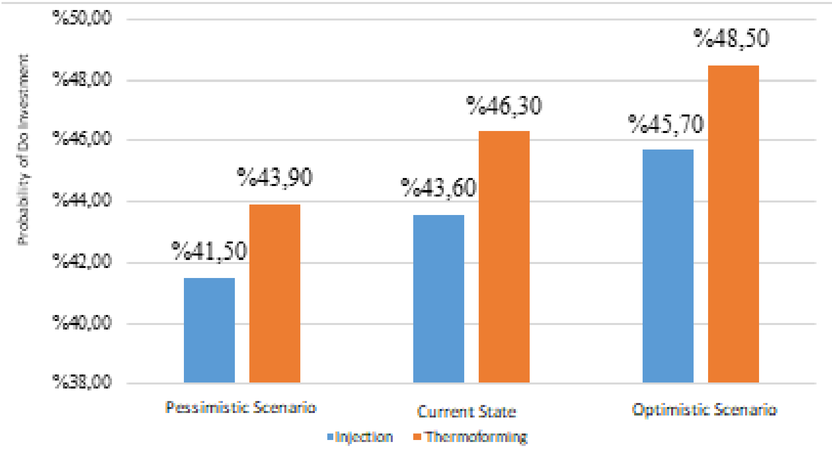

Figure 11. Probability of doing investment based on different scenarios

Bayesian Belief Network supports the managerial decision with respect to the status of different company resources. In this analysis, energy consumption is evaluated with the Lean manufacturing techniques to determine the points of interest to be changed with different scenarios caused by expert beliefs. An additional benefit of the BBN application is not creating a need for sensitivity analysis, since the scenarios cause changes in probabilities and take the role of sensitivity analysis. As an example, we can see the increase in budget decrease probability almost 50% when energy efficiency projects are given priority. It is observed that the biggest increase in energy efficiency will be achieved by investments in energy-efficient technologies of thermoforming.

In the future, this study will be expanded by raising the number of variables in the Bayesian network with the addition of opinions from a new set of decision-makers and considering the details of each process. It is further recommended that a time-based dynamic Bayesian network be designed to predict short-term, middle-term, and long-term strategies.

Declaration of Competing Interest

There is no conflict of interest in this study.

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Declaration of Ethical Standards

The study is conducted in accordance with ethical standards.

Credit Authorship Contribution Statement

İ.D.: Writing – review, Original draft & editing, Supervision, Validation, K.A.: Conceptualization, Investigation, Methodology, Software, Writing - review, Software, Original draft & editing, G.K.: Conceptualization, Supervision, Methodology, Writing – review, M.O.K.: Conceptualization, Supervision, Methodology, Writing – review.

Data Availability

Data will be made available on request.

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