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Review

Energy consumption prediction using machine learning; a review

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Abstract: Machine learning (ML) methods has recently contributed very well in the advancement of the prediction models used for energy consumption. Such models highly improve the accuracy, robustness, and precision and the generalization ability of the conventional time series forecasting tools. This article reviews the state of the art of machine learning models used in the general application of energy consumption. Through a novel search and taxonomy the most relevant literature in the field are classified according to the ML modeling technique, energy type, perdition type, and the application area. A comprehensive review of the literature identifies the major ML methods, their application and a discussion on the evaluation of their effectiveness in energy consumption prediction. This paper further makes a conclusion on the trend and the effectiveness of the ML models. As the result, this research reports an outstanding rise in the accuracy and an ever increasing performance of the prediction technologies using the novel hybrid and ensemble prediction models.

Keywords: energy consumption; prediction; machine learning models; deep learning models; artificial intelligence (AI); computational intelligence (CI); forecasting; soft computing (SC);

1. Introduction

Energy consumption is among one of the essential topics of energy systems. Energy consumption came under the consideration after the energy crisis in 1970s[1]. Also, It is shown that energy consumption throughout the world is rapidly increasing [2]. Therefore, each country tries to use as less energy as possible in their country in different areas from building to farms, from industrial process to vehicles [3]. As energy comes from three different resources like fossil fuels, renewable and nuclear resources [4], it need so much effort to keep tracking of energy consumption of these types in different area. However by doing so, we can predict the amount of energy, which is consumed in different areas and try to make plans, specialized for a specific usage and area.

For all energy types mentioned above, estimating the usage is useful for decision and policy makers. By knowing how much energy will be used for their process or work, they can be able to think of some changes in them to reduce the amount energy usage. Predicting future energy usage both in Short-term and Long-term manner will help us even to know, that in which type energy is used mostly and try to change the trend, as it is happed in the recent years for fossil fuels and now we have renewable energy. The amount of energy used in different areas is influenced by diffent factors such as water, wind, temperature. Having multiple factors, predicting the energy consumption is a complex problem[5].

Nowadays ML models are being used in different areas because they are useful and the way ML works is like a function which best maps the input data to output. Machine learning models can produce prediction for enery consumption with high accuracy. So they can be used by governments to implement enery-saving policies. For instance, ML models can predict the amount enery used in

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building [6]. They can also be used to predict the future use of different types of energy like electricity or natural gas[6].

This research work has been conducted in the prediction of different enery type usage. Predictions can be done on the usage of energy in a specific procedure in industry [7] or the total amout of energu used in a coutry [8]. This study tries to review the recent studies related to modeling and estimating of energy consumption in different area.

The organization of this paper is in a way to review different ML models for energy prediction like: ANFIS, ANN, DT, ELM, MLP, SVM/SVR, WNN, ENSEMBLE, HYBRID, and DEEP LEARNING. In each section related to each model we try to review the latest studies which uses ML models for forecasting energy usage in different applications.

2. Research Methodology

The database is created using the following search keywords to identify the manuscripts on energy consumption prediction using machine learning models. ISI and Scopus databases had been explored using the essential search keywords, i.e., (TITLE-ABS-KEY ("energy consumption") AND TITLE-ABS-KEY ("machine learning" OR "Deep learning" OR "ANN" OR "MLP" OR "ELM" OR "neural network" OR "ANFIS" OR "decision tree" OR wnn)).

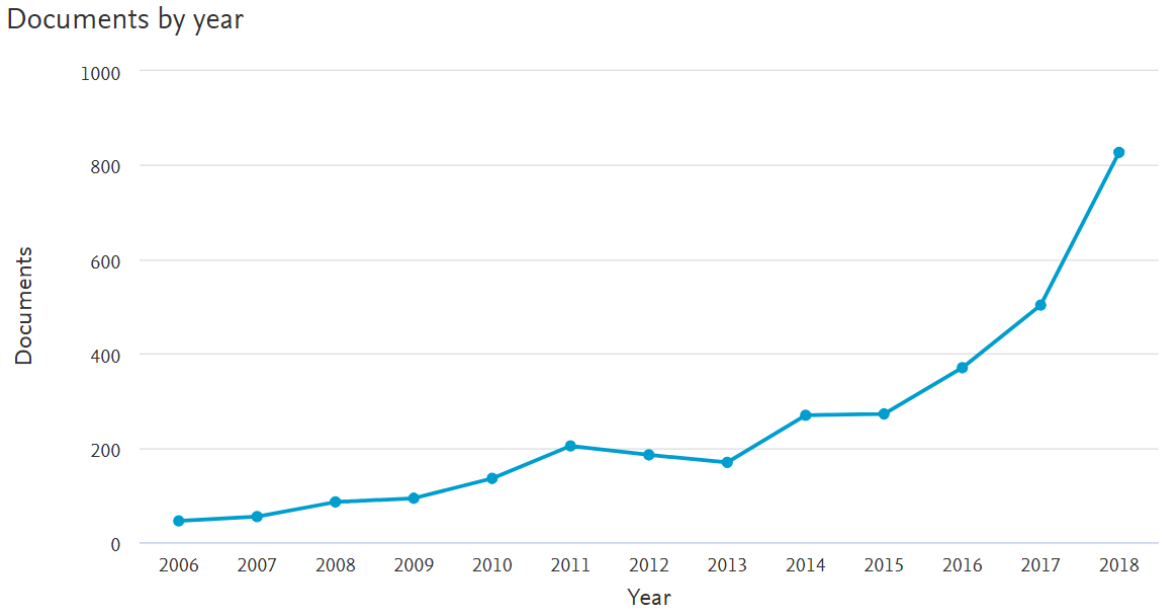

Figure 1. The progress of ML models for energy consumption prediction

Study the database shoes a dramatic increase in the number of papers from 2006 to 2018. The database include 4300 papers. The most relevant and original works have been revised in this state-of-the-art.

3. Machine learning models

Here comes the taxonomy chart and one paragraph explanation. The ML models include: ANFIS, ANN, DT, ELM, MLP, SVM/SVR, WNN, ENSEMBLE, HYBRID, and DEEP LEARNING.

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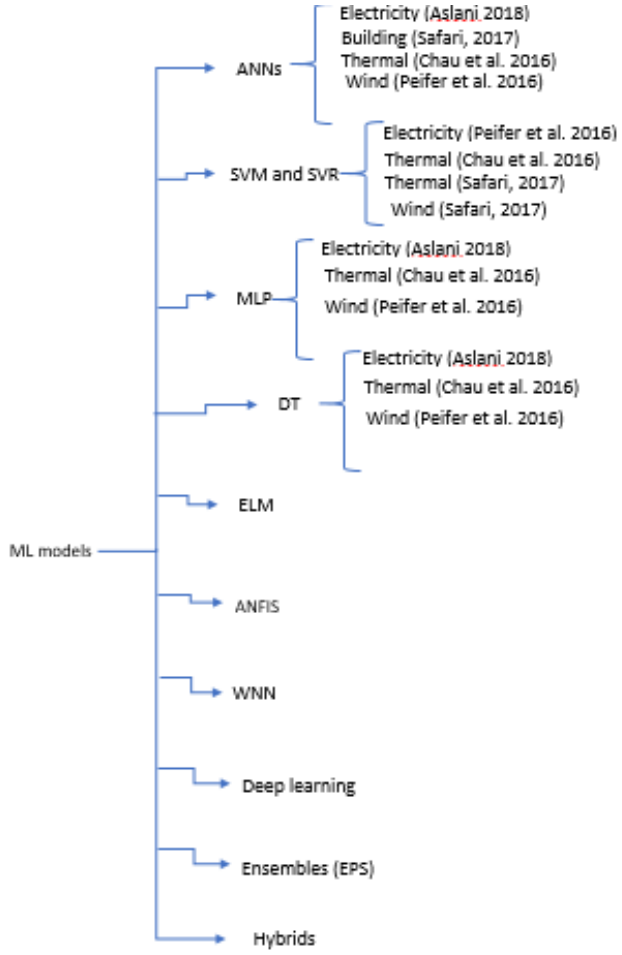

Figure 2. The taxonomy of research

3.1. ANFIS

Table 1. This is a table. Tables should be placed in the main text near to the first time they are cited.

Reference	Year	energy type	application	prediction type	region
Y. H. Gao, J.; Cai, L.; Chen, G.; Jia, N.; Zhu, L.; Wang, H.	2018	energy	MDF medium-density fiberboard	Long-term	U.S.
H. N.-P. Hosseinzadeh-Bandbafha, A.; Shamshirband, S.	2017	energy	fattening farms	Short-term	Iran
S. H. A. F. Kaboli, A.; Selvaraj, J.; Rahim, N. A.	2017	electricity	the whole country	Long-term	ASEAN-5 countries
O. M. Popoola	2016	electricity	lighting in residential houses	Short-term	South Africa
R. L. Maachou, A.; Khouider, A.; Bermad, A.	2016	energy	nitrate production in the	Long-term	Algeiers

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			wastewater treatment		
S. S. Naji, S.; Basser, H.; Alengaram, U. J.; Jumaat, M. Z.; Amirmojahedi, M.	2016	energy	buildings	Long-term	Iran
S. S. Naji, S.; Basser, H.; Keivani, A.; Alengaram, U. J.; Jumaat, M. Z.; Petković, D.	2016	energy	building	Long-term	iran
S. S. Naji, S.; Basser, H.; Alengaram, U. J.; Jumaat, M. Z.; Amirmojahedi, M.	2015	energy	bulilding with different envelope parameters	Long-term	Iran
B. R. Khoshnevisan, S.; Omid, M.; Mousazadeh, H.	2014	energy	agriculture	Long-term	Iran
V. N. A. Majazi Dalfard, M.; Nazari-Shirkouhi, S.; Sajadi, S. M.; Asadzadeh, S. M.	2013	Natural GAS	power generation	Long-term	IRAN

3.2. ANNs

Table 1. This is a table. Tables should be placed in the main text near to the first time they are cited.

Reference	Year	energy type	application	prediction type	region
B. Z. Sena, S. A.; Yakub, F.; Yusoff, N. M.; Ridwan, M. K.	2018	electricity	household	Real-time	Malaysia
J. F. Yue, H.; Yang, G.; Li, Z.	2018	solar	AGB estimation	Long-term	China
S. K. Saravanan, K.	2018	electricity	agriculture sector	Long-term	India
S. V. B. Oprea, A.; Reveiu, A.	2018	energy	building	Long-term	Romania
A. A. D. Z. Shojaie, A.; Vafaie, S.	2017	fuel	fuel station	Long-term	Iran
S. Ö. Tiryaki, Ş; Aydın, A.	2017	energy	machining of wood	Short-term	Turkey
J. W. J. Moon, S. K.	2016	thermal	accomodation buildings	daily	South Korea
M. M. Macas, F.; Fonti, A.; Giantomassi, A.; Comodi, G.;	2016	gas	buildings	hourly	Italy

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Annunziato, M.; Pizzuti, S.; Capra, A.					
E. D. Siami-Irdemoosa, S. R.	2015	fuel	mini dump trucks	Long-term	U.S.
M. S. Gunduz, H. B.	2015	hydro energy	hydroelectric power plant (renewable)	Long-term	Turkey

3.2. SVMs

Table 1. This is a table. Tables should be placed in the main text near to the first time they are cited.

Reference	Year	energy type	application	prediction type	region
H. F. Deng, D.; Eckelman, M. J.	2018	energy	comertial building	Long-term	U.S.
J. F. Yue, H.; Yang, G.; Li, Z.	2018	solar	AGB estimation	Long-term	China
X. L. Wang, D.; Zhao, X.; Sun, Z.	2018	energy	the whole country	yearly	China
C. E. T. Kontokosta, C.	2017	energy	buildings in a city	Long-term	U.S.
M. S. Stul, K.; Leenders, R.; Butaye, L.	2017	energy	industrial installations	Long-term	Belgium
D. P. Caicedo, A.	2016	electricity	indoor office lightning	Short-term	Netherlands
F. D. Zhang, C.; Lee, S. E.; Yang, J.; Shah, K. W.	2016	electricity	building	half-hourly and daily	Singapore
F. D. Zhang, C.; Lee, S. E.; Yang, J.; Shah, K. W.	2016	energy	institutional building	long	Singapore
S. S. Idowu, S.; Åhlund, C.; Schelén, O.	2016	water thermal	buldings	hourly	Sweden
W. H. Sun, Y.; Chang, H.	2015	fossil fuel energy	power generation	Long-term	China

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3.2. WNNs

Table 1. This is a table. Tables should be placed in the main text near to the first time they are cited.

Reference	Year	energy type	application	prediction type	region
J. G. Zhao, S.; Ren, D.; Li, Z.; Xue, L.	2015	energy	smart residential homes	Long-term	China
H Chitsaz, N amjady, H Zareipour	2014	wind	wind farms	hourly	Iran
	2013	electricity	load forcasting	Short-term	Canada/ Iran

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Hui Zhao ; Rong Liu ; Zhuoqun Zhao ; Chuanli Fan	2011	energy	energy consumption	Long-term	China
Eynard, Julien, Stéphane Grieu, and Monique Polit	2011	thermal	multi-energy district boiler	Short-term	France
C Chenm, S Duan, T cai, B Liu	2011	solar	solar power prediction	daily	China
Z. A. Bashir ; M. E. El-Hawary	2009	electricity	load demand	hourly	Canada
H Esen, F Ozgen, M Esen, A sengur	2009	solar	solar air heater	Long-term	Turkey
A. Oonsivilai ; M.E. El-Hawary	2002	electricity	electric power system comercial load	daily	Mexico
R Goa, L H Tsoukalas	2001	electricity	power consumption	Short-term	USA

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3.2. DTs

Table 1. This is a table. Tables should be placed in the main text near to the first time they are cited.

Reference	Year	energy type	application	prediction type	region
J. F. Yue, H.; Yang, G.; Li, Z.	2018	solar	AGB estimation	Long-term	China
P. M. Shine, M. D.; Upton, J.; Scully, T.	2018	water/ electricity	farm	monthly	Ireland
X. M. Lin, L.; Luo, Y.; Zhang, S.	2017	electricity	electric vehcle	Long-term	China
Z. H. Yu, F.; Fung, B. C. M.; Yoshino, H.	2010	energy	building	Long-term	Canada
G. K. F. Y. Tso, K. K. W.	2007	electricity	comparison	Long-term	Hong Kong

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3.2. DTs

Table 1. This is a table. Tables should be placed in the main text near to the first time they are cited.

Reference	Year	energy type	application	prediction type	region
H. F. Deng, D.; Eckelman, M. J.	2018	energy	comertial building		U.S.
J. F. Yue, H.; Yang, G.; Li, Z.	2018	solar	AGB estimation	Long-term	China
P. M. Shine, M. D.; Upton, J.; Scully, T.	2018	electricity/water	pasture based dairy farms	monthly	Irland

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Z. W. Wang, Y.; Zeng, R.; Srinivasan, R. S.; Ahrentzen, S.	2018	energy	educational buildings	hourly	U.S.
C. E. T. Kontokosta, C.	2017	energy	city scale energy use in buildings	yearly	U.S.
H. F. Deng, D.; Eckelman, M. J.	2017	energy	commertial building energy	long	U.S.
M. W. M. Ahmad, M.; Rezgui, Y.	2017	energy	building	hourly	Spain
SVM	2017	themporal	appliances in low-energy house	Short-term	Belgium
S. S. Idowu, S.; Åhlund, C.; Schelén, O.	2016	water thermal	buldings	hourly	Sweden
Greek Long-term energy consumption prediction using artificial neural networks	2010	energy	the whole country	Long-term	Greece

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3.2. ELMs

Table 1. This is a table. Tables should be placed in the main text near to the first time they are cited.

Reference	Year	energy type	application	prediction type	region
N. O. Izadyar, H. C.; Shamshirband, S.; Ghadamian, H.; Tong, C. W.	2015	thermal	residential heading demand	monthly	Iran
H. F. C. Gong, Z. S.; Zhu, Q. X.; He, Y. L.	2017	energy	petrochenical	Long-term	China
X. K. Lin, W.	2016	energy	cement industry	Long-term	China
S. K. Naji, A.; Shamshirband, S.; Alengaram, U. J.; Jumaat, M. Z.; Mansor, Z.; Lee, M.	2016	energy	building material construction	Long-term	Iran
J. Q. Wang, F.; Zhao, F.; Sutherland, J. W.	2016	energy	sintering process	yearly	U.S.
N. O. Izadyar, H. C.; Shamshirband, S.; Ghadamian, H.; Tong, C. W.	2015	natural gas	residential heating demand	monthly	Malaysia

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D. S. Zhai, Y. C.	2017	energy	ACMV systems	Long-term	Singapore
Y. Z. Han, Q.; Geng, Z.; Zhu, Q.	2018	energy	energy management optimization	Long-term	China

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3.2. MLPs

Table 1. This is a table. Tables should be placed in the main text near to the first time they are cited.

Reference	Year	energy type	application	prediction type	region
C. L. Deb, S. E.; Santamouris, M.	2018	energy	office building	Short-term	Singapore
P. M. Shine, M. D.; Upton, J.; Scully, T.	2018	electrical, water	farms	monthly	Ireland
Y. Z. Ding, Q.; Yuan, T.; Yang, K.	2018	thermal	HVAC System	daily	China
F. K. Wahid, D. H.	2017	energy	residential building	Short-term	South Korea
M. S. Safa, M.; Allen, J.; Shahi, A.; Haas, C. T.	2017	energy	offices and retail outlets	monthly	New Zealand
Y. Z. Ding, Q.; Yuan, T.; Yang, K.	2017	thermal	HVAC	Short-term	China
L. M. Mba, P.; Kemajou, A.	2016	energy	building in humid region	hourly	Cameroon
A. G. Capozzoli, D.; Causone, F.	2015	thermal	schools	Long-term	Italy
C. W. Zeng, C.; Zuo, L.; Zhang, B.; Hu, X.	2014	electricity	multi product pipeline	daily	China
D. C. Suh, S.	2012	electricity/ gas./ water	multi-family residential	Long-term	Korea

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3.2. ENSEMBLEs

Table 1. This is a table. Tables should be placed in the main text near to the first time they are cited.

Reference	Year	energy type	application	prediction type	region
P. M. Shine, M. D.; Upton, J.; Scully, T.	2018	electricity/water	pasture based dairy farms	monthly	Irland
S. A. Papadopoulos, E.; Woon, W. L.; Kontokosta, C. E.	2018	energy	buildings		UAE
S. N. Dai, D.; Li, Y.	2018	energy	Country level	Long-term	china
Z. W. Wang, Y.; Zeng, R.; Srinivasan, R. S.; Ahrentzen, S.	2018	electricity	educational buildings	hourly	U.S.

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M. H. C. Alobaidi, F.; Meguid, M. A.	2018	energy	Individual hosehold	Daily	France
M. W. M. Ahmad, M.; Rezgui, Y.	2017	energy	buildings	Hourly	Spain
L. W. Tang, S.; He, K.; Wang, S.	2015	nuclear energy	nuclear energy consumption in china	Long-term	China
R. Ž. S. Jovanović, A. A.; Živković, B. D.	2015	thermal	heating energy consumption	Short-term	Serbia
R. S. Jovanović, A.	2015	thermal	heating energy consumption	Long-term	Serbia
R. Ž. S. Jovanović, A. A.; Živković, B. D.	2015	thermal	energy consumption in a university campus	Short-term	Serbia

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3.2. HYBRIDs

Table 1. This is a table. Tables should be placed in the main text near to the first time they are cited.

Reference	Year	Energy type	application	Prediction type	Region
X. L. Wang, D.; Zhao, X.; Sun, Z.	2018	energy	the whole country	Long-term	China
C. D. Li, Z.; Zhao, D.; Yi, J.; Zhang, G.	2017	energy	building	Short-term	China
C. T. M. Cheung, K. W.; Wong, L. T.	2017	energy	cooling energy	Long-term	Chin
G. N. Golkarnarenji, M.; Badii, K.; Milani, A. S.; Jazar, R. N.; Khayyam, H.	2017	thermal	carbon fiber production line	Long-term	Australia
Y. T. Chen, H.; Berardi, U.	2017	electricity	commertial buildings	Hourly	China
B. L. Dong, Z.; Rahman, S. M. M.; Vega, R.	2016	elecetricity	residential building	hourly	U.S.
J. Q. Wang, F.; Zhao, F.; Sutherland, J. W.	2016	energy	sintering process	yearly	China
A. A. Azadeh, S. M.; Mirseraji, G. H.; Saberi, M.	2015	natural GAS	the whole country	Long-term	Iran
A. H. Abdoos, M.; Abdoos, A. A.	2015	electricity	electricity market	Hourly	Iran
J. C. An, Y.; Wu, M.	2015	energy	Blast furnace		China

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DEEP LEARNINGs

Table 1. This is a table. Tables should be placed in the main text near to the first time they are cited.

Reference	Year	energy type	application	prediction type	region
A. S. Rahman, A. D.	2018	thermal	comertial building	weekly	U.S.
C. D. Li, Z.; Zhao, D.; Yi, J.; Zhang, G.	2017	energy	building	Long-term	China
E. N. Mocanu, P. H.; Gibescu, M.; Kling, W. L.	2016	electricity	residential building	minutely	Netherlands
D. P. Antanasijević, V.; Ristić, M.; Perić-Grujić, A.	2015	energy	GHG	Long-term	Serbia
J. Q. Wang, F.; Zhu, J.; Ni, J.	2014	energy	a large-scale iron and steel enterprise (sintering process)	Long-term	China
E Mocanu, P H Ngueyen, M Gibescu, W L kling	2016	electricity	renewable energy sources	Long-term	Netherlands
C Fan, F Xiao, Y Zhao	2017	cooling	cooling load for building	daily	China
-J C .Riquelme	2016	electricity	load prediction for smart grid	Short-term	South Korea

[9-258], [7, 259-489], [490-739]

4. Discussion

The use of ML models have been increased during the last decade. Along with the conventional ML methods, e.g., ANNs and MLP, DTs, the application of hybrids and Ensemble methods has been dramatically increased. Through hybrid methods the researcher aim at higher accuracy and efficiency. The future direction of the research is to develop hybrid models with higher accuracy and higher speeds.

5. Conclusions

The use of ML models have been increased during the last decade. Along with the conventional ML methods, e.g., ANNs and MLP, DTs, the application of hybrids and Ensemble methods has been dramatically increased. Through hybrid methods the researcher aim at higher accuracy and efficiency. The future direction of the research is to develop hybrid models with higher accuracy and higher speeds.

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Conflicts of Interest: The authors declare no conflict of interest

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