Gottfried Wilhelm Leibniz Universität Hannover
Fakultät für Wirtschaftswissenschaften
Institut für Wirtschaftsinformatik

Analyzing the Applicability and Limitations of Artificial Intelligence in Decentralized Energy Systems

Masterarbeit

zur Erlangung des akademischen Grades „Master of Science (M.Sc.)“ im Masterstudiengang Wirtschaftswissenschaft der Wirtschaftswissenschaftlichen Fakultät der Leibniz Universität Hannover

vorgelegt von

Name: Stier
[redacted]

Vorname: Viktor Alexander
[redacted]

Prüfer: Prof. Dr. Michael H. Breitner

Betreuerin: M.Sc. Jana Gerlach

Hannover, den 18.10.2022

Table of contents

LIST OF FIGURES ..... **III**

LIST OF TABLES ..... **IV**

LIST OF EQUATIONS ..... **V**

LIST OF ABBREVIATIONS ..... **VI**

RESEARCH SUMMARY ..... **VII**

1 INTRODUCTION **1**

2 THEORETICAL BACKGROUND **3**

2.1 ARTIFICIAL NEURAL NETWORKS 3

2.1.1 Overall functioning of neural networks 4

2.1.2 Types of models 6

2.1.2.1 Single-Layer Model 6

2.1.2.2 Multi-Layer Model 9

2.1.2.3 Autoregressive recurrent neural networks model 10

2.2 TRAINING OF ARTIFICIAL NEURAL NETWORKS 12

2.2.1 Supervised Learning 13

2.2.2 Unsupervised Learning 13

2.2.3 Reinforcement Learning 14

2.3 OVER- AND UNDERFITTING 14

2.4 DECENTRALIZED ENERGY SYSTEMS 17

3 METHODOLOGY PREDICTION MODELS **18**

3.1 RELEVANCE OF THE TOPIC 18

3.2 PARAMETERS 21

3.2.1 Data Basis 21

3.2.2 Data Preparation 23

3.2.3 Correcting errors in the time series and filling gaps 24

3.2.4 Normalization of the data sets 29

3.3 LSTM IMPLEMENTATION USING TENSORFLOW 30

3.3.1 Baseline 31

3.3.2 Single-Step Models 31

3.3.3 Multi-Step Models 32

3.3.4 Correlation Heat Map 35

4 RESULTS **36**

4.1 RESULTS SOLARENERGY 36

4.2 RESULTS WIND ENERGY 39

5 EVALUATION OF LIMITATIONS AND APPLICABILITY **42**

6 DISCUSSION & OUTLOOK 45

BIBLIOGRAPHY 47

APPENDIX SUN PREDICTIONS 55

APPENDIX WIND PREDICTIONS 92

1 Introduction

While on the one hand climate change has been calling for a rethink of energy policy for several years, at the same time the consequences and risks of dependence on fossil fuels have become apparent in recent months, especially when, as in the case of Germany, these can only be satisfied by a few countries. In 2021, 55 percent of gas imports came from Russia, 35 percent of oil imports and 45 percent of coal imports. In the wake of Russia's attack on Ukraine, it is evident how difficult Germany is finding it to sanction Russia, as it does not want to weaken itself too much. At the same time, gas prices have risen sharply and with them, through the merit order, electricity prices in Europe.

After the destruction of the Nord Stream 1 pipeline, which is particularly important for Germany, a repair of the several hundred meter long opening is not yet foreseeable (Brinkmann & Krause, 2022; Nord Stream AG, 2022). This means that Germany will have to be prepared to buy far less gas at higher prices in the coming months and years. To prevent this from happening so easily in the future, it is now even more important for German energy policy to make itself independent of a few individual countries in order to be able to act in a more robust manner both politically and economically. For this to succeed, coal and gas-fired power plants must be scaled back and replaced. If this is done by relying on a supposedly endless source of energy such as nuclear power, it was possible to observe in the summer of 2022 what happens during a prolonged period of drought. Several nuclear power plants had to be shut down due to insufficient or too warm water in the river (The Economist, 2022). That's is why it is important to rely on renewable energies. This will most likely not be realized by a few wind or solar parks, but by many smaller installations, wherever there is space, and the investment is profitable. In recent years, it has become apparent that there is a variety of players on the market. More and more companies and private households are installing photovoltaic systems on their own roofs to produce electricity, which they feed into the grid for a small fee if they do not consume it themselves (*Energiewende und Dezentralität*, 2017, pp. 117–119). This accounts for a not insignificant share of the total generation of electricity. In March 2022, the installed capacity of photovoltaic systems in Germany was 58,400 megawatts (Destatis, 2022). The electricity grid operators are then responsible for keeping the grid frequency stable and decoupling individual generators from the grid if too much electricity is being generated. In the future, it can be assumed that many more photovoltaic systems will be installed, and depending on the weather, they will feed in different amounts of electricity. To ensure that there is still enough electricity in times when there is not much sunshine, for example in winter, more wind turbines will also be needed. On the one hand there is the advantage that the energy supply no longer depends centrally on a few generators such as gas-fired power plants, which in turn are connected to a pipeline that can easily be destroyed. This is an improvement in terms of safety because individual failures of wind power plants can be better compensated for. On the other hand, it also entails a considerable increase in the complexity of coordinating electricity. In addition, electricity supply is largely grid-bound and can only be stored to a limited extent. This implies that electricity trading markets are infrastructurally limited, i.e. by line bottlenecks (*Energiewende und Dezentralität*, 2017, pp. 32–33). Although the European electricity grid is structured as an interconnected grid, it is not possible to send as much electricity as desired from Spain to Germany if there is a deficit here (Sourkounis & Tourou, 2013).

This master thesis aims at elaborating the applicability and limitations of artificial intelligence in the context of distributed energy systems. Since wind and solar energy alone already account for more than 30% of the annual electricity generation and both types of energy are mainly dependent on the weather, this thesis tries to predict the electricity generation with the help of weather data. For the energy transition, it is essential to further expand these types of generation in the coming years and thus be exposed to even greater weather-related fluctuations. The thesis is structured as follows: In the first part, important terms for understanding the topic such as decentralized energy systems are first explained and the functionality, types, training and problems of artificial neural networks are discussed. After the theoretical basics, the explanation of the methodological approach follows in chapter 3. Then, in the following part, the results of the investigation on the different prediction models are presented. Chapter 5 deals with the evaluation of the applicability of artificial intelligence in distributed energy systems. Finally, the results of the thesis as well as aspects concerning the topic are discussed and an outlook is given.

6 Discussion & Outlook

The aim of this master thesis was to use weather data to predict the electricity production of photovoltaic and wind power plants and thus determine the possibilities and limitations of artificial intelligence in decentralized energy systems. Weather data from Jena were used as forecast variables. The prediction was to be made with the help of artificial intelligence in the form of neural networks. Various models were defined in the Google Colaboratoy Notebook based on the available standard models and then inputs and outputs were submitted for training.

The data that were available, especially those with the weather, had major dropouts that made automatic importing and processing impassable in this case. Tests have shown that even small gaps in the data set destroy the whole model in such a way that it runs through without a but no validation loss, MAE is created. It was enough if the date in a single line was only hh:mm instead of hh:mm:ss.

It became apparent that data on the generation of electricity, broken down by region and type, is very difficult to obtain. Especially for individual counties or city-states, it would have been interesting.

The results showed that the most complex model does not necessarily provide the best results. For example, in the multi-step prediction, the Dense Model delivered significantly better values than the Autoregressive recurrent neural network.

The number of adjusting screws in the model is hard to be grasped. From the number of epochs in the training to the many different feature set constellations to the choice of the right model and the right number of layers and overfitting countermeasures, all of which have an influence on the result. A separate file should have been created for each model, because some changes improved one model and significantly worsened the other at the same time.

Literature research has shown that, in theory, such a model can certainly be capable of outperforming the network operators' models (Lalanne, 2021). Since the data length in this model is very thin, it was not expected to outperform the network operators' data. However, the predictions made should not deviate too much from the predictions of the grid operator 50Hertz. Considering the data situation, the result can meet expectations despite its deviations. Nevertheless, further adjustments to the model are necessary, since it always underestimates the output, especially at higher generation peaks. It would be desirable for the future if there were a central database in which the generation of renewable energies could be recorded region by region. The smaller the recorded areas are, the more suitable they are for bundling with weather stations from the region and thus possibly obtaining a more meaningful result. Research is therefore needed into how the data is provided. Which agency collects such data and is it possible for strategic or security reasons that access to more accurate data is so difficult. Only after the problem of sparse data has been solved should the model be run again with new data, and only then should the results be used to evaluate the models.