Aalto University
School of Science
Master's Programme in Mathematics and Operations Research

Variable renewable energy generation in a future climate

Project plan

March 22, 2021

Team FMI

Tuukka Mattlar (project manager)
Patrik Lahti

Contents

1 Background

Climate change is one of the most topical subjects in political debate. The continuous growth of the human population requires increasing amounts of energy in order to sustain the growth. Yet, the use of greenhouse-emission intensive energy sources has had notable effect on climate change. From the beginning of the 21st century, the humankind has tried to find alternatives for energy production methods, which are less greenhouse-emission intensive. During the first decade of the 21st century, the renewable energy sources, such as solar power, wind power and water power, have started to get more profitable and affordable. The development of renewable energy sources has resulted increasing amount of investments into the renewable energy sources. Although, the renewable energy sources being are less greenhouse-emission intensive, there are issues related to replacing the traditional sources of energy with renewable ones. The renewable, weather-dependant production technologies are usually called variable renewable energy (VRE) technologies. The VRE energy sources include, e.g., solar power, producing power only during adequate solar conditions, and wind power, which needs sufficient wind speeds to produce energy at all and furthermore, there is a maximum wind speed under which the plant can be operated in order to prevent mechanical damage.

The traditional energy sources are easily adjustable and produce easily predictable amounts of energy. This makes it easy to sustain optimal levels of production with respect to the demand. Yet, the risk in replacing traditional energy sources with VRE is related to unpredictability of future climate and future weather conditions, i.e, how much capacity is needed to respond to changing demand of the society. On the other hand, the concern is not only to produce enough power to meet the demand, but to find a sustainable energy production portfolio, which matches the demand at all times. If the demand is not met by the production, the electricity distribution network experiences a shortfall, which if severe enough, either in length or in amplitude, could cause the whole electricity network to collapse, as there would not be enough voltage to serve all parties. Thus, the shortfalls must be compensated by buying electricity from external parties, e.g, energy markets, which, if possible, results to high costs.

The shortfalls in electricity networks are already an existing issue, as seen in the beginning of January 2021, as the unfavorable wind conditions resulted into underproduction of electricity in Romania, which has significant amounts of wind power in European scale. The underproduction caused the fluctuation of frequency of the current in the electricity network. If such a fluctuation occurs on a large enough scale, the network will collapse or separate.(1) In the future, if the percentage of the renewable energy sources increases, the issues related to energy production might get more frequent. Moreover, if the unfavorable weather conditions are wide-spread enough, there might even broader underproduction, which cannot be dealt as easily as in the case of Romanian underproduction, where isolating Romania from the wider European grid helped in balancing the load sufficiently. (1)

In this project, the variable energy generation in future climate is considered using predicted climate and weather data. The purpose of the project is to investigate which variables can be used to estimate the renewable energy production and how does the ability change spatially. Moreover, the goal is to find insights on frequency and length of the possible shortfalls given a predicted demand profile. A further question is also how does the variability of the energy generation effect the electricity markets, which is examined by employing a simple market model. The project aims to find sufficient variables and conversion models to generate the power outputs of the renewable energy sources, which in this work are restricted to wind power and the photo-voltaic solar power (PV) (see (2), (3)). With the conversion models, when future weather data can be used to estimate the probability and length of a shortfall corresponding different demand profiles. Moreover, the spatial dependence and correlation of the shortfalls is considered. This project is conducted in cooperation with the Finnish Meteorological Institute (FMI), which is responsible for weather models and predictions in Finland.

2 Objectives

The overall objective of this study is to deliver insights into the challenges and the possible solutions to the problems of future VRE production in a future climate scenario. As the field of renewable energy is emerging and complex, the problem can be addressed through several possible approaches. This study concentrates on the reasons and consequences, as well as solutions regarding the tail events, i.e, the shortfalls of the VRE production with respect to the demand. Therefore, the questions this study seeks answers to are, how frequent are the tail events, is there correlation with external factors affecting the tail events and whether there is possible solutions to prevent or reduce their occurrences. Moreover, as an auxiliary objective is to consider the economical impacts and threats related to the tail events.

Due to the complexity of the topic, solving the problem requires further research on the topic before further analysis. This also means that by gaining more knowledge, better ideas for new analysis can emerge during the project. Thus, the project will be agile, meaning that after each iteration the objectives and related tasks of the project is reconsidered to match the purpose of the assignment. However, achieving the initial goals requires to taking a direction suiting the purpose, the objectives are divided in ordered subcategories to prevent too large single intermediate goals and therefore, irrelevant work.

The first objective is to define and recognize the tail events and the circumstances in which the tail events are likely. By recognizing such events, the identification of the frequencies of the tail events at different locations is possible. The initial hypothesis is that the tail events require both PV power generation levels as well as wind speeds, i.e., low wind power generations, while the demand for electricity remains high. In order to find the sufficient circumstances for the tail events, it is necessary to consider multiple variables related to the weather conditions.

The second objective, i.e., the correlations between relevant variables and other external factors aims at trying to identity the reasons for the frequencies of different locations and their explanations. This is vital to understand the problem in its entirety and to be able to deliver solutions to the challenges related to the shortfall situations. The initial hypothesis is that the seasons and human-related demand cycles cause the most disturbances to balanced supply and demand equation, resulting in to the shortfalls. Moreover, the climate and semi-long period weather conditions are expected to cause such events.

The third objective aims at providing solutions to the problems and situations defined by two first objectives. These solutions are the most important outcome of this study, and they should be helpful in building the electricity grids with predicted conditions in the future climate scenario.

The objective considering the economical impact analysis is vital for any policies affecting the business and economy. The producers and consumers of energy are, under the general rules of economics, interested in the financially most attractive solutions. Thus, such analysis is the most important factor, when it comes to the real-world deployment of VRE production in the future climate scenario. Using such a model, the possibility to introduce energy storage opportunities can provide more realistic scenarios since such technologies are expected to be deployed in large scale, yielding even further possibilities.

The above objectives are in the order of relevance. The ordering and division between the objectives allows adjustments in the scope of the study, since the project-related objectives are to be kept compact enough to prevent insufficiently extensive study and too high a workload.

3 Tasks

To achieve the objectives of this project, there is a need for simulation and analysis of the VRE production. The data needed is available, provided by the World Climate Research Prorgamme, and more precisely, the coupled model intercomparison project (phase 6), i.e., the CMIP6. (4) As stated earlier about the agile nature of the project, the subsequent tasks will be reconsidered after having reached a sub-objective.

The first step to advance the project is to get familiar with the climate data and literature regarding the topic of this project. The basic visualizations of the wind and the solar radiation data give an initial insight of how the potential production and its influence. The data also exhibits the trends related to seasonal deviation related to phenomenon.

The literature review is carried out to learn more about the topic and to possibly collect ideas and best-practises related to the objective or methods used to reach the objective. For example, algorithms for converting weather conditions to coefficients corresponding production levels are required.

Having selected appropriate conversion algorithms, different factors and correlations can be analyzed. First, the aim is at constructing a comprehensive comparison of spatial locations and the external factors, such as the atmospheric pressure or any other factors considered in the literature. The methods required are conversion algorithms and methods for forecasting and modeling demand data for the future scenarios. Based on prevailing understanding, the methods proposed by Van Der Wiel(2) and Mattson (3) give a solid basis for the conversion and an example of the demand profile methods.

Such analysis and correlation discoveries can then be used to determine if any clear solutions can be easily drawn from the data. Initially, it is expected to observe decrease in tail events with a system of larger spatial spread, but this needs to be analysed.

The economic analysis has to involve external energy market factors and therefore might require building either a capacity expansion model or a electricity market model to investigate the costs and electricity prices in different scenarios. Such models are expected to be found during the literature review.

The exact methods and models are to be implemented and discussed later. By the time of the submission of project plan, no models nor algorithms have been selected.

To answer any further questions that arise later during the project, we first need to gather more knowledge and understanding of the domain.

4 Schedule

The schedule of the project will follow that of the course. Yet, the aim of this project is to be well ahead of the deadlines and schedules, which has been agreed upon by the team since the course schedule is regarded being relatively loose, giving the possibility to draw such decisions by ourselves as a team.

The course schedule is following:

- The project plan is to be delivered on 5.3.2021 and it is to be sent for a pre-review and comments for the opponent team by 3.3.2021.
- An interim report is due 9.4.2021 and again, it is to be sent for a pre-review for the opponent team by 7.4.2021.
- The final deliverable will be presented on 21.5.2021, and is to be prepared for pre-review for the opponent team by 19.5.2021.

To meet the deadlines stated in the schedule, the ultimate goal from the beginning is to concentrate on the final report and its content. The interim report is to be done roughly a week earlier since its main objective is to describe the current situation and to not cause any harm on the progress. The agreed iterative nature of the project furthermore provides possibility to reflect on already observed issues in the interim report.

From the schedule point of view of the project itself, as many as possible objectives are wish to be met but the limitation will be the time consumed and the limitation set by the schedule. Therefore, as soon as either all relevant objectives are met or the schedule or workload are about to be encountered, the analysis and final project delivery is started to be build according to the latest results.

5 Resources

The project team originally had four member but due to schedule issues two of these chose not to continue the project after the most initial steps. Therefore, the current team consists of two students, Patrik Lahti and Tuukka Mattlar, of which Tuukka is also acting as the project manager responsible of the administrative issues. Both students have background in Bachelors programme in Engineering Physics and Mathematics. Both students are currently pursuing Master of Science degree in Aalto University. Patrik majors in Mathematics and Operations Research where as Tuukka majors in Strategy in the Department of Industrial Engineering and Management. Moreover, Tuukka simultaneously has on-going studies at the Technical University of Munich in the Master degree program in Operations Research. The students have also knowledge of computer science, machine learning and energy markets from their minor studies. Even if the team is small, it has sufficient knowledge to excel in the project.

The contact person from FMI is Dr. Tommi Ekholm, who is a research professor at the FMI, specializing in climate change mitigation. Moreover, the project work is supported by Dr. Antti-Ilari Partanen, from FMI, who specializes in climate models and climate model data. The project team will be employing agile methods in the course of project due to the size of the group and availability of the FMI resources. The project work is also supported by the teacher-in-charge of the project seminar, Professor Ahti Salo, who will be assisting in choosing appropriate methods and sources. Moreover, Prof. Salo will provide feedback when needed.

The most critical resource in the project is availability of relevant data. In this project, the analysis will be based on predicted climate data forecasted using the CMIP6 model output. The data is freely available via internet platform (4). In addition to the data, the success of the project requires on-going and active connection with the FMI stakeholders to produce relevant and insightful models, as the topic is broad and has many approaches. The scope of the project will be set in the planning phase but due to exploratory nature of the project, the scope might need to be adjusted throughout the project. In the course of the project, the data analysis will be implemented using Python and Julia. Later, there may be need to build simple optimization models to allocate capacity for the energy resources. In this case, the Julia will be employed as the primary tool. Yet, if the modelling or analysis requires additional tools, those will be brought into use.

6 Risks

Table 1: Risks related to the project and the relevant issues regarding them.

Risk	Likelihood	Impact	Effect on project	How to prevent
Ill-posed scope	Low	High	Irrelevant work	Agile methods i.e. iterative way of working
Too much focus on too small details	Mid	Low	Too much work, over-quality in some parts and maybe lacking quality in other parts	Clear definition of subgoals and iterative upgrades on features later
Too large project	Low	High	Project does not get ready within the given time	Iteration of objectives
Lack of stakeholder involvement	Low	Mid-High	Either more work or worse results	Be prepared for any meetings to prevent unnecessary and frustrating work
Data is not suitable	Low-Mid	Mid	Misleading results	Planning and iterative progress
Lack of capabilities	Mid	High	Oversimplified analysis or incorrect results	Either more research or change of the scope
Lack of reasonable results	Mid	Low	Might not be able to answer any objectives	Use of good enough methods and resources

The main risks of the project are presented in the Table 1. The risks can be roughly divided in two sub-categories, project content related issues as well as management and other external issues. The content related risks mostly emerge from the magnitude and the quality of the scope and objectives and are therefore directly linked to the deliverables and the results. The external risks, such as losing a team member, directly affects the remaining team therefore primarily affecting the team work process.

The top priority, according the the risks identified, is to pose a sufficient scope that does not exceed the intended work load of the project yet delivers valid and essential content for the set objectives. This, being the main risk also identified by the course administration, it is planned to be controlled by an iterative process while working on the project.

Following the Table 1, unfortunately the occasion of losing a team member has already been encountered twice, thus the impact of such events in the future has risen highly.

References

[1] Tekniikka & Talous, "Euroopan sähköjärjestelmä käväisi lähellä romahdusta tammikuun 8. päivä – vaarallisin tilanne 14 vuoteen." https://www.tekniikkatalous.fi/uutiset/tt/9f81a101-222a-42f4-812f-0b26215f8fc7 [Accessed: 21th February 2021].

[2] K. van der Wiel, L. P. Stoop, B. Van Zuijlen, R. Blackport, M. Van den Broek, and F. Selten, "Meteorological conditions leading to extreme low variable renewable energy production and extreme high energy shortfall," *Renewable and Sustainable Energy Reviews*, vol. 111, pp. 261–275, 2019.

[3] N. Mattsson, V. Verendel, F. Hedenus, and L. Reichenberg, "An autopilot for energy models – automatic generation of renewable supply curves, hourly capacity factors and hourly synthetic electricity demand for arbitrary world regions," *Energy Strategy Reviews*, vol. 33, p. 100606, 2021.

[4] World Climate Reaseach Programme, "WCRP Coupled Model Intercomparison Project (Phase 6), CMIP6." https://esgf-data.dkrz.de/projects/cmip6-dkrz/ [Accessed: 21th February 2021].