

# A MODEL FOR SELECTING THE MOST SUITABLE RENEWABLE SOURCE OF ENERGY ON VESSELS USING BAYESIAN NETWORKS

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**Abstract:** The International Maritime Organization (IMO) is introducing increasingly strict controls in several aspects of maritime transport with the aim of preserving the environment. Various technologies are proposed and applied that reduce the emission of greenhouse gases. One of the approaches is the application of renewable energy sources RES. However, RES are not equally suitable for all types of ships sailing in different geographical areas. The flow diagram in the process of making a decision on the selection of the type of RES is proposed. This paper presents a model for selecting the most suitable RES on vessels. Furthermore, the optimal solution is selected using Bayesian networks. All significant parameters that influence the selection of the optimal solution can be taken into account and are elaborated individually.

**Keywords:** renewable energy sources, maritime, model, Bayesian network, decision algorithm

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## 1. INTRODUCTION

The amount of energy consumed by the shipping industry is increasing rapidly. Consequently, the negative impact on the environment is also increasing. A generally accepted trend is the introduction of renewables. According to (Issa et al. 2022), RES can be used for the production of green fuels or directly for propulsion. Furthermore, RES can be applied as part of the modernization of existing vessels or when designing new vessels. Regardless of the type of energy transition method chosen, it should be technically feasible and economically acceptable. By conducting a technical-economic analysis of the implementation of carbon-neutral fuel, it is assumed that it will generate 2-6 times higher costs compared to the conventional drive (Stolz et al. 2022). As the aforementioned analysis is extremely complex, the use of computer simulation models is almost inevitable. The simulation model should be able to analyze various parameters in order to obtain a comprehensive answer on the selection of the most suitable energy source.

In this paper, the use of Bayesian networks BN is proposed. The general structure of BN is extremely flexible, which is why it is often applied in different areas (Marcot et al. 2019). Due to their modular architecture, BNs are increasingly used in environmental applications (Serena et al. 2012).

In this paragraph, recent examples of the application of BN in the maritime sector are listed. The most important area of application of Bayesian networks is risk analysis related to maritime accidents (Fan et al. 2020; Huanhuan et al. 2023; Meizhi et al. 2020; Yu. et al. 2021). In the aforementioned works, risk factors affecting the safety of the crew, ship, cargo and the environment were taken into account. Observing the incidence of adverse events throughout history, significant risks were identified. Furthermore, using BN-based models reliably and accurately predicts the possibility of an incident. The obtained information is used by ship captains with the aim of increasing the level of safety. In the paper (Bayazit and Kaptan, 2023), using BN, the probability of the occurrence of an event that can cause environmental pollution was investigated. A model based on Bayesian networks was applied to analyze safety in the transport of electric vehicles by RoPax ships.

## 2. BAYESIAN NETWORK

Thomas Bayes, a British statistician and philosopher, was the first to present a theorem on conditional probability. In his honor, this theorem is called Bayes' theorem. The theorem justifies a way of thinking in which it is stated that truthfulness theories are confirmed by new evidence. This is conditional probability, the probability that one assumption is true provided that the other assumption is true. The main goal of Bayes' theorem is to formalize information about how one event can help in understanding another. The aim is to find the probability of an earlier event, provided that it has occurred later event (Barnett et al. 2006).

The Bayesian network is a graphical model based on probability theory and represents a group of random variables and their conditional dependence using a Direct Acyclic Graph DAG (Neapolitan 1989). A DAG consists of a group of nodes that represent variables, while ends represent a probabilistic random dependence between these variables. Accidental dependence between individual variables is expressed with the help of a structure nodes, which provides and supplies the qualitative part of random reasoning in Bayesian Network (BN).

BN consists of three different types of nodes:

- coincidence node – variable nodes that have ends directed towards the nodes called "children" nodes, a nodes that have links starting from them are called "parents" nodes,
- decision/solution node,
- utility/resource node.

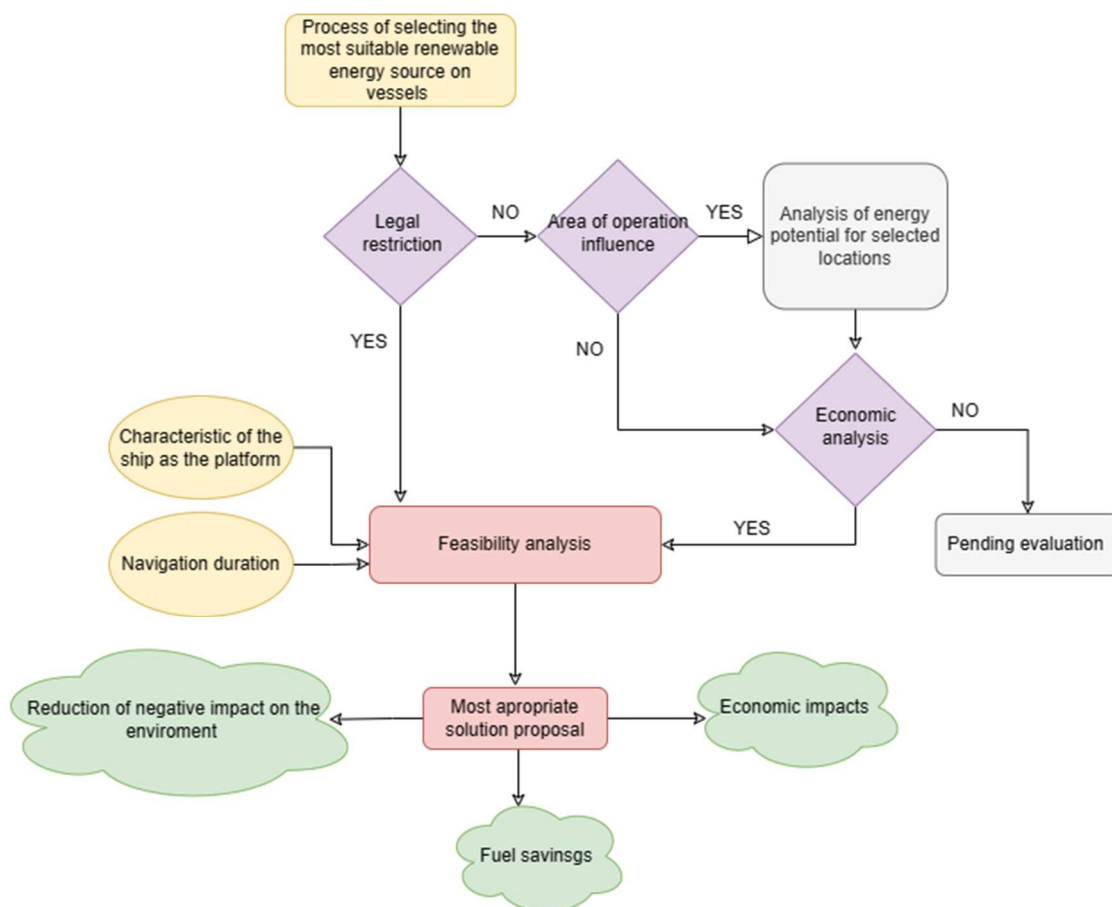
Mathematically, Bayes' theorem can be expressed by the following equation (Stuart and Ord 1994):

$$P(A|B) = \frac{P(B|A)P(A)}{P(B)} \quad (1)$$

where  $A$  and  $B$  are events and  $P(B) \neq 0$ .  $P(A|B)$  is a conditional probability: the probability of event  $A$  occurring given that  $B$  is true. It is also called the posterior probability of  $A$  given  $B$ ,  $P(B|A)$  is also a conditional probability: the probability of event  $B$  occurring given that  $A$  is true. It can also be interpreted as the likelihood of  $A$  given a fixed  $B$  because  $P(B|A) = L(A|B)$  and  $P(A)$  and  $P(B)$  are the probabilities of observing  $A$  and  $B$  respectively without any given conditions; they are known as the prior probability and marginal probability.

### 3. PROPOSED MODEL

To select the most suitable RES, a flowchart is proposed that takes into account various parameters that influence the decision. The decision-making process is shown in **Figure 1**.



**Figure 1** Flowchart diagram of the process of selecting the most suitable RES

The legal constraints are the starting point in the flowchart of the proposed model. Namely, there are navigation areas where carbon free zones are imposed, which can only be achieved through the use of renewables. This applies to special environment areas, for example national parks, special protected areas, and city ports. In this case, an

economic analysis is carried out, and regardless of the economic effect, the vessel must make the transition to renewables.

Furthermore, it is necessary to determine the importance of choosing a location that is defined by the energy potential for a specific energy source. Depending on the area of exploitation of the ship, the availability of a certain type of energy can differ significantly. For instance, solar and wind energy are not available at the same intensity in different geographical areas. The availability of electricity charging stations on land is relatively small, and the application is only at local level. Therefore, it is necessary to perform an analysis of the availability of each energy source in relation to the planned operational area of the ship.

When conducting an economic analysis, it is necessary to take into account for each type of RES the total price of the equipment per unit of installed power. However, the price of the equipment is not the only parameter that needs to be considered. The total amount of energy generated by the installed equipment depends on the energy potential hence in certain circumstances more expensive equipment will be more acceptable. There are areas of application where the return on investment in RES is 9 years for photovoltaic modules (Nugraha et al. 2022). Due to the characteristics of the ship and the navigation area, the economic profitability may not be accomplished, thus it is suggested to carry out a re-analysis in the foreseeable future. This makes a lot of sense due to the continuous increase in the efficiency of the equipment while reducing the price. In addition to the above, due to the price and questionable availability of fossil fuels, the transformation to renewable sources is becoming more and more acceptable.

The most important part of the model is the block for energy analysis, which considers all the parameters that influence the selection of the most suitable RES. Each ship as a platform for the installation of RES has its own specifics and is more or less suitable for the installation of a certain type of RES. For example, a ship with smaller dimensions is not suitable because it has a less available space for installing photovoltaic modules, hence the installed system would not be able to generate a significant level of energy. On the other hand, the application of large wind turbines is not suitable on tourist ships.

The energy needs of the ship depend on its size, operational profile and sailing length. Based on the above, the size and type of source and storage of electricity should be adapted to the operating conditions of the ship. After the energy analysis, the model assigns a coefficient (or percentage) of suitability for application to different types of RES. In the case of choosing a specific RES, it is possible to observe the effects of implementation.

Different objective functions can also be defined. Most often, the legal restriction to reduce harmful effects on the environment is the driver for the application of RES. However, with the advancement of technology, certain solutions are economically more profitable compared to the use of fossil fuels, which results in a reduction in fuel consumption.

A model for selecting the most suitable RES based on BN is proposed. There are various software solutions that use BN. Part of the software is based on the Java programming language, for example JavaBayes, jBNC, UnBBayes, Banjo. BNFinder is written purely in Python while bnlearn is part of the R package. In this particular case, the Netica program is used. Netica is a powerful, easy-to-use, complete program for working with belief networks and influence diagrams. It has an intuitive and smooth user interface for drawing the networks, and the relationships between variables may be entered as individual probabilities, in the form of equations, or learned from data files (Norsys - Netica Application).

Proposed model shown on **Figure 2**, enables the setting of initial conditions specific to a certain geographical area. It is also possible to define the capacities of the ship as a platform for RES accommodation. The energy needs of the ship should be taken into account in order to choose a suitable energy source. In accordance with the mentioned feature, the model selects the most suitable energy source. In **Figure 2**, the initial conditions do not indicate the characteristics of individual types of RES.

In accordance with aforementioned, **Figure 2** actually presents a Netica model based on BN in which it is possible to discern any outcome, suitable or not. For example, if there is a large wind energy potential, the model will ultimately favor wind energy as RES, as shown in **Figure 3**.

Input parameters of the observed model are Mean annual irradiation, Wind energy potential, Charging station availability, Platform installation capacities, Energy needs, and RES price per kWh. After conducting a potential analysis, energy and economic analysis, the suitability for use in defined conditions is determined for a certain RES. A significant advantage of using BN is that the model can be used in the reverse direction as well. For instance, if we choose the EES system for the outcome, the model will match the input parameters with the selection as shown in **Figure 4**.

#### 4. CONCLUSION

The advantage of using proposed model is that it takes into account various parameters that influence the selection of the most suitable renewable source. To be functional, the model needs to be adjusted in accordance with the specifics of the energy potential in relation to the geographical position and the navigation area. Moreover, it is necessary to analyze the possibility of accommodating a certain type of energy in accordance with the energy needs of the ship. In future research, the model could be expanded and significantly improved in such a way as to include the flow of the larger geographical area. Furthermore, ecologic and economic justification can be used as

an output variables of the model. The aforementioned variables took into account all aspects of the proposed model with the aim of obtaining an output as to whether the model is ecologically and economically viable.

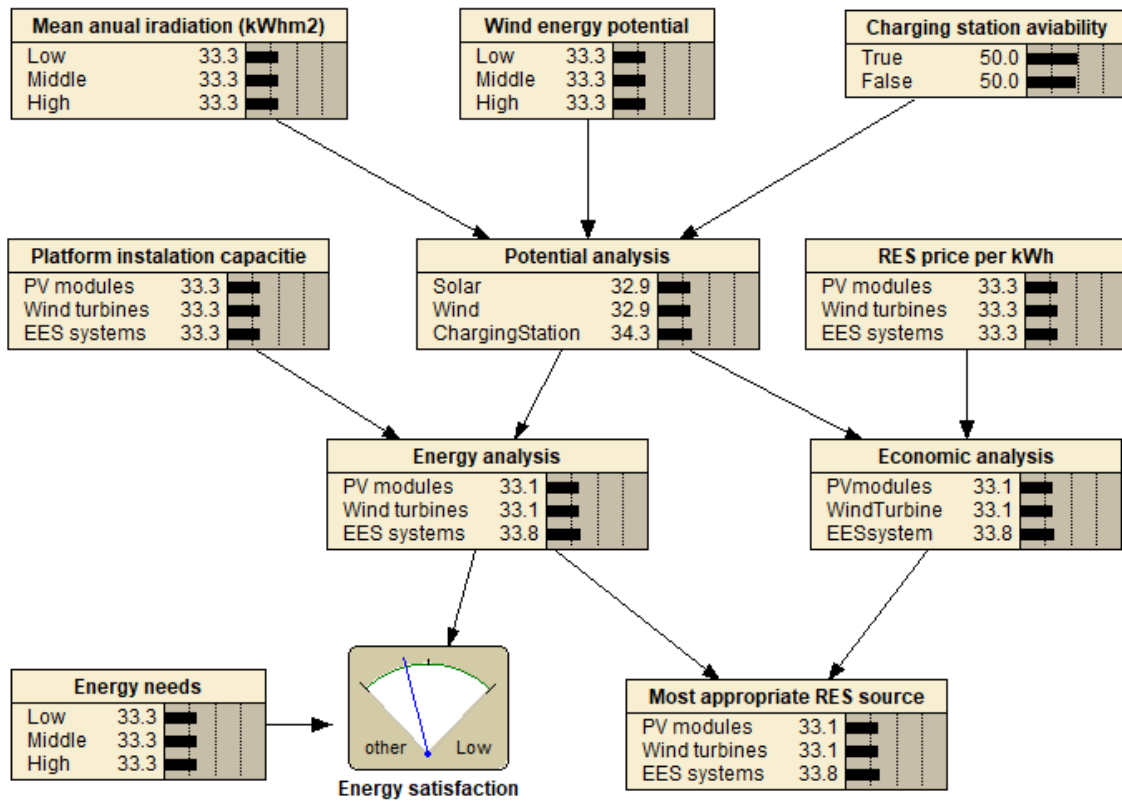


Figure 2 Bayesian network model created in Netica software

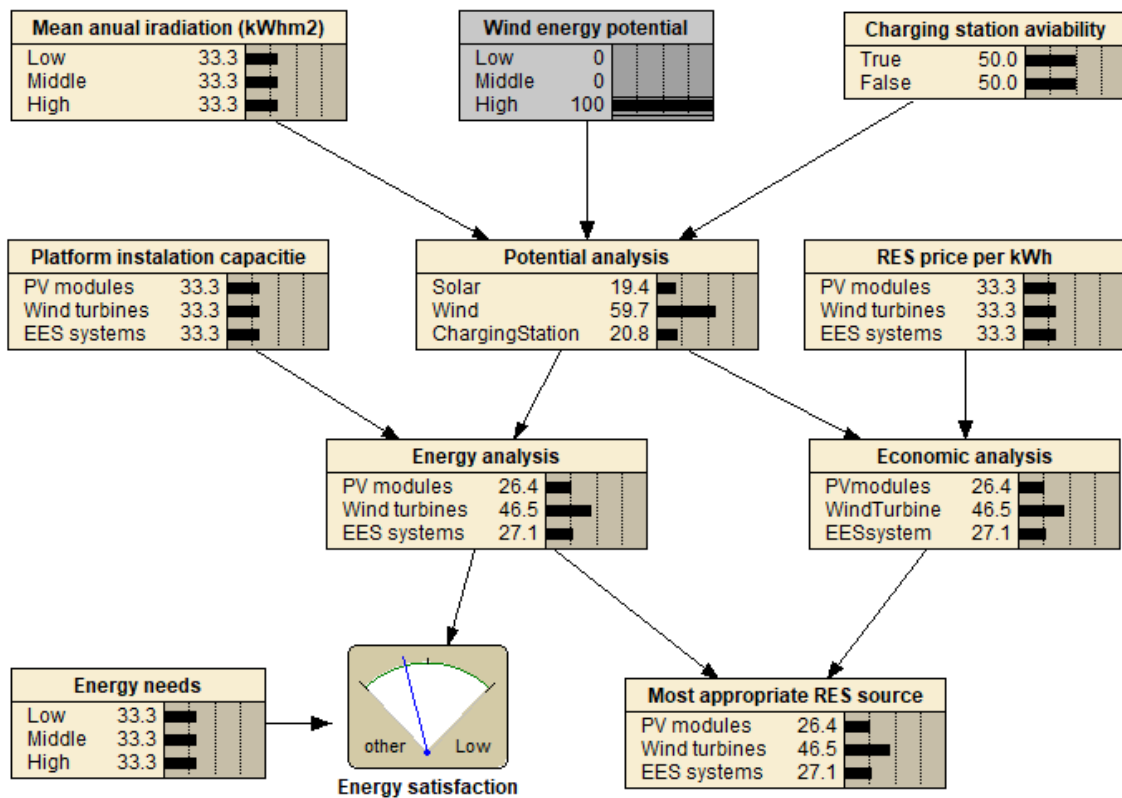


Figure 3 BN model with simulated high wind potential

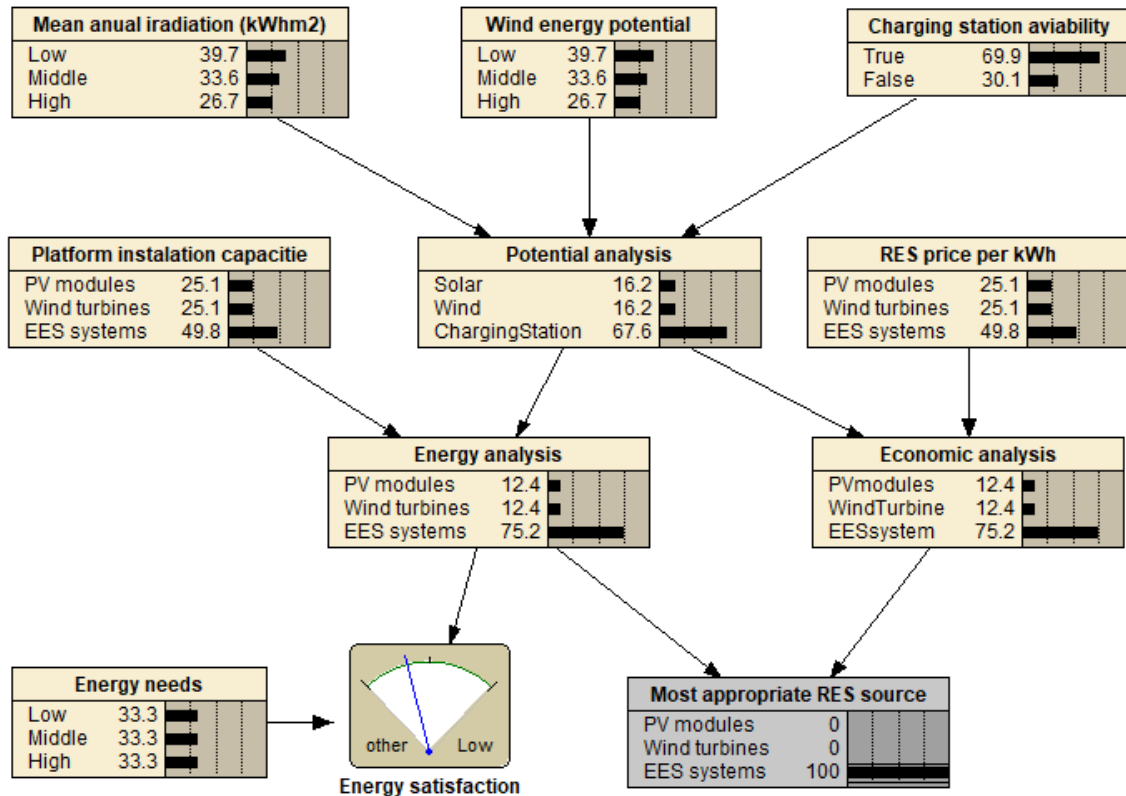


Figure 4 Bayesian Network application in reverse direction – regression

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