

Bayesian Networks based Policy Making in the Renewable Energy Sector

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Keywords: Bayesian Networks, Expert Models, Renewable Energy, Geothermal Energy, Hydro Energy.

Abstract: Extensive research on energy policy nowadays combines theory with advanced statistical tools such as Bayesian networks for analysis and prediction. The majority of these studies are related to observe energy scenarios in various economic or social conditions, but only a few of them target the renewable energy sector. Therefore, it is crucial to design a method to understand the causal relationships between variables such as consumption, greenhouse emissions, investment in renewables and investment in fossil fuels. This research paper aims to present expert models using the capabilities of Bayesian networks in the renewable energy sector, considering renewables in two countries: Germany and Italy. For this purpose, expert models are built in BayesiaLab with supervised learning. An augmented naïve model is applied to quantitative data consisting of the consumption rate of geothermal and hydro energy sectors. As a result, it is indicated that in the optimum case, geothermal and hydro energy consumption will be increased in parallel with investment. It is found that, as oil price grows, greenhouse emissions will decrease. The precision of the expert model is no less than 90%.

1 INTRODUCTION

Bayesian networks are widely being used in various fields of study, namely in environmental (Martos et al., 2016; Marcos et al., 2018; Roper, Renooij and Gaag, 2018), ecological (Barton et al., 2016; Corani and Scanagatta, 2016; McLaughlin and Reckhow, 2017; Orun et al., 2018; Liu and Callies, 2019), sustainable development (Keshtkar et al., 2013; Franco et al., 2016), agricultural (Mukashema, Veldkamp and Vrieling, 2014; Barton et al., 2016), mapping (Landuyt et al., 2015; Gonzalez - Redin et al., 2016), risk management (Gerstenberger et al., 2015; Tang et al., 2016a, 2016b; Kabir and Papadopoulos, 2019), reliability (Amrin, Zarikas and Spitas, 2018; Kameshwar et al., 2019), medicine (Zarikas, Papageorgiou and Regner, 2014; Zarikas et al., 2018) and safety (Zarikas et al., 2013; Washington et al., 2019). Further, the theory behind Bayesian networks

can be applied in diverse research areas to analyze the numerous data (Bapin and Zarikas, 2014; Amrin, Zarikas and Spitas, 2018). It is a prognostic method for conducting diagnostics and calculating probabilities, which is useful for uncertain data (Conrady, Jouffe and Elwert, 2014; Zarikas, 2014).

It is important to point out that the majority of studies have been dedicated to the energy sector based on the latest environmental report (Borunda et al., 2016). However, with the vast volume of data, there are a few studies related to the use of Bayesian networks in the renewable energy sector (Res et al., 2009; Cinar and Kayakutlu, 2010; Borunda et al., 2016; Gambelli et al., 2017), particularly for the energy policy cases (Kumar et al., 2010; Bhowmik et al., 2017). Therefore, it is pivotal to develop a technique to predict future progress in this field for the sources of energy such as geothermal energy, hydro energy, bioenergy, solar energy, wind energy. For this

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purpose, energy policies are important, so that they can contribute to the understanding of the future market for renewable energy production and consumption.

Case studies may be considered to be an effective method to create energy policies (Kim et al., 2018). For this, the algorithms in Bayesian networks can be modified and built in relevance with structural restrictions of the system (Campos and Castellano, 2007; Pitchforth and Mengersen, 2013; Perreault and Sheppard, 2019). Two approaches can be applied to data analysis in the renewable energy sector such as supervised and unsupervised learning. In case of unsupervised learning, it is useful to determine the causal relationships between variables, otherwise, supervised learning allows referring to one variable at a time (Conrady, Jouffe and Elwert, 2014). One of the relevant studies using unsupervised learning in BNs in this field is dedicated to forecasting the investment in the renewable energy sector in Turkey for the years 1970 to 2007 (Cinar and Kayakutlu, 2010). Several variables, which were expected to have even a slight impact on energy investment, were chosen. Also, gross domestic product, renewable energy production, fossil fuel production, urbanization, and industrialization were directly imported to Bayesian network. Three scenarios were created (optimistic, stable and pessimistic). As a result, in the optimistic scenario investment in renewables grew with a gradual decrease in greenhouse emissions. This leads to the fact that with a high rate of industrialization process and GDP the demand for renewables increases.

Another study in this area is related to the prediction of the future market of biofuels using supervised learning in Italy by 2030 (Gambelli et al., 2017). Two scenarios were developed such as “best scenario” and “worst scenario”. As an outcome, in the best scenario biofuels would demonstrate the highest percentage of market involvement in the near future. Nevertheless, one requirement is needed: advanced technological development and environmental policies should be taken into action simultaneously.

The main aim of current research is to develop expert models (Tselykh, Tselykh and Barkovskii, 2018; Jha, 2019) for the renewable energy sector using a supervised learning technique. Methodologies above will be modified to create expert models, concerning two energy sectors: hydro energy and geothermal energy. In addition, the application of Bayesian networks in the determination of the best scenarios for geothermal energy shows only 2 percent of research papers addressed this type of renewable, whilst for hydro energy, it is 21 percent (Borunda et al., 2016). Particularly, these studies will be concentrated on the widely used energy source (hydro energy) and on the

least favourable one (geothermal energy). Factors as GDP, fossil fuel and renewables consumption, greenhouse emissions will be taken into account to verify the results obtained from previous research.

In the following section, modified methods for this research will be given and explained. K-Folds analysis method will be discussed. In Section 3, results will be shown regarding the optimum and minimum cases for the renewable energy sector with maximum and minimum consumption rate. In Section 4, conclusions will be drawn regarding expert models and the impact of selected variables on renewables.

2 METHODOLOGY

Data analysis for the identification of the optimum and minimum cases for the renewable energy sector is undertaken using BayesiaLab software (Conrady and Jouffe, 2015). The optimum case is this with the highest percentage of the increase in renewable consumption and the minimum case is the less optimistic, where a significant decrease in renewable consumption will be observed by inserting evidence to a model. Data on renewables is obtained from the official site of OECD (Organisation for Economic Cooperation and Development). OECD is an organization that provides a wide range of data on economics, welfare, energy, and investment with open availability. Specifically, data on import and export, the consumption and the electricity production and price, the production of greenhouse emissions is collected from the dataset ‘Renewables balance’ and data on GDP is taken from ‘Energy statistics’ for two countries (Germany and Italy) for the years 1990 – 2017 (Organisation for Economic Cooperation and Development [OECD], n.d.). The information on the investment for both renewables and fossil fuels is extracted from ‘RD&D Budget’, whereas data on patents is from ‘Patent statistics’. Finally, data on gold and oil prices is from ‘Main economic indicators’. Renewables such as geothermal energy and hydro energy are used for the preliminary analysis related to its full availability and will be shown as separate models next sections.

2.1 Augmented Naïve Bayesian Model

To analyze those cases mentioned above, expert models are created. The first stage for this is to identify the discretization method and the learning type. The supervised learning algorithm is used for this research, considering that consumption of either renewable type will be set as a target variable.

Before these steps will be conducted, it can be mentioned that the discretization type is chosen to be “Tree” for supervised learning for “Oil_Price (RI)”, “TRenEnergy_import (ktoe)”, “Gold_Price (US dollars)”, “TRenEnergy_export (ktoe)”, “Geothermal_electricity (GWh)”, “GDP”, “Investment_renewables (millions)”, “Investment_fossilfuels (millions)”, “EnvironPolicy (%)”, “Electricity_Price (RI)”, “GhEmissions_production (tonnes)”, “Geothermal_techpatents”. A tree is considered to be the most commonly used discretization methods for supervised learning. The major process involves using the class information of child nodes and applying a hierarchical discretization based on the correlation. The reason behind applying this type of discretization lies in the optimization process of correlation between the target variable (“Geothermal_consumption (ktoe)”) and predictor variables.

The manual discretization process is applied to “Geothermal_consumption (ktoe)” with generating states by choosing R2-GenOpt discretization type based on the regression model (Montgomery and Runger, 2014):

$$R^2 = SS_R / SS_T \tag{1}$$

It can be clearly shown from the above formula that a sum due to regression is over a total sum of squares, considering that discretization is chosen for strengthening the connection between discrete and continuous variables. This is called genetic optimization.

It can be noted that all variables are continuous while supervised learning requires at least one discrete target variable. Therefore, using R2-GenOpt converts a continuous variable to a discrete one (“Geothermal_consumption (ktoe)”). Values for missing parts of the data are generated by Missing Values Imputation, which gives the Structural EM method, applicable to a small set for data for the purpose of this research (Conrady, Jouffe and Elwert, 2014). The method of Structural Expectation Maximization is based on finding the ‘most suitable’ estimate for the missing part of the dataset by evaluating possible structures for the parameter.

For the strength of each arc, Pearson’s correlation method is used by showing the strongest and the least strong connections. Thus, the structural analysis uses Pearson’s correlation coefficients

$$P(\alpha_i, \alpha_j) = cov(\alpha_i, \alpha_j) / \sqrt{var(\alpha_i) \cdot var(\alpha_j)} \tag{2}$$

for evaluating the differences between two nodes and summation of the resultant values, which gives the

values with high precision and accuracy (Mu, Liu and Wang, 2018).

Furthermore, a supervised learning procedure is carried out by choosing the augmented naïve model. It is applicable to analyze a small set of data. The structure of the augmented naïve model is characterized by having similar properties as the naïve model, but adding a higher precision and accuracy to the model (Figure 1(b)). It is, therefore, achieved by creating new connections between the adjacent nodes (Montgomery and Runger, 2014). In the naïve model, nodes are considered to be independent of each other without any correlation between neighboring nodes (Figure 1(a)).

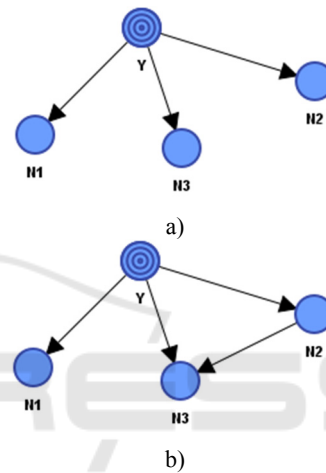


Figure 1: A simplistic naïve and augmented naïve models (Y – target node; N1, N2, N3 – child nodes): a) naïve model; b) augmented naïve model.

The augmented naïve model uses the famous Bayes formula to identify joint probabilities not only between dependent variables and one target variable, but also correlations between several child nodes.

$$P(A|B) = P(B|A) \cdot P(A) / P(B) \tag{3}$$

2.2 K-Folds Analysis

In order to demonstrate the precision of each model presented in these studies, k-folds analysis is executed. K-Fold cross-validation is useful in machine learning to evaluate the precision of a machine learning model on unseen data. It is a technique in which a particular sample of a dataset is reserved on which there is no need to train the data. Then, the model is tested on this sample before finalizing it. Thus, a small reserved sample is utilised to calculate how the model is supposed to behave in general when used to make predictions on data, but not used during the

training of the model. The algorithm is characterised by a single parameter “k” denoting the number of groups that our sample is to be split into. This is the reason the method it is called k-fold cross-validation.

3 RESULTS AND DISCUSSIONS

In this section, the method explained previously is applied to create expert models in the renewable energy sector for two countries: Germany and Italy. Two sources of energy are used in predicting the optimum and minimum cases for consumption such as geothermal energy and hydro energy. The dependencies between child nodes are built by an automatic calculation of correlation using supervised learning.

3.1 Augmented Naïve Bayesian Model for Renewables in Germany

In this subsection, two expert models are presented for geothermal energy and hydro energy in Germany. For both cases, consumption is considered to be a target variable with the manual discretization. In case of geothermal energy, the discretization method is chosen to be “Tree” for “Gold_Price (US dollars)”, “TRenEnergy_export (ktoe)”, “Geothermal_electricity (GWh)”, “GDP”, “Investment_renewables (millions)”, “Investment_fossilfuels (millions)”, “EnvironPolicy (%)”, “Electricity_Price (RI)”, “GhEmissions_production (tonnes)”. The type of discretization as “Perturbed Tree” is automatically generated states for two variables such as “TRenEnergy_Import (ktoe)” and “Oil_Price (RI)”, whereas R2-GenOpt is chosen for “Geothermal_techpatents”.

In Figure 2(a), the model for geothermal energy is presented using the supervised learning algorithm with a structural coefficient of one. In Figure 2(b), it is shown that the new connection between variables “Geothermal_techpatents” and “Oil_Price (RI)” is created by editing the structural coefficient to 0.5. But, the relationship between “TRenEnergy_import (ktoe)” and “Oil_Price (RI)” is deleted. The correlation between variables are shown in the same figure (Figure 2(b)) using Pearson’s correlation, where the strongest relationship is bounded to be between “Geothermal_consumption (ktoe)” and “Investment_renewables (millions)”, “Geothermal_consumption (ktoe)” and “GDP”, “Geothermal_consumption (ktoe)” and “Geothermal_electricity (GWh)”, “Geothermal_consumption (ktoe)” and “Electricity_Price (RI)”. The least strong connection is between “Geothermal_consumption (ktoe)” and “Geothermal_techpatents”.

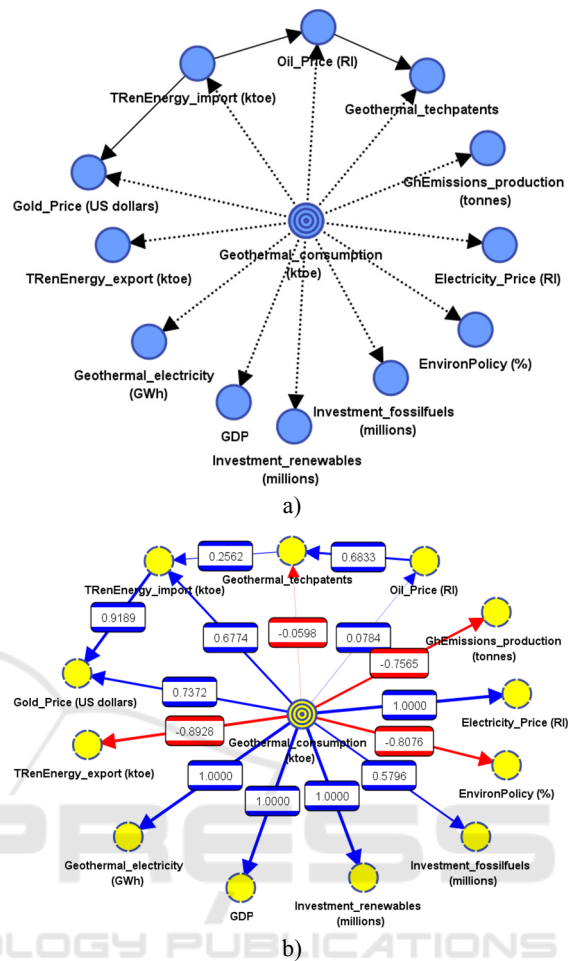


Figure 2: Supervised learning for geothermal energy in Germany: a) with the structural coefficient of 1; b) with the structural coefficient of 0.5 and with Pearson’s correlation.

After applying the augmented naïve model for variables in the geothermal energy sector, it is important to use the joint probability to predict the optimum and minimum cases for geothermal energy consumption. Firstly, the optimum case for geothermal energy is observed in Figure 3. By setting the evidence for the optimum case of “Investment_renewables (millions)” to 100%, the same percentage is obtained for the optimum state of “Geothermal_consumption (ktoe)”, whereas the minimum state of “GhEmissions_production (tonnes)” is shown to be 80%.

Furthermore, the minimum case for geothermal energy is shown in Figure 4. By setting the evidence for the optimum state of “Investment_fossilfuels (millions)” and the minimum state of “Gold_Price (US dollars)” to 100%, the same percentage is obtained for the minimum state of “Geothermal_consumption (ktoe)”. The optimum state of “GhEmissions_production (tonnes)” is described by 95.65% increase.

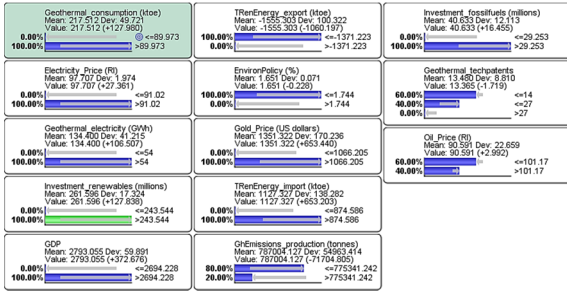


Figure 3: Optimum case for geothermal energy consumption in Germany.

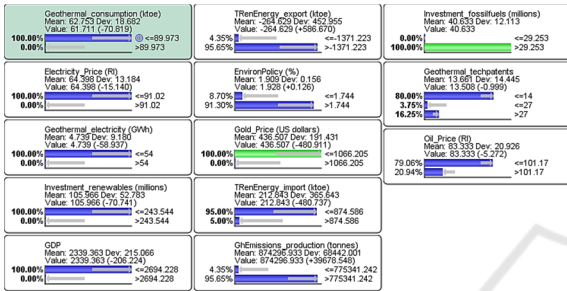


Figure 4: Minimum case for geothermal energy consumption in Germany.

Table 1: Occurrences, reliability and precision of expert model for geothermal energy in Germany.

Occurrences		
Value	<=89.973 (23)	>89.973 (5)
<=89.973 (22)	22	0
>89.973 (6)	1	5
Reliability		
Value	<=89.973 (23)	>89.973 (5)
<=89.973 (22)	100.0000%	0.0000%
>89.973 (6)	16.6667%	83.3333%
Precision		
Value	<=89.973 (23)	>89.973 (5)
<=89.973 (22)	95.6522%	0.0000%
>89.973 (6)	4.3478%	100.0000%

It can be said that the optimum case where the consumption of geothermal energy will increase is the state with increasing investment in renewable energy. However, the minimum case is obtained by setting a condition with the increasing investment in fossil fuels and the decreasing price for gold. To verify this expert model, k-folds analysis is undertaken as shown in Table 1 with the precision approximately equals to 95.6%, which demonstrates a quite acceptable result for further analysis.

A similar expert model is created for the hydro energy sector as shown in Figure 5. The discretization type is chosen to be “Tree” for three variables such as

“Hydro_electricity (GWh)”, “GDP” and “GhEmissions_production (tonnes)”. The remaining set of variables is discretized by choosing “Perturbed Tree”. It is observed (Figure 5(b)) that the strongest correlation is between “Hydro_consumption (ktoe)” and “Hydro_electricity (GWh)”, “GDP” and “GhEmissions_production (tonnes)”. The less apparent connection is the same as with geothermal energy. New relationships are created between “TRenEnergy_Import (ktoe)” and “Hydro_techpatents”, “TRenEnergy_Export (ktoe)” and “Oil_Price (RI)”, “Electricity_Price (RI)” and “Investment_fossilfuels (millions)”, “Oil_Price (RI)” and “GDP”.

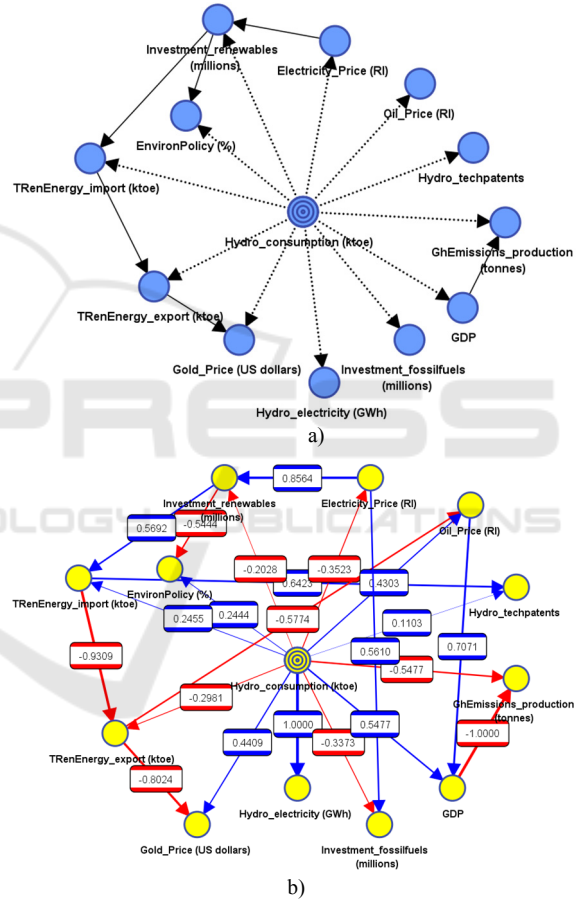


Figure 5: Supervised learning for hydro energy in Germany: a) with the structural coefficient of 1; b) with the structural coefficient of 0.5 and with Pearson’s correlation.

The optimum case for hydro energy is demonstrated in Figure 6. The maximum increase of 58.33% in “Hydro_consumption (ktoe)” is achieved by setting the value for evidence for “Investment_renewables (millions)” and “Hydro_techpatents” to 100%.

The minimum case for hydro energy consumption is the same as for geothermal energy as shown in Figure 7.

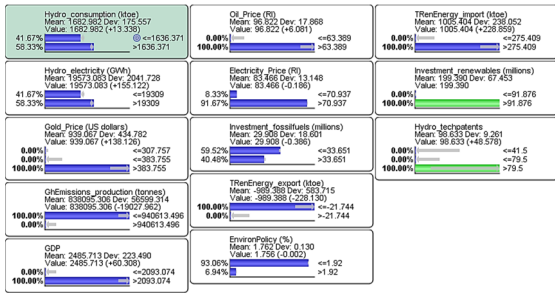


Figure 6: Optimum case for hydro energy consumption in Germany.

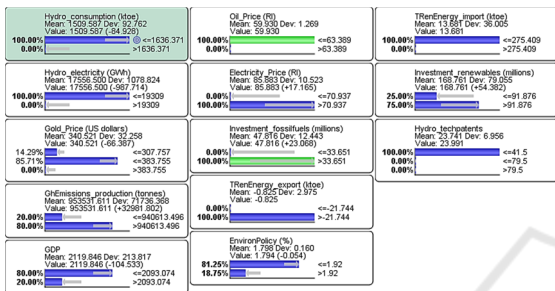


Figure 7: Minimum case for hydro energy consumption in Germany.

The optimum condition for hydro energy with the increasing investment in renewables leads to the gradual growth of hydro consumption.

At the same time, the minimum case is shown to be quite similar to one shown with geothermal energy case, which is explained by using the same dependent variables. The precision (100%) of the model is described in Table 2.

3.2 Augmented Naïve Bayesian Model for Renewables in Italy

In this subsection, two more expert models are designed for geothermal and hydro energy in Italy. A target variable remains the same from previous analysis. In terms of geothermal energy, the discretization method is chosen to be “Tree”, except for “Geothermal_techpatents” R2-GenOpt is applied. The expert model is considered to remain stable even by changing the structural coefficient to 0.5 (Figure 8(b)).

The strongest relationship is shown between “Oil_Price (RI)” and “Coal_Price (RI)”, “Geothermal_consumption (ktoe)” and “Geothermal_electricity (GWh)”, “Geothermal_consumption (ktoe)” and “TREnergy_Import (ktoe)”. The weakest connection is between “GHEmissions_production (tonnes)” and “EnvironPolicy (%)”.

Table 2: Occurrences, reliability and precision of the model for hydro energy in Germany.

Occurrences		
Value	$\leq 1636.371 (10)$	$> 1636.371 (18)$
$\leq 1636.371 (10)$	10	0
$> 1636.371 (18)$	0	18
Reliability		
Value	$\leq 1636.371 (10)$	$> 1636.371 (18)$
$\leq 1636.371 (10)$	100.0000%	0.0000%
$> 1636.371 (18)$	0.0000%	100.0000%
Precision		
Value	$\leq 1636.371 (10)$	$> 1636.371 (18)$
$\leq 1636.371 (10)$	100.0000%	0.0000%
$> 1636.371 (18)$	0.0000%	100.0000%

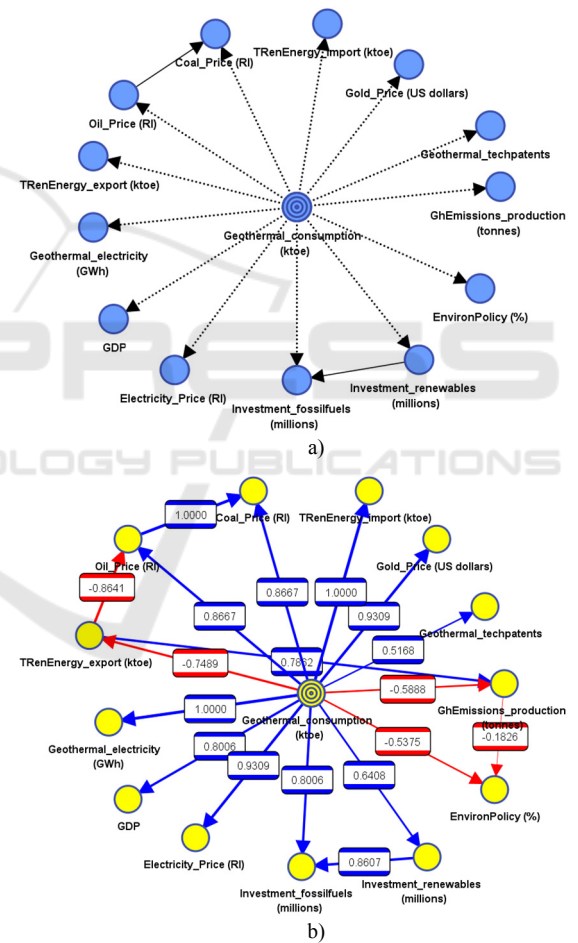


Figure 8: Supervised learning for geothermal energy in Italy: a) with the structural coefficient of 1; b) with the structural coefficient of 0.5 and with Pearson’s correlation.

By giving evidence (100%) to “Investment_renewables (millions)” and “Geothermal_techpatents”, “Geothermal_consumption (ktoe)” is indicated at the maximum state of 94.94% for the case with optimum

conditions. The optimum states for “Geothermal _ electricity (GWh)” and “TRenEnergy_import (ktoe)” are described by the same percentage as for “Geothermal_consumption (ktoe)”, explained by a high correlation (Figure 9).

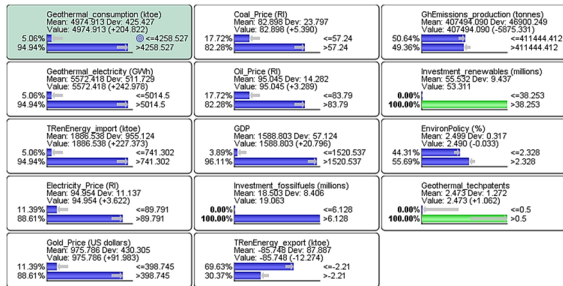


Figure 9: Optimum case for geothermal energy consumption in Italy.

The minimum case is described by 60% of probability of decreased geothermal consumption by giving evidence to “Coal_Price (RI)” and “Investment_fossilfuels (millions)”. Therefore, “GhEmissions_production (tonnes)” is maximized, explained by the opposite correlation with “Geothermal_consumption (ktoe)” (Figure 10).

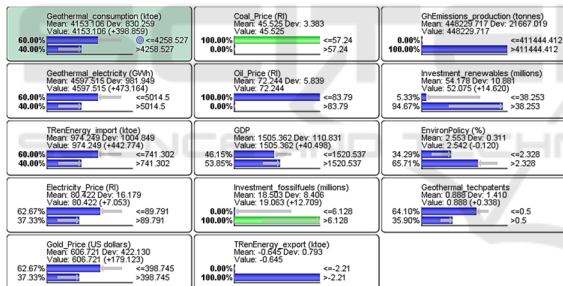


Figure 10: Minimum case for geothermal energy consumption in Italy.

In addition, the growth in investment for renewables has a slight effect on environmental policy, whereas GDP increases. The precision of this expert model created for the geothermal energy sector in Italy is 92.3%, which is considered to be relevant to these studies (Table 3).

Further, the augmented naïve model has been applied to the hydro energy sector in Italy. The most obvious connection is described between “Hydro_consumption (ktoe)” and “Hydro_electricity (GWh)”, whereas the weakest one is between “Hydro_consumption (ktoe)” and “EnvironPolicy (%)”. The relationships between “Coal_Price (RI)” and “Hydro_techpatent”, “Oil_Price (RI)” and “GDP” are created by changing the structural coefficient as shown in Figure 11(b).

Table 3: Occurrences, reliability and precision of the model for geothermal energy in Italy.

Occurrences		
Value	<=4258.527 (13)	>4258.527 (15)
<=4258.527 (12)	12	0
>4258.527 (16)	1	
Reliability		
Value	<=4258.527 (13)	>4258.527 (15)
<=4258.527 (12)		0.0000%
>4258.527 (16)	6.2500%	93.7500%
Precision		
Value	<=4258.527 (13)	>4258.527 (15)
<=4258.527 (12)	92.3077%	0.0000%
>4258.527 (16)	7.6923%	

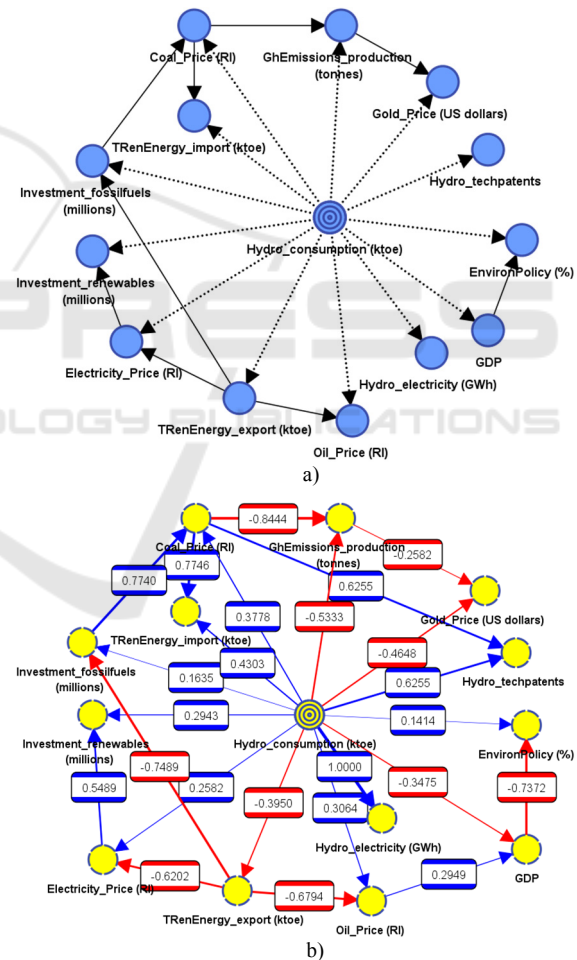


Figure 11: Supervised learning for hydro energy in Italy: a) with the structural coefficient of 1; b) with the structural coefficient of 0.5 and with Pearson’s correlation.

In the optimum case, adding evidence to “Investment_renewables (millions)” and “Hydro_techpa-

ments” leads to 100% probability of the maximum state of “Hydro_consumption (ktoe)”. It can be, therefore, mentioned that the price for electricity reaches its maximum state for the optimum situation (Figure 12).

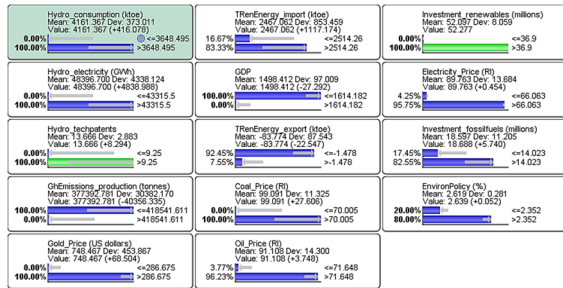


Figure 12: Optimum case for hydro energy consumption in Italy.

In the minimum case, setting evidence to “Coal_Price (RI)” and “Investment_fossilfuels (millions)” leads to 100% probability for minimum level of hydro energy consumption (Figure 13).

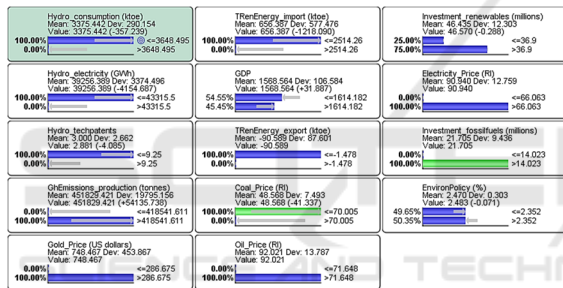


Figure 13: Minimum case for hydro energy consumption in Italy.

From figures, it is obvious that GDP has a clear impact on the consumption rate of hydro energy. The precision of the expert model for hydro energy in Italy equals to 100 % according to Table 4.

Table 4: Occurrences, reliability and precision of the model for hydro energy in Italy.

Occurrences		
Value	<=3648.495 (18)	>3648.495 (10)
<=3648.495 (18)	18	0
>3648.495 (10)	0	10
Reliability		
Value	<=3648.495 (18)	>3648.495 (10)
<=3648.495 (18)	100.0000%	0.0000%
>3648.495 (10)	0.0000%	100.0000%
Precision		
Value	<=3648.495 (18)	>3648.495 (10)
<=3648.495 (18)	100.0000%	0.0000%
>3648.495 (10)	0.0000%	100.0000%

4 CONCLUSIONS

Bayesian networks have been a well-known tool used in diverse areas of science and technology. However, its usage could be extended in the renewable energy policy sector using the expert model.

At this work, the renewable sources such as geothermal energy and hydro energy were taken into concern as one of the widespread and the least preferable types of renewables, respectively. Two expert models were created using the augmented naive method. Initially, structural coefficient was equal to one, then in order to increase the precision, it was taken as a half of value. This resulted in new causal connections. It was noticeable that editing the structural coefficient might give some robustness to the system, however it was suggested to use the range no less than 0.1 and no more than 1.

From the analysis, it was shown that the consumption of geothermal energy in Germany could be optimized by the increasing investment in renewables, which proves the previous research works. Greenhouse emissions were decreased to 80% for the optimized case. On the other hand, the minimum case demonstrated that the increasing investment in fossil fuels and the cheapest price for gold resulted in a situation with the minimized state for geothermal energy consumption.

In terms of hydro energy in Germany, it was only a slight increase in hydro consumption as a response for the growing number of technical patents and the investment. The minimum case showed that similar results as for geothermal energy source, which was explained by using the same input variables.

In case of Italy, the increasing number of technical patents and the investment in geothermal energy lead to a considerable increase in geothermal consumption, whereas a gradual change in environmental policy could be noticed. For the minimum case, the evidence was set to a coal price, which resulted in the worst scenario (minimum case) for this type of renewable. As for hydro energy consumption, it was indicated that its optimum case was set by giving the maximum evidence to technical patents, whereas the minimum situation was involved the decrease in the coal price and the increased emissions.

Therefore, from the obtained results and precision data, it can be said that Bayesian Networks is a suitable tool for data analysis in renewable energy policy making. Methods in previous sections will be developed further as a small set of data only was utilized during this research. Furthermore, it is crucial to extend this method applying to other sources of renewable energy such as solar, wind and bio.

REFERENCES

- Amrin, A., Zarikas, V. and Spitas, C. (2018) 'Reliability analysis and functional design using Bayesian networks generated automatically by an "Idea Algebra" framework', *Reliability Engineering and System Safety*. Elsevier Ltd, 180 (July), pp. 211–225. doi: 10.1016/j.res.2018.07.020.
- Bapin, Y. and Zarikas, V. (2014) 'Probabilistic Method for Estimation of Spinning Reserves in Multi-connected Power Systems with Bayesian Network-based Rescheduling Algorithm', *Proceedings of the 11th International Conference on Agents and Artificial Intelligence*, pp. 840–849. doi: 10.5220/0007577308400849.
- Barton, D. N. *et al.* (2016) 'Assessing ecosystem services from multifunctional trees in pastures using Bayesian belief networks', *Ecosystem Services*, 18, pp. 165–174. doi: 10.1016/j.ecoser.2016.03.002.
- Barton, D. N. *et al.* (2016) 'Diagnosing agrosilvopastoral practices using Bayesian networks', *Agroforestry Systems*, 91(2), pp. 325–334. doi: 10.1007/s10457-016-9931-1.
- Bhowmik, C. *et al.* (2017) 'Optimal green energy planning for sustainable development: A review', *Renewable and Sustainable Energy Reviews*. Elsevier Ltd, 71 (December 2016), pp. 796–813. doi: 10.1016/j.rser.2016.12.105.
- Borunda, M. *et al.* (2016) 'Bayesian networks in renewable energy systems: A bibliographical survey', *Renewable and Sustainable Energy Reviews*. Elsevier, 62, pp. 32–45. doi: 10.1016/j.rser.2016.04.030.
- Campos, L. M. De and Castellano, J. G. (2007) 'Bayesian network learning algorithms using structural restrictions', 45, pp. 233–254. doi: 10.1016/j.ijar.2006.06.009.
- Cinar, D. and Kayakutlu, G. (2010) 'Knowledge-Based Systems Scenario analysis using Bayesian networks: A case study in energy sector', *Knowledge-Based Systems*. Elsevier B.V., 23(3), pp. 267–276. doi: 10.1016/j.knosys.2010.01.009.
- Conrady, S., Jouffe, L. and Elwert, F. (2014) 'Causality for Policy Assessment and Impact Analysis Directed Acyclic Graphs and Bayesian Networks for Causal', (November). doi: 10.13140/2.1.2350.1763.
- Corani, G. and Scanagatta, M. (2016) 'Environmental Modelling & Software Air pollution prediction via multi-label classification', 80. doi: 10.1016/j.envsoft.2016.02.030.
- Franco, C. *et al.* (2016) 'Environmental Modelling & Software A Bayesian Belief Network to assess rate of changes in coral reef ecosystems', *Environmental Modelling and Software*. Elsevier Ltd, 80, pp. 132–142. doi: 10.1016/j.envsoft.2016.02.029.
- Gambelli, D. *et al.* (2017) 'Third generation algae biofuels in Italy by 2030: A scenario analysis using Bayesian networks', 103(April 2016), pp. 165–178. doi: 10.1016/j.enpol.2017.01.013.
- Gerstenberger, M. C. *et al.* (2015) 'Bi-directional risk assessment in carbon capture and storage with Bayesian Networks', *International Journal of Greenhouse Gas Control*. Elsevier Ltd, 35, pp. 150–159. doi: 10.1016/j.ijggc.2015.01.010.
- Gonzalez-Redin, J. *et al.* (2016) 'Spatial Bayesian belief networks as a planning decision tool for mapping ecosystem services trade-offs on forested landscapes', *Environmental Research*, 144, pp. 15–26. doi: 10.1016/j.envres.2015.11.009
- Jha, S. K. (2019) 'A comprehensive search for expert classification methods in disease diagnosis and prediction', (April 2018). doi: 10.1111/exsy.12343.
- Kabir, S. and Papadopoulos, Y. (2019) 'Applications of Bayesian networks and Petri nets in safety, reliability, and risk assessments: A review', *Safety Science*. Elsevier, 115(April 2018), pp. 154–175. doi: 10.1016/j.ssci.2019.02.009.
- Kameshwar, S. *et al.* (2019) 'Probabilistic decision-support framework for community resilience: Incorporating multi-hazards, infrastructure interdependencies, and resilience goals in a Bayesian network', *Reliability Engineering & System Safety*, 191, 106568. doi: 10.1016/j.res.2019.106568
- Keshkar, A. R. *et al.* (2013) 'Application of Bayesian networks for sustainability assessment in catchment modeling and management (Case study: The Hablehood river catchment)', *Ecological Modelling*. Elsevier B.V., 268, pp. 48–54. doi: 10.1016/j.ecolmodel.2013.08.003.
- Kim, J. *et al.* (2018) 'Sustainable Technology Analysis of Artificial Intelligence Using Bayesian and Social Network Models'. doi: 10.3390/su10010115.
- Kumar, A. *et al.* (2010) 'Renewable energy in India: Current status and future potentials', (October). doi: 10.1016/j.rser.2010.04.003.
- Landuyt, D. *et al.* (2015) 'Environmental Modelling & Software a GIS plug-in for Bayesian belief networks: Towards a transparent software framework to assess and visualise uncertainties in ecosystem service mapping', *Environmental Modelling and Software*. Elsevier Ltd, 71, pp. 30–38. doi: 10.1016/j.envsoft.2015.05.002.
- Liu, Z. and Callies, U. (2019) 'Implications of using chemical dispersants to combat oil spills in the German Bight e Depiction by means of a Bayesian network *', *Environmental Pollution*. Elsevier Ltd, 248, pp. 609–620. doi: 10.1016/j.envpol.2019.02.063.
- Marcos, D. *et al.* (2018) 'Ecotoxicology and Environmental Safety Assessing mercury pollution in Amazon River tributaries using a Bayesian Network approach', *Ecotoxicology and Environmental Safety*. Elsevier Inc., 166(June), pp. 354–358. doi: 10.1016/j.ecoenv.2018.09.099.
- Martos, A. *et al.* (2016) 'Towards successful environmental performance of sustainable cities: Intervening sectors. A review', *Renewable and Sustainable Energy Reviews*. Elsevier, 57, pp. 479–495. doi: 10.1016/j.rser.2015.12.095.
- McLaughlin, D., and Reckhow, K. (2017) 'A Bayesian network assessment of macroinvertebrate responses to nutrients and other factors in streams of the Eastern Corn Belt Plains, Ohio, USA', *Ecological Modelling*, 345, pp. 21–29. doi: 10.1016/j.ecolmodel.2016.12.004

- Montgomery, D. C. and Runger, G. C. (2014) *Applied Statistics and Probability for Engineers*. 6th edn. John Wiley & Sons Inc.
- Mu, Y., Liu, X. and Wang, L. (2018) 'A Pearson's correlation coefficient based decision tree and its parallel implementation', *Information Sciences*. Elsevier Inc., 435, pp. 40–58. doi: 10.1016/j.ins.2017.12.059.
- Mukashema, A., Veldkamp, A. and Vrieling, A. (2014) 'International Journal of Applied Earth Observation and Geoinformation Automated high resolution mapping of coffee in Rwanda using an expert Bayesian network', *International Journal of Applied Earth Observations and Geoinformation*. Elsevier B.V., 33, pp. 331–340. doi: 10.1016/j.jag.2014.05.005.
- Organisation for Economic Cooperation and Development. (n.d). Retrieved from [https:// stats. oecd .org/](https://stats.oecd.org/)
- Orun, A. *et al.* (2018) 'Use of Bayesian inference method to model vehicular air pollution in local urban areas', *Transportation Research Part D*. Elsevier, 63(May), pp. 236–243. doi: 10.1016/j.trd.2018.05.009.
- Perreault, L. and Sheppard, J. (2019) 'International Journal of Approximate Reasoning Compact structures for continuous time Bayesian networks', *International Journal of Approximate Reasoning*. Elsevier Inc., 109, pp. 19–41. doi: 10.1016/j.ijar. 2019.03.005.
- Pitchforth, J. and Mengersen, K. (2013) 'Expert Systems with Applications A proposed validation framework for expert elicited Bayesian Networks', *Expert Systems with Applications*. Elsevier Ltd, 40(1), pp. 162–167. doi: 10.1016/j.eswa. 2012. 07.026.
- Res, C. *et al.* (2009) 'Applying Bayesian modelling to assess climate change effects on biofuel production', 40, pp. 249–260. doi: 10.3354/ cr00833.
- Ropero, R. F., Renooij, S. and Gaag, L. C. Van Der (2018) 'Discretizing environmental data for learning Bayesian-network classifiers', *Ecological Modelling*. Elsevier B.V., 368, pp. 391–403. doi: 10.1016/ j.ecolmodel. 2017.12.015.
- Tang, C. *et al.* (2016a) 'Risk analysis of emergent water pollution accidents based on a Bayesian Network', *Journal of Environmental Management*. Elsevier Ltd, 165, pp. 199–205. doi: 10.1016/ j.jenvman. 2015. 09.024.
- Tang, C. *et al.* (2016b) 'Risk forecasting of pollution accidents based on an integrated Bayesian Network and water quality model for the South to North Water Transfer Project', *Ecological Engineering*. Elsevier B.V., 96, pp. 109–116. doi: 10.1016/ j.ecoleng.2015.11.024.
- Tselykh, A., Tselykh, L. and Barkovskii, S. (2018) 'Knowledge discovery using maximization of the spread of influence in an expert system', (April 2017), pp. 1–19. doi: 10.1111/exsy. 12312.
- Washington, A. *et al.* (2019) 'Adoption of a Bayesian Belief Network for the System Safety Assessment of Remotely Piloted Aircraft Systems', *Safety Science*, 118, pp. 654-673. doi: 10.1016/j.ssci.2019.04.040
- Zarikas, V. *et al.* (2013) 'Statistical survey of elevator accidents in Greece', *Safety Science*. Elsevier Ltd, 59, pp. 93–103. doi: 10.1016/ j.ssci .2013. 05.001.
- Zarikas, V. (2014) 'Modeling decisions under uncertainty in adaptive user interfaces', (May 2007). doi: 10.1007/ s10209-007-0072-1.
- Zarikas, V. *et al.* (2018) 'Medical Decision Support Tool from a Fuzzy-Rules Driven Bayesian Network', 2(Icaart), pp. 539–549.
- Zarikas, V., Papageorgiou, E. and Regner, P. (2014) 'Article approach for medical decision support', 0(0). doi: 10.1111/exsy.12089.