



PhD Thesis Assessment Report

<i>PhD student:</i>	<u>Grzegorz Jaroslaw Marcjasz</u>
<i>Title of thesis:</i>	Deep learning in point, probabilistic and ensemble forecasting of electricity prices
<i>Department:</i>	Department of Operations Research and Business Intelligence, Wrocław University of Science and Technology
<i>Date of defence:</i>	

a) Coherence and scope of research

This thesis examines the applicability of deep learning for various electricity price forecasting, especially for short-term forecasting of the day-ahead and intraday prices. It comprehensively covers all three types of tasks, point, probabilistic, and ensemble (probabilistic) forecasting of electricity spot prices. It advances state-of-the-art techniques, such as Lasso regression and standard deep-learning neural networks (DNN), by providing the latest literature review and implementing even some benchmark models with open-access programming code. It extends the so-called NBEATS framework, to derive a partially interpretable ML algorithm to project the impact of external factors. It also develops a distributional DNN approach to gain a probabilistic forecast, which is even further developed in the fifth paper to derive ensemble probabilistic price forecasting.

The thesis shows a good understanding of the existing literature and the candidate's ability to operationalise relevant theory and key concepts in empirical quantitative research. The thesis represents a coherent and logically consistent research project with a well-defined and adequate scope. The scope covers a focused area of energy data analysis, i.e. electricity price forecasting (EPF), carried out with the latest DNN approaches. The different analyses are successfully brought together under the umbrella of advanced electricity spot price forecasting and the coverage of point, distributional and ensemble forecasting methods forms a nice coherence building on previous experiences.

The research methodology, including the methodological choices made in terms of data collection and the analytical procedures adopted, is sound and well-described throughout the thesis, but the justification of the single steps and of the chosen methods could be explained more. This can be seen also as a limitation of the work. Furthermore, some methods (such as distributional DNN) could have been described in more detail, both in section 3.2 as well as in Paper 4. Besides, the selection of the input features could have been more motivated and the dismissal of cross-border factors could have been explained.

Overall, the results of the research are in harmony with other cutting-edge research showing the strength of DNN in not only point but also probabilistic as well as ensemble forecasting of electricity spot prices. Thus, the candidate has demonstrated the ability to independently carry out a well-defined research project.

b) Major novel research results obtained

- one of the first main findings/results is that a robust hyper-parameter selection including 15 neural networks averaged, as provided in Paper 1, outperforms other ensembled NNs.

-Using a sufficiently long training period (min 1 year), comparing it to other well-established methods, making the models open access and considering computational times for new methods, are found as best practices of EPF studies.

The method provided in Paper 3, NBEATSx, allows both a high accuracy of forecasting and the output interpretable.

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<p>- A novel research result is also the provision of a distributional DNN, which can after a proper hyper-parameter optimisation, selection of the right distribution to be estimated (Johnson SU distribution), the model outperforms other approaches, such as quantile regression averaging).</p> <p>- Finally, the author demonstrates that DDNN ensemble (temporal dependency) forecasting method does not only provide accurate for a consecutive period, better to say their probabilities, but also finds that with this approach achieves significantly higher profits for a "battery-packed RES" than the second-best model, such as a LASSO-QRA probabilistic method.</p> <p><i>c) Significant advancement made to the technical field</i> Remarkable advancements to the scientific field are among others: A comprehensive latest review of state-of-the-art machine learning and statistical models is presented and based on this benchmark LEAR and DNN models for point forecasting has been provided. Paper 3 presents a novel approach to a neural basis expansion analysis (NBEATS; a sequence-to-sequence model based on a system of deep neural networks) that integrates external factors forming the NBEATSx. Expanding models based on time series to include external factors are very welcome and crucial to improve forecasts, but also interpretability. The distributional DNN (DDNN) in Paper 4 can be seen as the new state-of-the-art for probabilistic forecasting. Paper 5 provides "a DDNN ensemble that uses JSU-distributed networks and applies the Gaussian Copula on such probabilistic forecasts to reconstruct the temporal dependency between the consecutive subperiods". It is innovative to find other distributions that fit better than normal distributions in searching for better probabilistic forecasts.</p> <p><i>d) Impact of the research within the research area</i> The PhD candidate was extraordinarily successful in writing five papers in well-known journals (in the field of energy modelling and economics) that are part of this thesis and in (co-)authoring several other journal papers. Four of the five papers have already been published, while the fifth paper is under review. The papers and the others are already well-cited given the short period they were published, so the PhD candidate has achieved an h-index of 12 (Google Scholar) within a few years. Especially, by addressing novel aspects such as distributional DNN providing probabilistic forecasting, the PhD candidate has set new scientific standards. Also, the provided benchmark LEAR and DNN models as well as the provided reviews can help other researchers develop and apply their own tools with adjustments to their needs. Furthermore, the thesis clearly has the potential to contribute to stakeholders' applications in the energy industry, as the models provided deliver both accurate point and probabilistic forecasts. Though it becomes clear that energy traders and suppliers can benefit from the models developed, it is only to some extent discussed how the results can help policymakers. Finally, within the energy modelling scientific community, the newly developed and extended open-source models will be well-perceived and open chances for future generations of PhD researchers.</p>	

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e) Clarity of the thesis	
<p>The thesis is written in clear and understandable language and provides relevant information. The papers as well as the synopsis/thesis follow a clear structure aligned with the four research questions. Furthermore, the thesis provides a good description of the research design and methodology, theoretical perspectives and key concepts of (distributional) DNN and statistical methods. It also contains a comprehensive description of the main findings of the five papers. Some background information is only located in papers of the thesis, but also in other papers of the author, forcing the interested reader to look for those to allow for a full understanding of the thesis.</p> <p>All contributions of the thesis and enhancements beyond the state of the art are equally well-written and exciting for the reader.</p> <p>Considering all aspects mentioned above, I can confirm the requirements of the Act in the discipline of management and quality studies and I recommend to allow for its public defense.</p>	

Examiner

Title, name, affiliation Professor Dogan Keles - Technical University of Denmark

Date 13/11/2023 Signature 