



## **School of Social Sciences**

### **Supply Chain Management (SCM)**

#### **Postgraduate Dissertation**

The effectiveness of spatial and technological aggregation in  
managing the volumetric risk of renewable energy resources in  
Greece

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Patras, Greece, June 2023

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*I would like to offer my special thanks to my supervisor Dr. Nikolaos Thomaidis for his contribution, guidance and support to make this work possible.*

*I dedicate this dissertation to my family for their continuous support and understanding.*

## **Abstract**

The constantly increasing trend in energy demand worldwide, combined with the predicted depletion of planet's energy reserves from conventional resources, as well as the greenhouse emissions gas and the pollution issues that we have to face, lead to an increasingly widespread use of Renewable Energy Sources. However, the main challenge of Renewable Energy Sources is the unpredictability of volume's energy production due to unexpected weather conditions. This dissertation examines the spatially and technological aggregation for controlling the volumetric risk in Greece by presenting optimal power portfolios, in particular for wind energy, solar energy and the composite case (mixing wind and solar). For the purpose of our analysis, we implement the Modern Portfolio Theory for the optimization model. More specifically, we address the portfolio's risk (standard deviation) and yield (energy output). Furthermore, we investigate risk for optimal portfolios by minimizing coefficient of variation (CV). The results of our research show that these two strategies have great effectiveness for managing the volumetric risk.

**Keywords:** Renewable energy; Volumetric Risk; Power Portfolios; Optimization; Modern Portfolio Theory.

## Η αποτελεσματικότητα της χωρικής και τεχνολογικής συγκέντρωσης στη διαχείριση της αβεβαιότητας των ανανεώσιμων πηγών ενέργειας στην Ελλάδα.

Βοργιά Ναταλία

### Περίληψη

Η αύξηση της ζήτησης της ενέργειας σε όλο τον κόσμο, οι προβλέψεις εξάντλησης των συμβατικών πόρων της Γης, οι εκπομπές αερίων του θερμοκηπίου και τα προβλήματα ρυπάνσης είναι οι λόγοι που οδήγησαν στη διάδοση της χρήσης των Ανανεώσιμων Πηγών Ενέργειας. Ωστόσο, η κύρια πρόκληση των Ανανεώσιμων Πηγών Ενέργειας είναι η ανικανότητα πρόβλεψης της παραγωγής ενέργειας εξαιτίας των απροσδόκητων καιρικών συνθηκών. Η παρούσα διπλωματική εργασία εξετάζει τη χωρική και τεχνολογική στρατηγική διασποράς ώστε να μπορέσουμε να διαχειριστούμε την αβεβαιότητα παραγωγής στην Ελλάδα παρουσιάζοντας βέλτιστα χαρτοφυλάκια ισχύος. Για τους σκοπούς της ανάλυσης μας, θα εφαρμόσουμε τη μέθοδο Modern Portfolio Theory για το μοντέλο βελτιστοποίησης, ιδίως για την αιολική ενέργεια, την ηλιακή ενέργεια και τη σύνθετη περίπτωση (ανάμειξη αιολικής και ηλιακής). Πιο συγκεκριμένα, θα υπολογίσουμε τον κίνδυνο και την αναμενόμενη απόδοση χαρτοφυλακίων. Επιπλέον, θα διερευνήσουμε τον κίνδυνο σε βέλτιστα χαρτοφυλάκια μέσω της ενδιάμεσης περίπτωσης, δηλαδή ελαχιστοποιώντας το συντελεστή διακύμανσης. Τα αποτελέσματα της έρευνάς μας δείχνουν ότι αυτές οι δύο στρατηγικές (χωρική και τεχνολογική διασπορά) έχουν μεγάλη αποτελεσματικότητα στη διαχείριση της αβεβαιότητας.

### Λέξεις – Κλειδιά

Ανανεώσιμες Πηγές Ενέργειας, Κίνδυνος Παραγωγής, Χαρτοφυλάκια Ισχύος, Βέλτιστα Χαρτοφυλάκια, Modern Portfolio Theory

## Table of Contents

Abstract .....	5
Περίληψη .....	6
Table of Contents .....	7
List of Figures .....	9
List of Tables .....	12
List of Abbreviations & Acronyms.....	13
Chapter One: Introduction .....	14
1.1 Dissertation goals .....	14
1.2 Structure of the dissertation.....	15
Chapter two: Theoretical Background .....	16
2.1 Renewable Energy Sources.....	16
2.1.1 Penetration of Renewable Energy Sources in Greece.....	16
2.1.2 SDG's (Goal 7 – Affordable and Clean Energy) .....	17
2.2 Solar Energy.....	18
2.3 Wind Energy .....	19
2.4 Modern Portfolio Theory .....	21
2.4.1 Essential Characteristics .....	21
2.4.2 Risk and Reward Profiles.....	21
2.4.3 Mean – Variance Analysis .....	21
2.4.4 Power Portfolios.....	22
2.5 Risk analysis and Coefficient of Variation .....	23
2.6 Literature Review.....	24
Chapter three: Methodology .....	25
3.1 Goal of the research .....	25
3.2 Empirical Study .....	25
3.2.1 Selection of sample data .....	25
3.2.2 Preliminary Data Analysis and Descriptive Statistical Analysis of Sample Data.....	27
3.2.3 Correlation of RES Capacity Factors.....	34
3.3 Mathematical Formulation of the portfolio selection .....	37
3.3.1 Portfolio Optimization .....	37
3.3.2 Minimum Variance Portfolio.....	39
3.3.3 Maximum Yield Portfolio.....	39

3.3.4 Minimum Coefficient of Variation Portfolio .....	40
Chapter four: Results .....	41
4.1 Minimizing risk for wind power plants .....	41
4.2 Maximizing yield for wind power plants .....	43
4.3 Minimizing risk for solar power plants .....	44
4.4 Maximizing yield for solar power plants .....	46
4.5 Minimizing risk for wind & solar power plants .....	47
4.6 Maximizing yield for wind and solar power plants .....	50
4.7 Minimizing risk by minimizing CV .....	52
4.7.1 Minimizing CV for wind power plants .....	52
4.7.2 Minimizing CV for solar power plants .....	53
4.7.3 Minimizing CV for wind & solar power plants .....	55
4.8 Comparison of portfolios .....	57
Chapter five: Conclusion .....	59
References .....	61
Appendix A .....	65
Appendix B .....	68
Appendix C .....	72
Appendix D .....	85



## List of Figures

Figure 1: SDG's Goal 7

Figure 2: Photovoltaic electricity potential

Figure 3 (a): Wind Capacity (MW) per region of Greece

Figure 3 (b): Spatial distribution of wind capacity in Greece

Figure 4: 13 Regions of Greece (NUTS2 level)

Figure 5 (a): Average total annual wind production per region in MWh, map of Greece

Figure 5 (b): Average total annual wind production per region in MWh

Figure 5 (c): Standard deviation of total annual wind energy production per region in MWh, map of Greece

Figure 5 (d): Standard deviation of total annual wind energy production per region in MWh

Figure 6 (a): Average total annual solar production per region in MWh, map of Greece

Figure 6 (b): Average total annual solar production per region in MWh

Figure 6 (c): Standard deviation of total annual solar energy production per region in MWh, map of Greece

Figure 6 (d): Standard deviation of total annual solar energy production per region in MWh

Figure 7: Correlation matrix of annual wind & solar capacity factors

Figure 8: Synthesis of the minimum risk wind portfolio (map of Greece)

Figure 9: Synthesis of the maximum yield wind portfolio (map of Greece)

Figure 10: Synthesis of the minimum risk solar portfolio (map of Greece)

Figure 11: Synthesis of the maximum yield solar portfolio (map of Greece)

Figure 12 (a): Synthesis of the minimum risk wind & solar portfolio, wind distribution (map of Greece)

Figure 12 (b): Synthesis of the minimum risk wind & solar portfolio, solar distribution (map of Greece)

Figure 13 (a): Synthesis of the maximum yield wind and solar portfolio, wind distribution (map of Greece)

Figure 13 (b): Synthesis of the maximum yield wind and solar portfolio, solar distribution (map of Greece)

Figure 14: Synthesis of the minimum CV wind portfolio (map of Greece)

Figure 15: Synthesis of the minimum CV solar portfolio (map of Greece)

Figure 16 (a): Synthesis of the minimum CV wind & solar portfolio, wind distribution (maps of Greece)

Figure 16 (b): Synthesis of the minimum CV wind & solar portfolio, solar distribution (maps of Greece)

Figure 17: Summary table of optimal portfolios

Figure 18: Total annual wind production of Attica from 1986 to 2015

Figure 19: Total annual solar production of Attica from 1986 to 2015

Figure 20: Total annual wind production of North Aegean from 1986 to 2015

Figure 21: Total annual solar production of North Aegean from 1986 to 2015

Figure 22: Total annual wind production of South Aegean from 1986 to 2015

Figure 23: Total annual solar production of South Aegean from 1986 to 2015

Figure 24: Total annual wind production of Crete from 1986 to 2015

Figure 25: Total annual solar production of Crete from 1986 to 2015

Figure 26: Total annual wind production of Eastern Macedonia & Thrace from 1986 to 2015

Figure 27: Total annual solar production of Eastern Macedonia & Thrace from 1986 to 2015

Figure 28: Total annual wind production of Central Macedonia from 1986 to 2015

Figure 29: Total annual solar production of Central Macedonia from 1986 to 2015

Figure 30: Total annual wind production of Western Macedonia from 1986 to 2015

Figure 31: Total annual solar production of Western Macedonia from 1986 to 2015

Figure 32: Total annual wind production of Epirus from 1986 to 2015

Figure 33: Total annual solar production of Epirus from 1986 to 2015

Figure 34: Total annual wind production of Thessaly from 1986 to 2015

Figure 35: Total annual solar production of Thessaly from 1986 to 2015

Figure 36: Total annual wind production of Ionian Islands from 1986 to 2015

Figure 37: Total annual solar production of Ionian Islands from 1986 to 2015

Figure 38: Total annual wind production of Western Greece from 1986 to 2015

Figure 39: Total annual solar production of Western Greece from 1986 to 2015

Figure 40: Total annual wind production of Central Greece from 1986 to 2015

Figure 41: Total annual solar production of Central Greece from 1986 to 2015

Figure 42: Total annual wind production of Peloponnese from 1986 to 2015

Figure 43: Total annual solar production of Peloponnese from 1986 to 2015

## List of Tables

Table 1: 13 regions of Greece (NUTS2 level)

Table 2: Synthesis of the minimum risk wind portfolio

Table 3: Expected yield & risk of minimum risk wind portfolio

Table 4: Synthesis of the maximum yield wind portfolio

Table 5: Expected yield & risk of maximum yield wind portfolio

Table 6: Synthesis of the minimum risk solar portfolio

Table 7: Expected yield & risk of minimum risk solar portfolio

Table 8: Synthesis of the maximum yield solar portfolio

Table 9: Expected yield & risk of maximum yield solar portfolio

Table 10: Synthesis of the minimum risk wind and solar portfolio

Table 11: Expected yield & risk of minimum risk wind & solar portfolio

Table 12: Synthesis of the maximum yield wind and solar portfolio

Table 13: Expected yield & risk of minimum risk wind & solar portfolio

Table 14: Synthesis of the minimum CV wind portfolio

Table 15: Expected yield & Standard deviation of minimum CV wind portfolio

Table 16: Synthesis of the minimum CV solar portfolio

Table 17: Expected yield & Standard deviation of minimum CV wind portfolio

Table 18: Synthesis of the minimum CV wind & solar portfolio

Table 19: Expected yield & Standard deviation of minimum CV wind & solar portfolio

Table 20: Total annual wind production

Table 21: Total annual solar production

Table 22: Descriptive statistical analysis for wind per region

Table 23: Descriptive statistical analysis for solar per region

Table 24: Variance-Covariance matrix of annual wind & solar capacity factors

## List of Abbreviations & Acronyms

IPCC	Intergovernmental Panel on Climate Change
EU	European Union
RES	Renewable Energy Sources
UN	United Nations
HWEA	Hellenic Wind Energy Association
TWh	Terawatt hour
MV	Mean – Variance
EMHIRES	European Meteorological - derived High Resolution
MWh	Megawatt hour
MV	Minimum Variance
MY	Maximum Yield
CV	Coefficient of Variation

## **Chapter One: Introduction**

### **1.1 Dissertation goals**

One of the most important commodities in our live is energy. The majority of activities in our daily life, as well as the technological evolution we have, require the use of energy. Moreover, the depletion of the planet's natural resources is an issue that has been concerning scientists for many years. In recent years, the rate of use of the planet's resources is much greater than the rate of replenishment of those resources.

Continuing, the exploitation of natural resources increases the greenhouse gases, and as a result the environmental pollution. The global temperature increase is expected to exceed 1.5 degrees Celsius between the years 2023-2052, that would be catastrophic for certain ecosystems with consequences that would be irreversible (Allen, 2018). For these reasons, all stakeholders and governments have to take immediate action in order to ensure the elimination of the risk of our planet and avoid the scenario of natural disaster.

All the aforesaid have led to the wide adoption of renewable energy sources (RES), specifically wind and solar. On one hand, RES have a lot of advantages, such as they have zero emissions to the atmosphere and are practically inexhaustible. On the other hand, RES have many challenges. The main challenge is that we are incapable to predict the precise timing and volume of the energy production. This characteristic is because of unexpected weather conditions and decreases the amount of clean energy that integrated to grid.

A way of minimizing such challenges and managing the risk is by increasing spatial and technological diversification (Castro, 2022). The spatial diversification is referred to the distribution of energy production in different areas of our country; namely, the volumetric risk is dispersed. On the contrary, the technological diversification allocates the energy production with separate technologies, such as combination of wind and solar parks. In this dissertation, we will focus on the effectiveness of these two strategies in order to manage the volumetric risk of renewable energy sources in Greece by finding optimal solutions for dispersing wind and solar portfolio's risk.

## **1.2 Structure of the dissertation**

Here, we will represent the structure of this dissertation as follows.

Beginning with chapter two, we will show the theoretical background of this dissertation. We will refer to the penetration of renewable energy sources in our lives as well as in Goal 7, a common framework which was established for promoting the use of RES in EU member states. Afterward, a small report for wind and solar energy in Greece will be performed. Ending, we will mention the Modern Portfolio Theory and analyze some key terms that will be used in this dissertation.

In chapter three we will show the methodology of this dissertation. First of all, the goal of this research will be analyzed. Afterward, the empirical study of this dissertation will be represented (sample data selection, the preliminary analysis of our sample, descriptive statistical analysis and the correlation matrix). Lastly, the mathematical formulation of the portfolio selection will be represented.

In chapter four, we will present the results of the quantitative analysis for this research will be depicted, based on the equations that provided in mathematical formulation of the portfolio selection and finally all possible portfolios, according to aggregators' preferences will present.

In chapter five, our conclusions regarding the findings of this research will be discussed and we suggest areas for further research.

## **Chapter two: Theoretical Background**

### **2.1 Renewable Energy Sources**

#### **2.1.1 Penetration of Renewable Energy Sources in Greece**

The renewable energy sources (RES) or friendly forms of energy or new energy sources or green energy are forms of exploitable energy that originate from various natural processes such as wind, solar, geothermal, water circulation, and others. Why should a country turn to renewable energy sources? The answer is simple. RES are not exhaustible, they have much lower ecological footprint than conventional energy sources, and the cost of their installation and use is now much lower than in recent past (Cunha and Ferreira, 2014).

The energy sector in Greece is going through a transitional stage, as the national plan for energy and climate change has only been implemented in the last few years. Among other things, the plan includes the phase-out of coal, further liberalization of the electric market, increased penetration of RES in electricity generation, and other reforms. The main domestic source of energy in Greece was from lignite and it is expected to be replaced in the next few years, therefore the effort for closing all operating lignite units and replace them with RES (such as wind and solar parks) is being made (Makri, 2019).

As we referred, the motivation and the interest towards green energy has been strengthened. The electricity market has been regulated to a large extend, while the dominant role of DEI (Public Power Corporation) appears to be limited, making the market competitive and accessible to potential aggregators. The current trend in Greece, regarding investments in renewable energy sources, is upward, as the cost of their use has significantly decreased, and the licensing framework has recently improved. In previous years, the licensing process was characterized by long, complicated, and bureaucratic procedures that discouraged potential aggregators (Regulatory Authority for Energy).

Moreover, in recent years, the Hellenic Energy Exchanger has started operating, with the aim of greater transparency and the avoidance of distortions that plague the electricity market.



### 2.1.2 SDG's (Goal 7 – Affordable and Clean Energy)

The “Agenda 2030 for Sustainable Development – transforming our world” adopted by countries members of United Nations (U.N.) in 2015 and contains an action plan with 17 goals and 169 targets for people, planet, peace, prosperity and collaboration. In this context, the Greek side, following consultation with ministries, representatives of social partners, and other stakeholders, set the goals of sustainable development based on national priorities. The seven goal is talking about guaranteed access to affordable and clean energy for all people (Eurostat, 2023).

But why is seven goal so important?

- From 2000 to 2016, the percentage of population with access to electricity increased from 78% to 87%.
- In 2015, more that 20% of energy was generated from RES.
- The renewable energy sector gave jobs to 10 million people in 2017.
- 1 in 5 people on the planet do not have access to modern forms of electricity.
- Thee billion of the population still use wood, coal, charcoal, and animal waste for heating and cooking.
- Energy boosts the phenomenon of climate change, representing 60% of total greenhouse gas emissions.
- The reduction of carbon intensity in the energy sector is an important goal in addressing the issue of climate change.

For all the above reasons, affordable and accessible energy for everyone is the only way to curb the phenomenon of climate change and at the same time help the increasing rate of the world's population.

The goal aims to ensure universal access to affordable, reliable, and modern energy services by 2030. Moreover, there would be a remarkable increase in the share of renewable energy sources in the global energy mix, energy should become more efficient, and collaboration between organizations and countries should be developed to fully utilize existing and new infrastructure and technologies.



Figure 1: SDG's Goal 7 (Eurostat, 2023)

## 2.2 Solar Energy

The sun is an inexhaustible source of energy that can be converted either directly or indirectly into electrical energy. Photovoltaic systems directly harness solar energy by converting it into electricity through the photovoltaic phenomenon. The high solar potential of Greece makes the utilization of this technology particularly efficient. For a country with abundant sunshine like Greece, solar energy is an inexhaustible energy recourse (Suri M., 2020).

Below a map of Greece is illustrated with photovoltaic electricity potential. We observe that the Southern regions of Greece gives more potential solar energy than the North Greece.

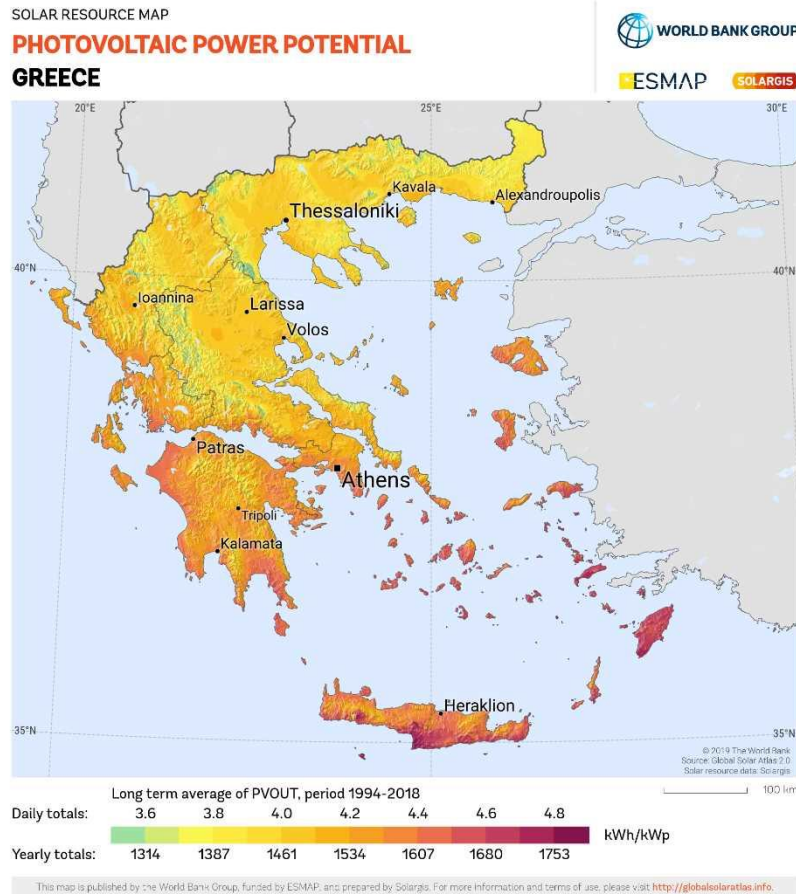


Figure 2: Photovoltaic electricity potential (2020 The World Bank, Source: Global Solar Atlas 2.0, Solar resource data: Solargis)

## 2.3 Wind Energy

The wind energy is currently an attractive solution to the problem of electricity production. The “fuel” is abundant, decentralized, and free. Furthermore, there are no emissions of gases and other pollutants, and the environmental impact is small compared to conventional fuel power plants. Moreover, the economic benefits of a region from the development of wind industry are significant. Recently, our country succeeded tremendous steps in the direction of wind energy transition. According to Hellenic Wind Energy Association (HWEA) the electricity generation from wind in 2022 in Greece was 10.7TWh.

Figure 3 (a) and (b) shows the wind penetration in Greece.

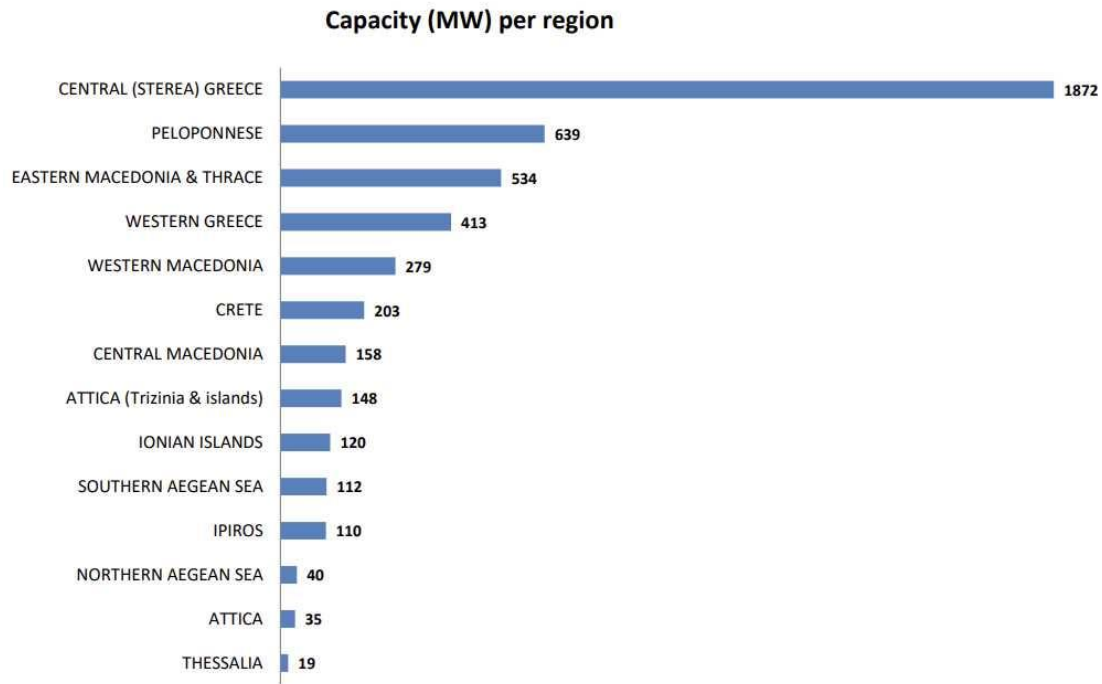


Figure 3 (a): Wind Capacity (MW) per region of Greece (Hellenic Wind Energy Association, 2022)

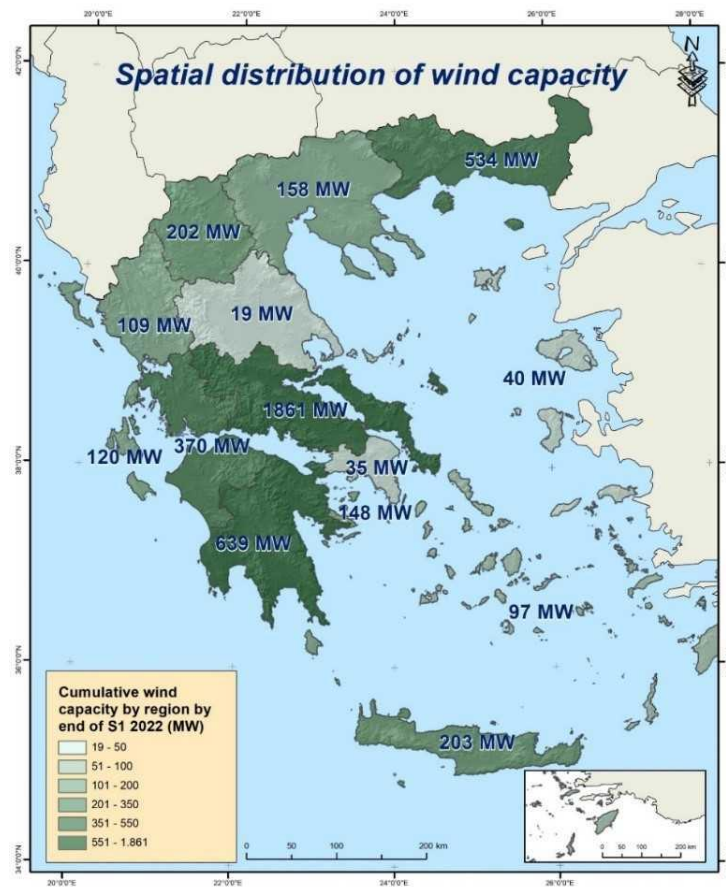


Figure 3 (b): Spatial distribution of wind capacity in Greece (Hellenic Wind Energy Association, 2022)

## **2.4 Modern Portfolio Theory**

### **2.4.1 Essential Characteristics**

Modern Portfolio Theory (MPT) is widely used for financial concepts and introduced by Markowitz in 1952. Essentially, MPT creates a diversified portfolio of assets to maximize returns while reducing risk by using mathematical and statistical principles. For this reason, it is a valuable tool for investors who desire to build a diversified portfolio and manage their risks effectively (Markowitz, 1952). MPT can be also applied in the energy as well (Campecino, 2021).

### **2.4.2 Risk and Reward Profiles**

Investing in renewable energy sources would carry challenges, therefore, the aggregators expose themselves to risks. The main risk that investors of RES are exposed is the uncertainty of power production ascribed to variable weather conditions. This is also known as volumetric risk. There are strategies that promise to reduce the volumetric risk, such strategies are technological and spatial diversification that we will analyze in this dissertation (Castro, 2022).

But not all investors have the same attitude towards risk. There are three types of investors based on their risk profile and are categorized as conservative, moderate, and aggressive. First, conservative investors tend to put first the safety of their investments and are willing to accept lower returns in exchange for lower risk. Second, moderate investors accept moderate risks for the possibility of high returns. Thirdly, aggressive investors who desire higher returns but taking higher risks. It is important to note that every investor is unique, and their profile is possibly to change over time (Boreiko and Massarotti, 2020).

### **2.4.3 Mean – Variance Analysis**

The Mean – Variance (MV) analysis is the basic tool of MPT, since is founded on the risk profile of the investors. The aim is to find a portfolio that maximizes the yield and minimizing risk, simultaneously. This analysis takes into account each individual investment's production capacity (expected yield), the risk associated with each investment and the correlation between the investments in the portfolio. The result is a

portfolio which balances the risk and expected yield in order to achieve the best possible outcome. Thus, diversification is a very important technique for managing the risk. It is crucial that the assets which compose a portfolio do not have a perfect correlation or a correlation coefficient of one for having a diversified portfolio (Cunha and Ferreira, 2014).

Modern Portfolio Theory based on the following measurements:

- Portfolio's yield, given by the mean of total annual wind & solar production from regions of Greece that compose the portfolio;
- Portfolio's risk, given by the standard deviation of the portfolio yield in a given period; (Castro, 2022)

In chapter three will be represented the mathematics equations of these measurements.

#### **2.4.4 Power Portfolios**

As we referred above Modern Portfolio Theory (MPT) is widely used for financial concept. The MPT can be applied in energy sector for creating optimal power portfolios. As stated above, one way to minimize variability is by raising technological and spatial diversification, for instance mixing generation from different technologies, such as from wind and solar technologies, at different locations. There are a lot of studies that investigate the diversification of RES in different locations. For example, Thomaidis and Moukas (2022) based on this strategy designed efficient RES portfolios for power demand in Europe. Further studies will mention in 2.6 subsection.

Even though power portfolios find implementation in various cases, in this work, the viewpoint of an investor is to look for distributing the production capacity from wind energy, solar energy or a combination of them into different locations for:

1. Minimizing the total risk, and
2. Maximizing the total expected yield.

Continuing, it is very important to explain the definition of capacity factor measurement, since Capacity Factor (CF) is an important measurement that we will use in this dissertation, specifically in chapter three.



Capacity factor is a measure of the actual output of a power plant or other electricity generation equipment compared to its maximum possible output in a given time period. It is calculated as the ratio of the actual output of the plant in megawatt-hours (MWh) over a specified period of time to the maximum possible output over the same period, this is measured in megawatts (MW) (Gonzalez, 2016).

The capacity factor is typically expressed as a percentage, and it is a worthy measure of the efficiency and reliability of a power plant or other electricity generator. The capacity factors is calculated by the following equation:

$$\text{Capacity Factor} = \frac{\text{Actual Energy Generated (MWh)}}{\text{Capacity (MW)} \cdot \text{Time Period (h)}}$$

The range of hourly capacity factor is between 0 and 1. The closer to 1 the value of capacity factor is the greater the production is at its maximum power. The capacity factor is determined by the availability of energy resources such as wind or solar.

In this dissertation, we consider that the installed capacity of portfolios is equals to 1 MW.

## 2.5 Risk analysis and Coefficient of Variation

The coefficient of variation is a statistical measure that is used to compare the variability of two or more sets of data with different measurement units or scales. It is computed by dividing the standard deviation of a set of data by its mean and is expressed as a percentage.

The coefficient of variation is used in risk analysis to assess the level of risk associated with different investments or assets. A higher coefficient of variation indicates a higher level of risk, while a lower coefficient of variation indicates a lower level of risk (Campecino, 2021).

## 2.6 Literature Review

As we mention diversification strategy reducing the volumetric risk. There are plenty of studies that have been adopted this strategy.

In their research Thomaidis et al., try to find ways for power balancing between two technologies (wind and solar). The case study based on data from Iberian Peninsula by applying mean-variance portfolio optimization. They found out that the composite case (mixing wind and solar resources) is more efficient rather than having only one technology (Thomaidis et al., 2016).

Another research from Santos-Alamillos, Thomaidis et al., have investigated optimal locations of wind farms in Spain, regarding the spatiotemporal balancing of the wind energy to minimize the delivery output fluctuations. They attempted to answer the question of whether the current wind farm network is efficient by using hourly capacity factors from different areas in Spain. They found out that the existing dispersion of wind farms is not so efficient, as there is another optimal dispersion to succeed smoother delivery energy output (Santos-Alamillos et al., 2016).

Furthermore, Santos-Alamillos, Thomaidis et al., have studied optimal scenarios to distribute new renewable capacity among European countries. The purpose is to provide which European countries have better performance in increasing overall energy production or reducing variability. The case study based on PV and WF capacity factors from various countries of Europe. They found out that the current dispersion of European wind and PV capacity is a long way from optimal but the choice of where resources will be developed depends on the desired goal (Santos-Alamillos et al., 2017).

Last, in their research Thomaidis et al., have studied two strategies in order to manage the volumetric risk of wind output production in Spain. The first one is founded on diversification (spatial dispersing of wind farms) and the second one is referred to hedging (compensate aggregators from unexpected reductions in power delivery by using financial instruments). The case study based on combination of advanced weather modelling, time series analysis, simulation, and optimization methods. The results of this analysis encourage the researcher to suggest financial contracts and blending strategies that are suitable to the risk profile of each aggregator (Thomaidis et al., 2022).



## Chapter three: Methodology

Chapter three will present the goal of this research and responded to a few questions that come from it. Afterwards, we will represent the selection of the sample data and the processing of data. Furthermore, we will analyze and discuss the descriptive statistical analysis of sample data.

### 3.1 Goal of the research

In chapter two were mentioned the risks that we have due to the unpredictability of weather conditions, for this reason the energy production from RES is characterized from uncertainty. The goal of this chapter is to examine the effectiveness of the spatial and technological diversification in order to reduce the risk that an aggregator has to carry out, concerning the variability of wind and solar production and keep the energy production in high levels, simultaneously.

Below we provide some of the questions that this research will answer:

- In which regions in Greece do we find the maximum and minimum wind & solar power production throughout the years?
- In which regions in Greece do we find the maximum and minimum variance wind & solar power production throughout the years?
- Which pair of regions are positive and negative correlated and how does this correlation affect them?
- Which are the optimal power portfolios, according to the preferences of the aggregators?

### 3.2 Empirical Study

#### 3.2.1 Selection of sample data

All sample data were retrieved from the EMHIRES dataset (European Meteorological derived High Resolution RES generation time series for present and future scenarios). The publishing of the EMHIRES dataset provided useful and available data about European wind and solar power generation, that are derived from weather data, for NUTS-2 level, among them Greece. The given time series from EMHIRES dataset are hourly wind and solar capacity factors for 30 years (from 1986 to 2015) in 13 regions of Greece (Gonzalez, 2016, 2017).

The 13 regions of Greece that are part of the sample data are summarized in table 1 and are illustrated in figure 4.

Table 1: 13 regions of Greece (NUTS2 level)

Rank	Code	NUTS 2
1	EL30	Attica
2	EL41	North Aegean
3	EL42	South Aegean
4	EL43	Crete
5	EL51	Eastern Macedonia & Thrace
6	EL52	Central Macedonia
7	EL53	Western Macedonia
8	EL54	Epirus
9	EL61	Thessaly
10	EL62	Ionian Islands
11	EL63	Western Greece
12	EL64	Central Greece
13	EL65	Peloponnese



Figure 4: 13 Regions of Greece (NUTS2 level) (Eurostat, 2021)

### 3.2.2 Preliminary Data Analysis and Descriptive Statistical Analysis of Sample Data

The given datasets correspond to hourly capacity factors (wind and solar) for a period of 30 years. To reduce computational requirements, the hourly capacity factors of wind and solar datasets were consolidated into annual ones. Now, the interpretation of the results for us will be easier, as the form of the observations includes annual wind and solar capacity factors in 13 regions of Greece.

Appendix A includes two tables. The first table shows the total annual wind energy production, and the second table shows the total annual solar energy production of 13 regions. In all figures, production is standardized to 1MW of installed capacity.

Observing both tables with the results in Appendix A, we can extract information about wind and solar energy every year, from 1986 to 2015. We conclude that the region of South Aegean has the maximum wind production in 1987, which is 2983.507 MWh. However, the minimum wind production has the Western Macedonia region in 2014, which is 747.590 MWh. Regarding the solar production, it can be seen that South Aegean has the highest solar production in 1993, which is 1798.992 MWh and Western Macedonia region has the lowest solar production in 1996, which is 1291.034 MWh.

Following on from the transformation of sample observations from hourly to yearly wind and solar capacity factors, a descriptive statistics analysis on the total annual wind and solar energy production was performed by using the Data Analysis tool of Excel. Appendix B includes two tables. The first table contains the results of wind production from the descriptive statistics analysis and the second table contains the solar production per region.

Scanning the results, we can extract useful historical data about the wind and solar energy in Greece. Beginning with wind data, figure 5 shows the average total annual wind energy production as well as the standard deviation per region. It is evident that the highest average total annual wind energy production has the region of South Aegean, which is 2586.372 MWh with a standard deviation of 210.986 MWh.

Apparently seeing the figure 2, Eastern Macedonia & Thrace, North Aegean and Attica are regions that also have high wind energy production.

From the opposing point of view, the lowest average total yearly wind production has the region of Western Macedonia, which is 1015.358 MWh with a standard deviation of 141.281 MWh. The regions of Thessaly and Epirus have also low wind production, as well as Western and Central Greece that have similar low wind production. Therefore, we observe that the eastern side of Greece is affected by winds relative to western.

Moreover, we observe that Thessaly is the region with the minimum value of standard deviation, which is 112.496 MWh. This means that observations of Thessaly are clustered to the average total annual wind energy production. This does not apply for the Attica region, which has the maximum standard deviation (227.940 MWh) by means that the observations of Attica are far from the average total annual wind energy production.

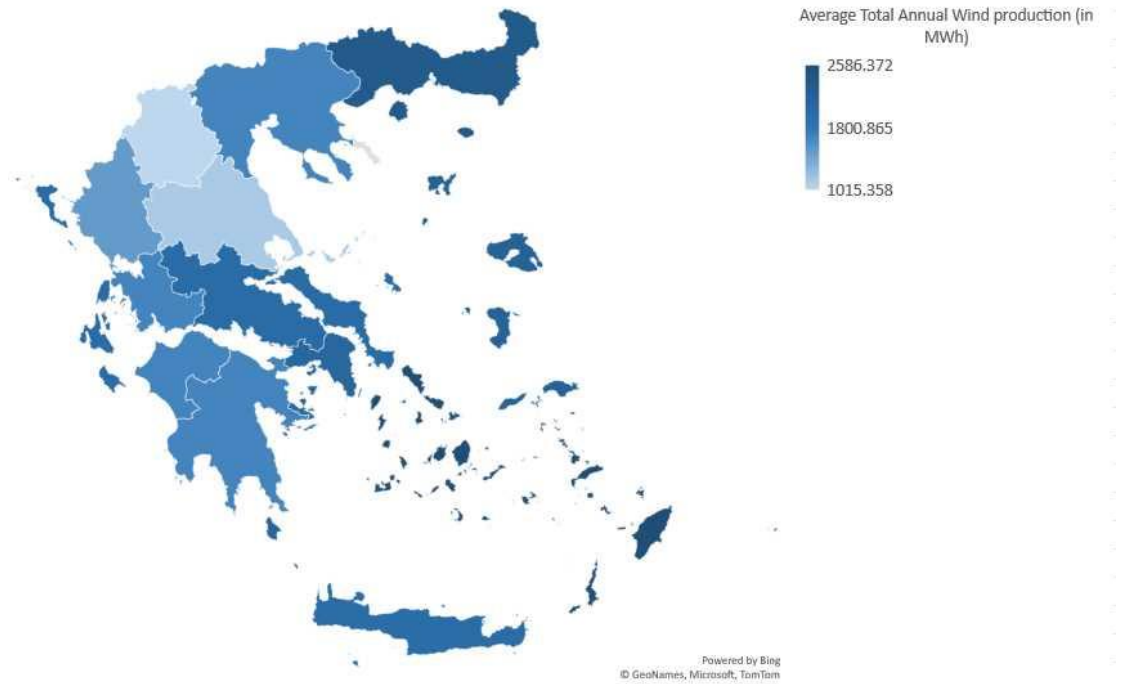


Figure 5 (a): Average total annual wind production per region in MWh, map of Greece

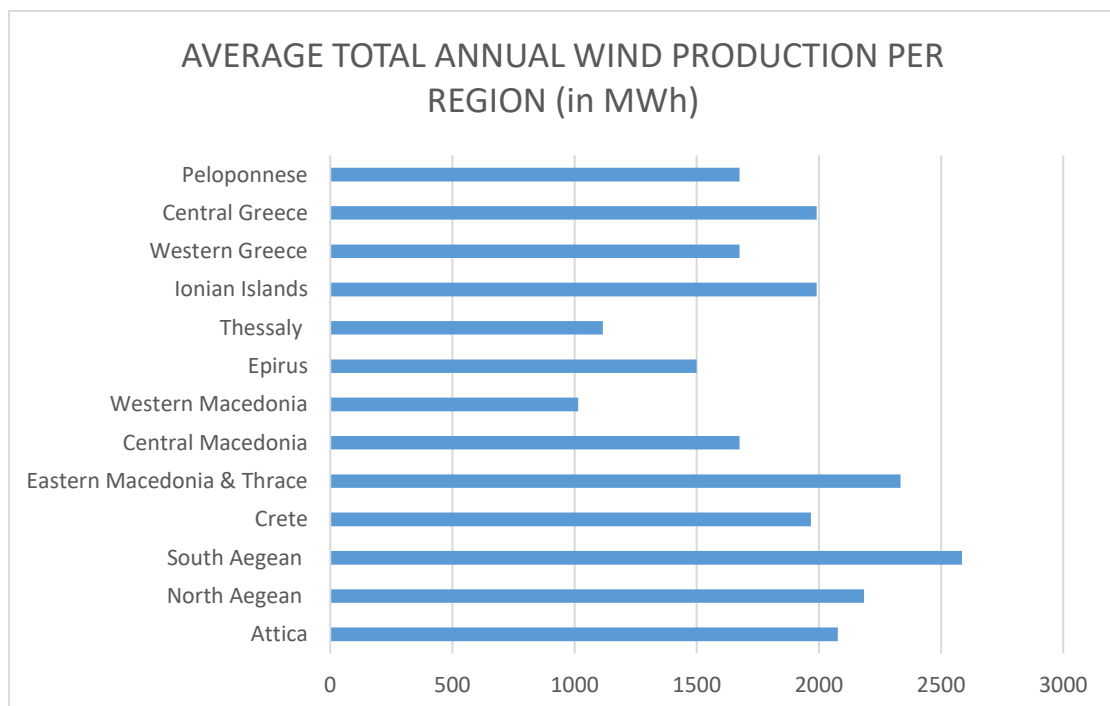


Figure 5 (b): Average total annual wind production per region in MWh

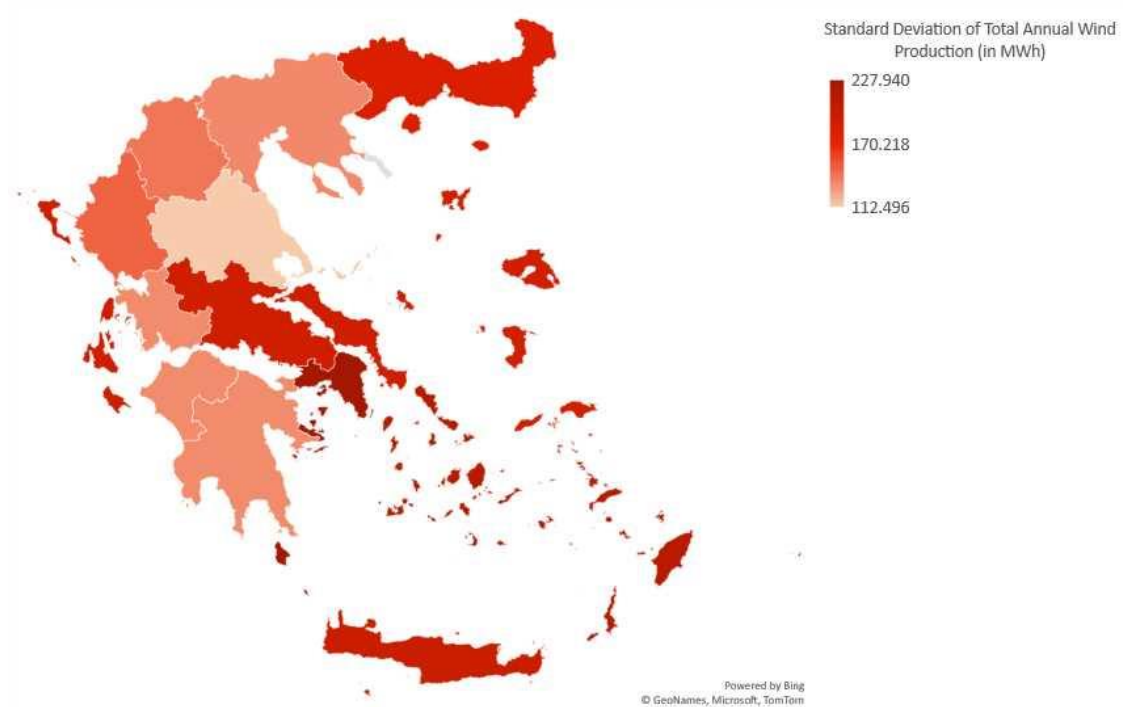


Figure 5 (c): Standard deviation of total annual wind energy production per region in MWh, map of Greece

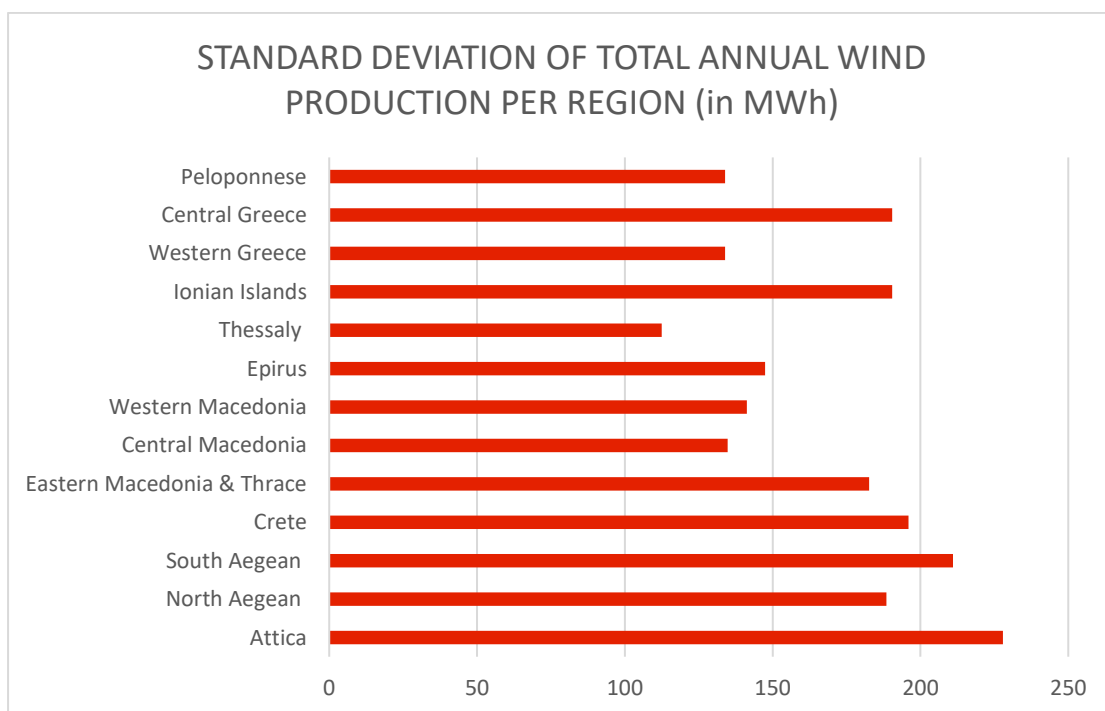


Figure 5 (d): Standard deviation of total annual wind energy production per region in MWh

Continuing with solar data, figure 6 shows the average total annual solar energy production as well as the standard deviation per region. Although there are no big fluctuations in average total annual solar energy production per region, we observe that South Aegean region has the highest value, which is 1729.848 MWh with a standard deviation 34.783 MWh. Then, follow the regions of Crete, North Aegean, and Attica with high solar production. On the other hand, Western Macedonia region has the lowest value, which is 1425.364 MWh with a standard deviation of 53.989 MWh. The regions of Thessaly, Central Macedonia, Eastern Macedonia & Thrace and Epirus have also low solar energy production.

Furthermore, we observe that Crete is the region with the minimum value of standard deviation 33.674 MWh. This means that observations of Crete show the least dispersion. On the contrary, Epirus has the highest volumetric risk with a standard deviation of the annual solar energy production being equal to 56.879 MWh.

Moreover, in Appendix C is illustrated the total annual wind and solar productions per regions from 1986 to 2015.

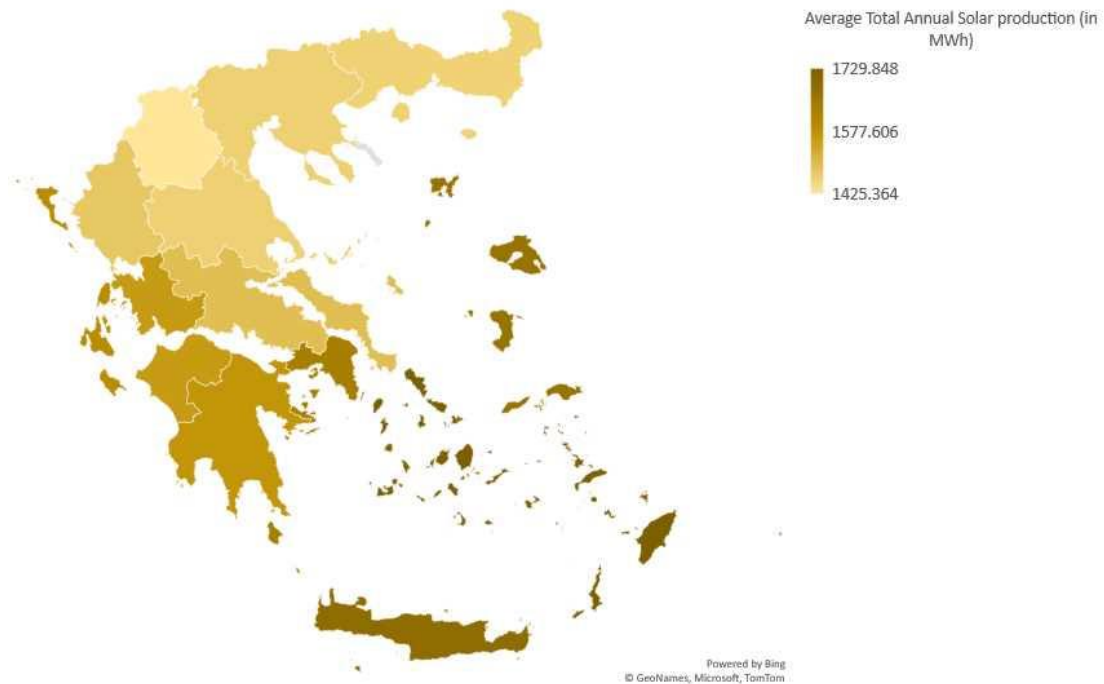


Figure 6 (a): Average total annual solar production per region in MWh, map of Greece

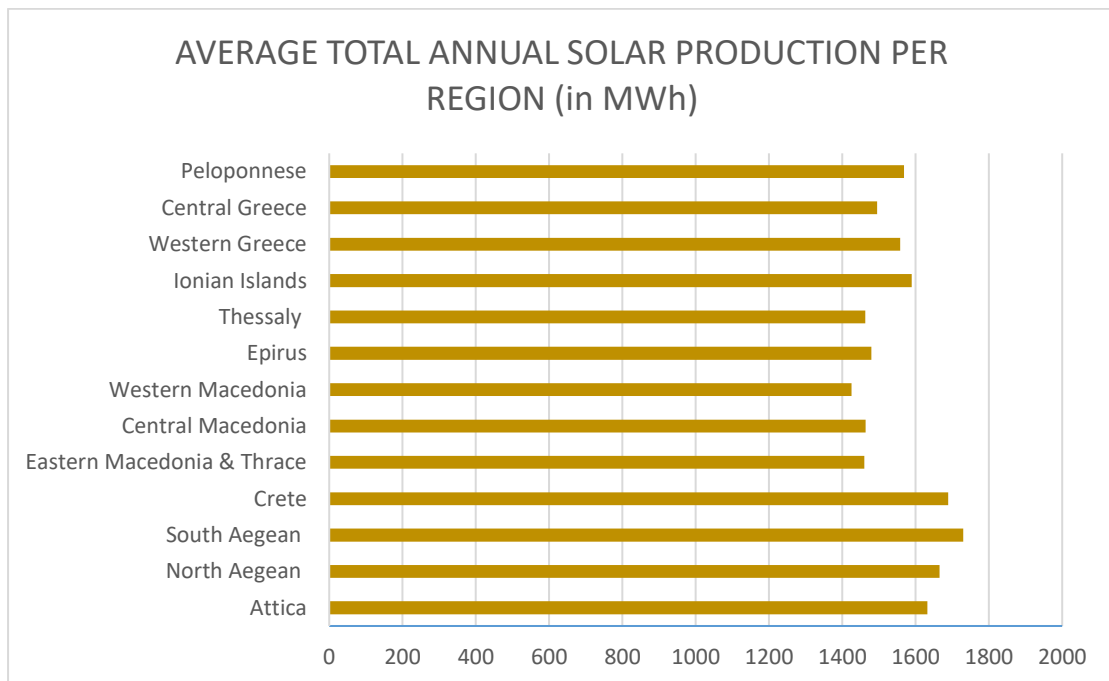


Figure 6 (b): Average total annual solar production per region in MWh



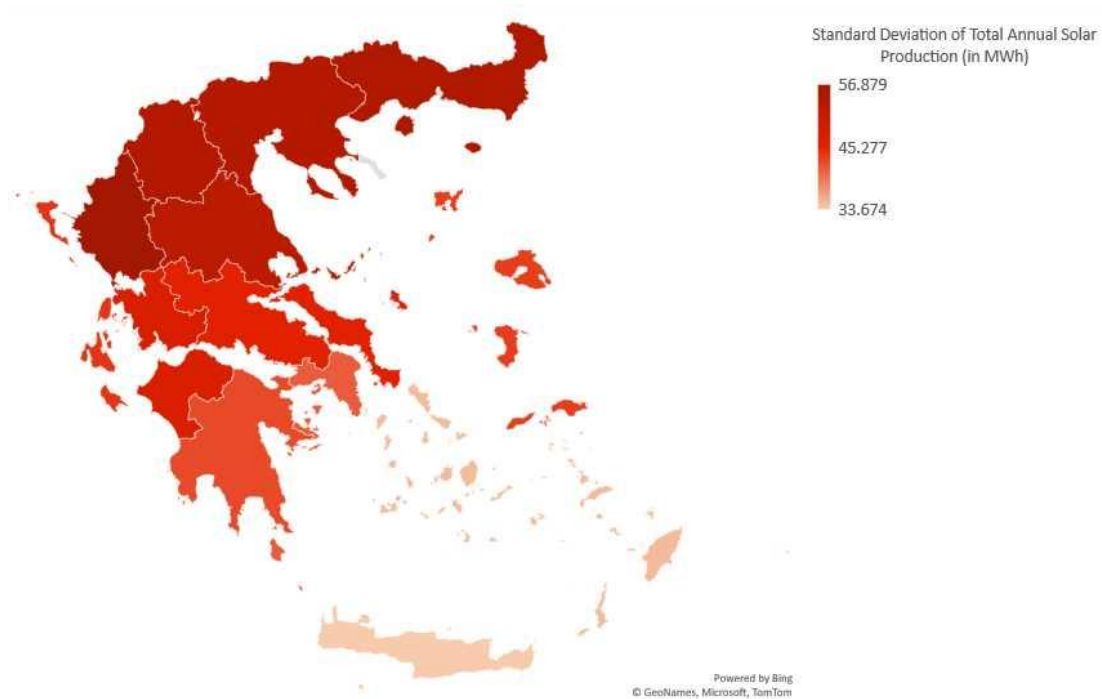


Figure 6 (c): Standard deviation of total annual solar energy production per region in MWh, map of Greece

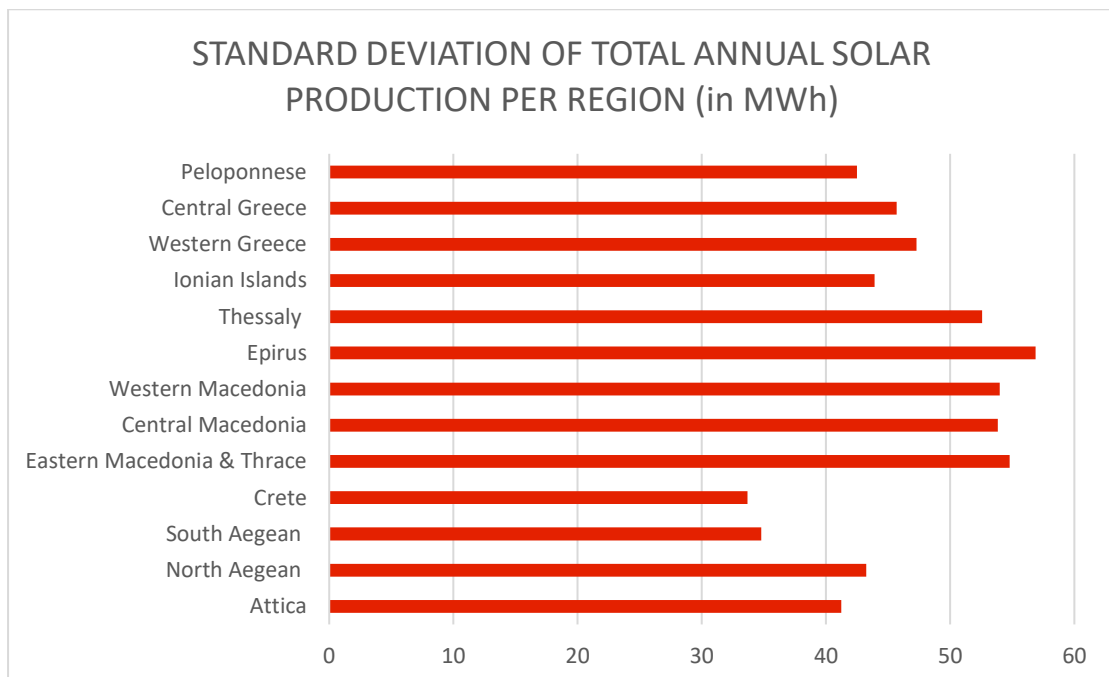


Figure 6 (d): Standard deviation of total annual solar energy production per region in MWh

### 3.2.3 Correlation of RES Capacity Factors

Besides the above statistical measurements, a correlation matrix is used in order to evaluate the relationship for all the possible pairs of regions that using the same or different technology (wind and solar). The correlation matrix was calculated by using the Data Analysis tool of Excel and is represented in figure 7.

It should be noted that when the coefficient contained in the cell of the below table is equal to zero, then there is no linear correlation between two pairs of regions. When the coefficient is equals to +1, then there is a perfectly positive linear correlation and when it is -1 there is a perfectly negative linear correlation. According to the above statement, the cells with darkest shade of blue color have strongest correlations than the cells with light or faded blue color. Moreover, the cells with red color correspond to the regions that have negative correlation.

Comparing the two wind production sites, it is evident that weakest correlation (0.087) is observed between Attica (EL30-W) and Western Macedonia (EL53-W). Thus, the wind capacity factors of Attica and Western Macedonia are rarely associated. On the contrary, the regions with high correlation (0.985) are Attica (EL30-W) with Ionian Islands (EL62-W) and Central Greece (EL64-W). These two pairs have the same high value correlation coefficient. Furthermore, the pairs of regions Ionian Islands (EL62-W) with Central Greece (EL64-W) and Western Greece (EL63-W) with Peloponnese (EL65-W) have strong correlation, as the correlation coefficient is equals to 1. Here, in all these possible pairs of regions that are using the only wind technology, we do not have any negative correlation between of them.

Comparing two solar production sites, it is obvious that the regions with the smallest correlation (0.275) is between Crete (EL43-S) and Epirus (EL54-S). This means that their solar capacities are barely associated. On the other hand, the regions with high correlation (0.977) are Ionian Islands (EL62-S) and Peloponnese (EL63-S). Here, in all these possible pairs of regions that are using the only solar technology, we do not have any negative correlation between of them.

Making a comparison between two regions with different technologies, we observe that there are many pairs of regions with small correlation coefficient by meaning that these regions with different technologies are hardly associated or they do not have any correlation at all. North Aegean (EL41-S) and Western Macedonia (EL53-W) regions

have zero correlation coefficient, so there is no correlation between of them. Moreover, the regions with smallest correlation coefficient (0.008) are the pairs of Crete (EL43-S) with Ionian Islands (EL62-W) and Crete (EL43-S) with Central Greece (EL64-W), so these pairs are hardly associated. On the other hand, the Epirus (EL54-S) and Attica (EL30-W) have the highest coefficient correlation (0.430), therefore these two regions are strongly correlated. Here, we observe a considerable number of pairs with negative correlation, which provide great dispersion of volumetric risk.

Let's assume that the regions, which using the same or different technology, are assets. Through the correlation matrix we can understand which investments going up or getting lower our portfolio diversification by having a quick overview. The majority of the potential investors would not like to invest in two regions that present similar wind pattern or have positive correlation because these two regions will have the same production at the same time.

Additionally, in Appendix D is illustrated the Variance-Covariance matrix of yearly wind & solar capacity factors, which calculated by using the Data Analysis tool of Excel and will be part of our calculations.

CORRELATION MATRIX OF YEARLY WIND & SOLAR CAPACITY FACTORS																										
	EL30-W	EL41-W	EL42-W	EL43-W	EL51-W	EL52-W	EL53-W	EL54-W	EL61-W	EL62-W	EL63-W	EL64-W	EL65-W	EL30-S	EL41-S	EL42-S	EL43-S	EL51-S	EL52-S	EL53-S	EL54-S	EL61-S	EL62-S	EL63-S	EL64-S	EL65-S
EL30-W	1																									
EL41-W	0.766	1																								
EL42-W	0.519	0.868	1																							
EL43-W	0.506	0.707	0.905	1																						
EL51-W	0.805	0.807	0.608	0.505	1																					
EL52-W	0.591	0.671	0.632	0.581	0.874	1																				
EL53-W	0.087	0.238	0.419	0.455	0.375	0.778	1																			
EL54-W	0.649	0.616	0.576	0.564	0.840	0.939	0.707	1																		
EL61-W	0.335	0.395	0.458	0.449	0.559	0.677	0.570	0.714	1																	
EL62-W	0.985	0.811	0.569	0.523	0.871	0.681	0.173	0.730	0.387	1																
EL63-W	0.560	0.461	0.422	0.458	0.665	0.705	0.487	0.807	0.721	0.617	1															
EL64-W	0.985	0.811	0.569	0.523	0.871	0.681	0.173	0.730	0.387	1	0.617	1														
EL65-W	0.560	0.461	0.422	0.458	0.665	0.705	0.487	0.807	0.721	0.617	1	0.617	1													
EL30-S	0.163	0.032	-0.101	-0.134	0.084	0.078	0.040	0.080	-0.190	0.165	-0.076	0.165	-0.076	1												
EL41-S	0.358	0.297	0.125	0.006	0.248	0.168	0.000	0.146	0.008	0.337	-0.008	0.337	-0.008	0.786	1											
EL42-S	0.094	0.099	-0.011	-0.091	0.047	0.068	0.068	0.048	-0.078	0.091	-0.097	0.091	-0.097	0.887	0.890	1										
EL43-S	-0.033	0.100	0.129	0.123	0.079	0.241	0.359	0.238	0.110	0.008	0.102	0.008	0.102	0.706	0.520	0.771	1									
EL51-S	0.396	0.291	0.214	0.154	0.313	0.294	0.156	0.255	0.075	0.382	0.068	0.382	0.068	0.763	0.918	0.777	0.441	1								
EL52-S	0.358	0.193	0.121	0.115	0.230	0.262	0.203	0.308	-0.006	0.356	0.101	0.356	0.101	0.805	0.829	0.785	0.512	0.890	1							
EL53-S	0.315	0.182	0.157	0.164	0.188	0.315	0.358	0.368	0.017	0.320	0.092	0.320	0.092	0.744	0.687	0.709	0.511	0.750	0.905	1						
EL54-S	0.430	0.183	0.065	0.035	0.275	0.267	0.154	0.334	0.026	0.400	-0.007	0.400	-0.007	0.641	0.732	0.616	0.275	0.764	0.828	0.849	1					
EL61-S	0.217	0.065	0.026	0.079	0.122	0.236	0.292	0.268	-0.087	0.229	0.037	0.229	0.037	0.836	0.707	0.772	0.609	0.770	0.930	0.928	0.738	1				
EL62-S	0.397	0.137	-0.052	-0.056	0.220	0.177	0.053	0.260	-0.047	0.366	-0.018	0.366	-0.018	0.792	0.761	0.736	0.430	0.731	0.836	0.846	0.930	0.792	1			
EL63-S	0.342	0.106	-0.045	-0.066	0.226	0.220	0.127	0.290	-0.038	0.326	-0.016	0.326	-0.016	0.796	0.759	0.732	0.436	0.758	0.855	0.876	0.948	0.826	0.977	1		
EL64-S	0.104	-0.010	-0.060	-0.045	0.080	0.199	0.276	0.199	-0.069	0.121	-0.018	0.121	-0.018	0.932	0.735	0.847	0.708	0.778	0.869	0.870	0.704	0.948	0.794	0.831	1	
EL65-S	0.106	-0.016	-0.105	-0.083	0.067	0.145	0.191	0.169	-0.092	0.108	-0.081	0.108	-0.081	0.903	0.709	0.838	0.697	0.698	0.815	0.833	0.729	0.875	0.872	0.884	0.933	1

Figure 7: Correlation matrix of annual wind & solar capacity factors

### 3.3 Mathematical Formulation of the portfolio selection

#### 3.3.1 Portfolio Optimization

Here, the fundamental calculations that compose the portfolio optimization process will present. All these actions will provide us all the optimal portfolios assured of the goals that we have every time and under some limitations that we will mention below.

First and foremost, the fundamental measures of a portfolio must be mentioned. The essential measures for the optimization process of a portfolio are the mean and standard deviation portfolio. The mean of a power portfolio is the “yield” or the “expected return”, here is the expected total annual wind and solar production. On the other hand, the standard deviation of a power portfolio is the “risk”, here is the standard deviation of wind and solar production per year.

Portfolio’s mean is calculated:

In mathematical terms is:

$$\mu_p = \sum_{i=1}^N \mu_i w_i = \boldsymbol{\mu}' \mathbf{w}$$

where,  $\boldsymbol{\mu} = [\mu_{EL30}^W \ \mu_{EL41}^W \ \mu_{EL42}^W \cdots \ \mu_{EL63}^S \ \mu_{EL64}^S \ \mu_{EL65}^S]'$  is the array of mean total annual wind/solar production and  $\mu_i$  is the mean total annual wind and solar capacity factor of region/technology  $i = 1, 2, \dots, N$ ,  $N$  is the number of assets,  $N = 13 \times 2$  in our case. The  $w_i$  is the percentage of the total capacity absorbed by region/technology  $i$  for the total distribution plan and  $\mathbf{w}$  is the matrix in which contained each region/technology weight,

$$\mathbf{w} = \begin{bmatrix} w_{EL30}^W \\ w_{EL41}^W \\ w_{EL42}^W \\ \vdots \\ w_{EL63}^S \\ w_{EL64}^S \\ w_{EL65}^S \end{bmatrix}$$

This function is subject to the following constraints:

- $0 \leq w_i \leq 1$ , this means that the region's weight takes values between zero and one.
- $\sum_{i=1}^N w_i = 1$ , this means that the sum of region's installed capacity has to be equal to the total capacity of investors, in other words 100%.

Portfolio's standard deviation is calculated:

In mathematical terms is:

$$\sigma_p = \sqrt{\sum_{i=1}^N w_i^2 \sigma_i^2 + \sum_{i=1}^N \sum_{j=1}^N w_i w_j \sigma_{ij}} = \sqrt{\mathbf{w}' \boldsymbol{\Sigma} \mathbf{w}}$$

where,  $\boldsymbol{\Sigma}$  is the covariance matrix of annual wind and solar capacity factors that is represented in Appendix D.

This function is subject to the following constraints:

- $0 \leq w_i \leq 1$ , this means that the region's weight takes values between zero and one.
- $\sum_{i=1}^N w_i = 1$ , this means that the sum of region's installed capacity has to be equal to the total capacity of investors, in other words 100%.

Portfolio's Coefficient of Variation is calculated:

In mathematical terms is:

$$CV_p = \frac{\sigma_p}{\mu_p} = \frac{\sqrt{\sum_{i=1}^N w_i^2 \sigma_i^2 + \sum_{i=1}^N \sum_{j=1}^N w_i w_j \sigma_{ij}}}{\sum_{i=1}^N \mu_i w_i}$$

Where,  $CV_p$  is the portfolio's coefficient of variation,  $\sigma_p$  is the portfolio's standard deviation and  $\mu_p$  is the portfolio's mean.

### 3.3.2 Minimum Variance Portfolio

Assuming that we have two types of aggregators. The first one desires the maximum yield exposing himself to the risk that may occur and the second one who desires the minimum risk possibly with a great loss of energy yield. This is the commonly range for investors, who are enthusiastic about invest in a portfolio. Optimal portfolios are got as the solution of the below mathematical problem:

The formulation of minimum variance (MV) portfolio is the following:

$$\text{Minimize} \quad \sigma_p = \sqrt{\mathbf{w}' \boldsymbol{\Sigma} \mathbf{w}} = \sqrt{\sum_{i=1}^N w_i^2 \sigma_i^2 + \sum_{i=1}^N \sum_{j=1}^N w_i w_j \sigma_{ij}}$$

$$\text{Subject to:} \quad 0 \leq w_i \leq 1$$

$$\sum_{i=1}^N w_i = 1$$

By adjusting the weights to the regions.

### 3.3.3 Maximum Yield Portfolio

This type of investor desires the maximum yield portfolio, ignoring the risk level. Seeking to have the maximum portfolio mean, we run the following optimization process.

The formulation of maximum yield (MY) portfolio is the following:

$$\text{Maximize} \quad \mu_p = \boldsymbol{\mu}' \mathbf{w} = \sum_{i=1}^N \mu_i w_i$$

$$\text{Subject to:} \quad 0 \leq w_i \leq 1$$

$$\sum_{i=1}^N w_i = 1$$

By adjusting the weights to the regions.

### 3.3.4 Minimum Coefficient of Variation Portfolio

As we referred in chapter two, the CV is a measure of risk. Minimizing risk by minimizing Coefficient of Variation is more trustworthy measure of risk than standard deviation, as does not only minimize risk but also maximizes the yield.

The formulation of minimum coefficient of variation portfolio is the following:

$$\text{Minimize} \quad CV_p = \frac{\sigma_p}{\mu_p}$$

$$\text{Subject to:} \quad 0 \leq w_i \leq 1$$

$$\sum_{i=1}^N w_i = 1$$

By adjusting the weights to the regions.



## Chapter four: Results

In chapter four the results from the implementation of optimal portfolios process of our research will be represented. We have six optimal portfolios, according to the risk preferences of the aggregators. The first portfolio is the minimum risk for wind power plants, the second is the maximum yield for wind power plants. Continuing, the third portfolio is the minimum risk for solar power plants, the fourth is the maximum yield for solar power plants. In the end, the fifth and sixth portfolios are the minimum risk for wind & solar power plants and the maximum yield for wind & solar power plants, respectively. Furthermore, the minimization of CV process for wind, solar and the combination of two these technologies portfolio's will be represented.

### 4.1 Minimizing risk for wind power plants

Here, our goal is to minimize risk for the wind portfolio, therefore, to minimize the wind portfolio's standard deviation by using the Solver tool of Excel. The distribution of the installed capacity for minimum standard deviation wind portfolio is:

Table 2: Synthesis of the minimum risk wind portfolio

$W_{EL30}$	$W_{EL41}$	$W_{EL42}$	$W_{EL43}$	$W_{EL51}$	$W_{EL52}$	$W_{EL53}$	$W_{EL54}$	$W_{EL61}$	$W_{EL62}$	$W_{EL63}$	$W_{EL64}$	$W_{EL65}$	Total
0%	4.831%	0%	0%	0%	0%	23.922%	0%	59.447%	7.017%	1.028%	1.958%	1.797%	100%

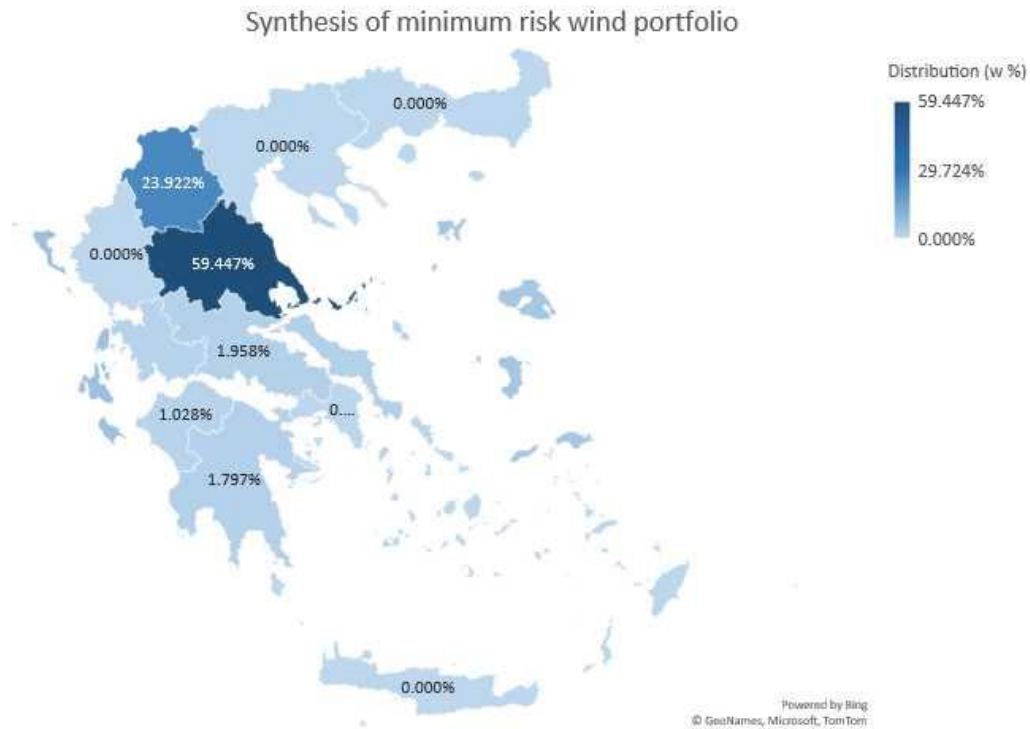


Figure 8: Synthesis of the minimum risk wind portfolio (map of Greece)

Figure 8 shows the distribution of the installed capacity for minimum risk portfolio only in wind technology. According to Fig. 8, a minimum risk allocation of the portfolio's installed capacity would put 59.447% in Thessaly (EL61) and 23.92% in Western Macedonia (EL63). This minimum risk portfolio aims to manage the variability of wind energy production, though with a remarkable reduction mean output (yield).

The minimum standard deviation and its mean for the minimum risk wind portfolio are summarized in the following table:

Table 3: Expected yield & risk of minimum risk wind portfolio

Portfolio's mean ( $\mu_p$ )	1238.143 MWh
Portfolio's standard dev. ( $\sigma_p$ )	103.798 MWh

As a consequence, the expected yearly average wind production of the minimum risk portfolio is equal to 1238.143 MWh with a standard deviation at 103.798 MWh.

## 4.2 Maximizing yield for wind power plants

Running the optimization process, our goal is to maximize the yield of the wind portfolio, therefore, to maximize the wind portfolio's mean by using the Solver tool of Excel. The distribution of the installed capacity for the maximum yield wind portfolio is:

Table 4: Synthesis of the maximum yield wind portfolio

0%	<b>W<sub>EL30</sub></b>
0%	<b>W<sub>EL41</sub></b>
100%	<b>W<sub>EL42</sub></b>
0%	<b>W<sub>EL43</sub></b>
0%	<b>W<sub>EL51</sub></b>
0%	<b>W<sub>EL52</sub></b>
0%	<b>W<sub>EL53</sub></b>
0%	<b>W<sub>EL54</sub></b>
0%	<b>W<sub>EL61</sub></b>
0%	<b>W<sub>EL62</sub></b>
0%	<b>W<sub>EL63</sub></b>
0%	<b>W<sub>EL64</sub></b>
0%	<b>W<sub>EL65</sub></b>
<b>100%</b>	<b>Total</b>

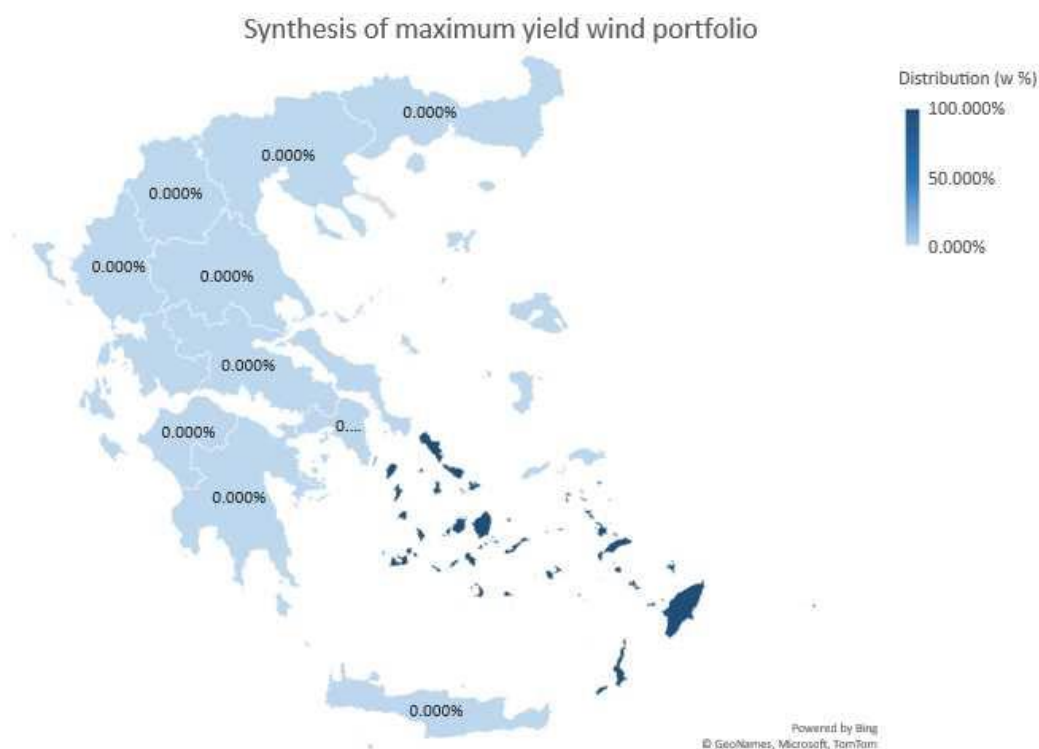


Figure 9: Synthesis of the maximum yield wind portfolio (map of Greece)

Figure 9 shows the distribution of the installed capacity for maximum yield portfolio only in wind technology. According to Fig. 9, a maximum yield allocation of the portfolio's installed capacity would put 100% in South Aegean (EL42) region. This

maximum yield portfolio focuses on maximizing the mean output of wind energy production, though with a significant presence of risk.

The maximum mean and its standard deviation for the maximum yield wind portfolio are summarized in the following table:

Table 5: Expected yield & risk of maximum yield wind portfolio

Portfolio's mean ( $\mu_p$ )	2586.372 MWh
Portfolio's standard dev. ( $\sigma_p$ )	207.439 MWh

As a consequence, the expected yearly average wind production of the maximum mean portfolio is equal to 2586.372 MWh with a standard deviation at 207.439 MWh.

It is worth noting that South Aegean region, as we referred above, has the highest average total yearly wind production, which is 2586.372 MWh. This means that the region of South Aegean is the ideal choice if an aggregator seeks for maximization of the average total wind production.

### 4.3 Minimizing risk for solar power plants

Running the optimization process our goal is to minimize risk of the solar portfolio, therefore, to minimize the solar portfolio's standard deviation by using the Solver tool of Excel. The distribution of installed capacity for the minimum standard deviation solar portfolio is:

Table 6: Synthesis of the minimum risk solar portfolio

$W_{EL30}$	$W_{EL41}$	$W_{EL42}$	$W_{EL43}$	$W_{EL51}$	$W_{EL52}$	$W_{EL53}$	$W_{EL54}$	$W_{EL61}$	$W_{EL62}$	$W_{EL63}$	$W_{EL64}$	$W_{EL65}$	Total
0%	1.880%	9.822%	65.655%	0%	0%	0%	0%	0%	22.643%	0%	0%	0%	100%

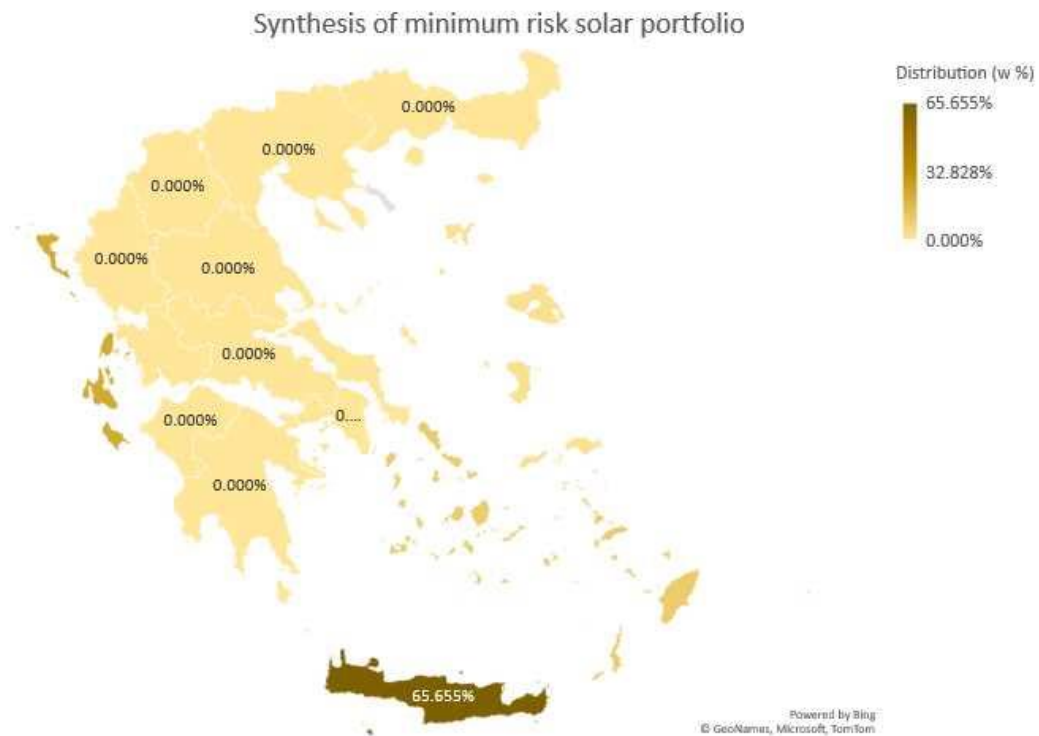


Figure 10: Synthesis of the minimum risk solar portfolio (map of Greece)

Figure 10 shows the distribution of the installed capacity for minimum risk portfolio only in solar technology. According to Fig. 10, a minimum risk allocation of the portfolio's installed capacity would put 65.65% in Crete (EL43) and 22.64% in Ionian Islands (EL62). This minimum risk portfolio aims to manage the variability of solar energy production, though with a remarkable reduction mean output (yield).

The minimum standard deviation and its mean for the minimum risk solar portfolio are summarized in the following table:

Table 7: Expected yield & risk of minimum risk solar portfolio

Portfolio's mean ( $\mu_p$ )	1670.051 MWh
Portfolio's standard dev. ( $\sigma_p$ )	30.955 MWh

As a consequence, the expected yearly average solar production of the minimum risk portfolio is equal to 1670.051 MWh with a standard deviation at 30.955 MWh.

#### 4.4 Maximizing yield for solar power plants

Running the optimization process our goal is to maximize the yield of the solar portfolio, therefore, to maximize the solar portfolio's mean by using the Solver tool of Excel. The distribution of installed capacity for maximum yield solar portfolio is:

Table 8: Synthesis of the maximum yield solar portfolio

$W_{EL30}$	$W_{EL41}$	$W_{EL42}$	$W_{EL43}$	$W_{EL51}$	$W_{EL52}$	$W_{EL53}$	$W_{EL54}$	$W_{EL61}$	$W_{EL62}$	$W_{EL63}$	$W_{EL64}$	$W_{EL65}$	Total
0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%

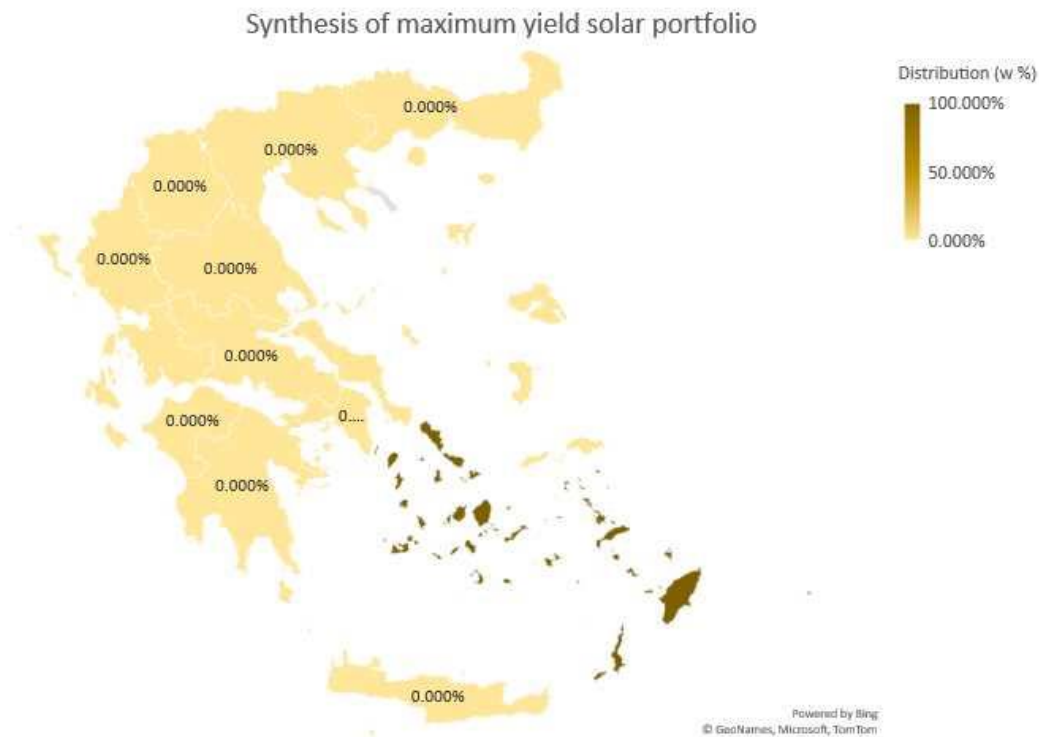


Figure 11: Synthesis of the maximum yield solar portfolio (map of Greece)

Figure 11 shows the distribution of the installed capacity for maximum yield portfolio only in solar technology. According to Fig. 11, a maximum yield allocation of the portfolio's installed capacity would put 100% in South Aegean (EL42) region. This maximum yield portfolio focuses on maximizing the mean output of solar energy production, though with a significant presence of risk.

The maximum mean and its standard deviation for the maximum yield solar portfolio are summarized in the following table:

Table 9: Expected yield & risk of maximum yield solar portfolio

Portfolio's mean ( $\mu_p$ )	1729.848 MWh
Portfolio's standard dev. ( $\sigma_p$ )	34.198 MWh

As a consequence, the expected yearly average solar production of the maximum mean portfolio is equal to 1729.848 MWh with a standard deviation at 34.198 MWh.

It is worth noting that South Aegean region, as we referred above, has the highest average total yearly solar production, which is 1729.848 MWh. This means that the region of South Aegean is the ideal choice, if an aggregator seeks for maximization of the average total solar production.

#### 4.5 Minimizing risk for wind & solar power plants

Running the optimization process our goal is to minimize risk from combining wind and solar resources, therefore, to minimize the wind and solar portfolio's standard deviation by using the Solver tool of Excel. The distribution of installed capacity for minimum standard deviation wind and solar portfolio is:

Table 10: Synthesis of the minimum risk wind and solar portfolio

	W <sub>EL30</sub>	W <sub>EL41</sub>	W <sub>EL42</sub>	W <sub>EL43</sub>	W <sub>EL51</sub>	W <sub>EL52</sub>	W <sub>EL53</sub>	W <sub>EL54</sub>	W <sub>EL61</sub>	W <sub>EL62</sub>	W <sub>EL63</sub>	W <sub>EL64</sub>	W <sub>EL65</sub>	Total
<b>Wind</b>	0%	0%	0%	0.006%	0%	0%	0%	0%	5.475%	0%	0.838%	0%	0.005%	<b>6.32%</b>
<b>Solar</b>	0%	1.903%	10.372%	58.074%	0%	0%	0%	0%	0%	23.326%	0%	0%	0%	<b>93.68%</b>

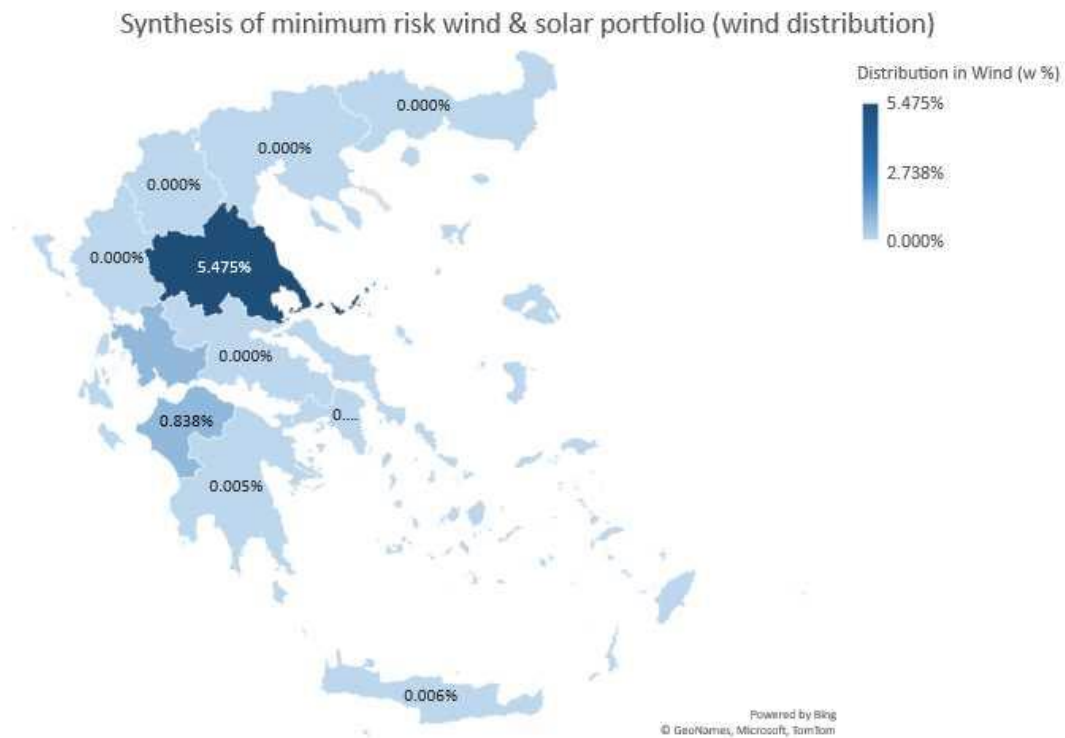


Figure 12 (a): Synthesis of the minimum risk wind & solar portfolio, wind distribution (map of Greece)

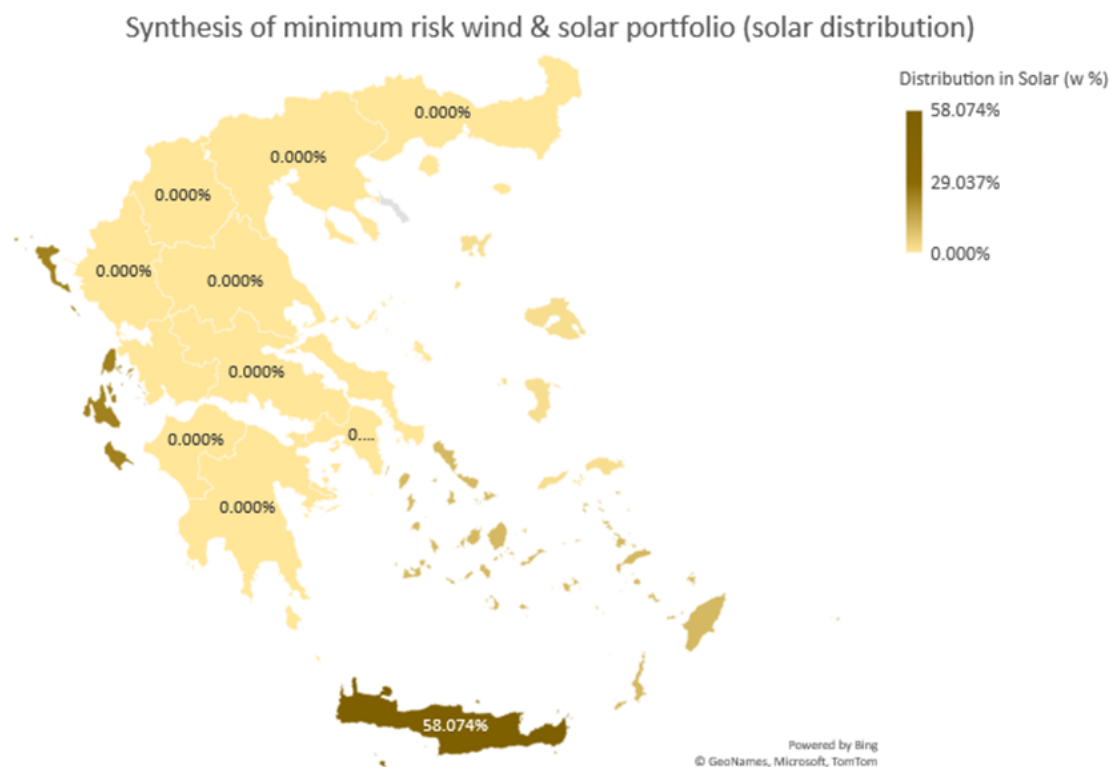


Figure 12 (b): Synthesis of the minimum risk wind & solar portfolio, solar distribution (map of Greece)



Figure 12 shows the distribution of the installed capacity for minimum risk portfolio from combining wind and solar technologies. According to Fig. 12, a minimum risk allocation of the portfolio's installed capacity would put 93.68% to solar resources and the rest 6.32% to wind resources. This minimum risk portfolio aims to manage the variability from combining wind and solar energy production.

The minimum standard deviation and its mean for the minimum wind & solar portfolio are summarized in the following table:

Table 11: Expected yield & risk of minimum risk wind & solar portfolio

Portfolio's mean ( $\mu_p$ )	1638.138 MWh
Portfolio's standard dev. ( $\sigma_p$ )	30.16065 MWh

As a consequence, the expected yearly average wind and solar production of the minimum risk portfolio is equal to 1638.138 MWh with a standard deviation at 30.16065 MWh.

The risk of minimum risk portfolio from combining wind and solar resources goes down to 30.160 MWh, which is below half the standard deviation that can be accomplished with wind technology (103.79 MWh). Furthermore, the expected yield is improving to 1638.18 MWh compared to 1238.14 MWh (wind technology). That makes the combining minimum risk portfolio more efficient.

#### 4.6 Maximizing yield for wind and solar power plants

Running the optimization process our goal is to maximize the portfolio's yield from combining wind and solar resources, therefore, to maximize the wind and solar portfolio's mean by using the Solver tool of Excel. The distribution of installed capacity for maximum yield wind and solar portfolio is:

Table 12: Synthesis of the maximum yield wind and solar portfolio

Solar	Wind	
0%	0%	$\mathbf{W_{EL30}}$
0%	0%	$\mathbf{W_{EL41}}$
0%	100%	$\mathbf{W_{EL42}}$
0%	0%	$\mathbf{W_{EL43}}$
0%	0%	$\mathbf{W_{EL51}}$
0%	0%	$\mathbf{W_{EL52}}$
0%	0%	$\mathbf{W_{EL53}}$
0%	0%	$\mathbf{W_{EL54}}$
0%	0%	$\mathbf{W_{EL61}}$
0%	0%	$\mathbf{W_{EL62}}$
0%	0%	$\mathbf{W_{EL63}}$
0%	0%	$\mathbf{W_{EL64}}$
0%	0.005%	$\mathbf{W_{EL65}}$
<b>0%</b>	<b>100%</b>	<b>Total</b>

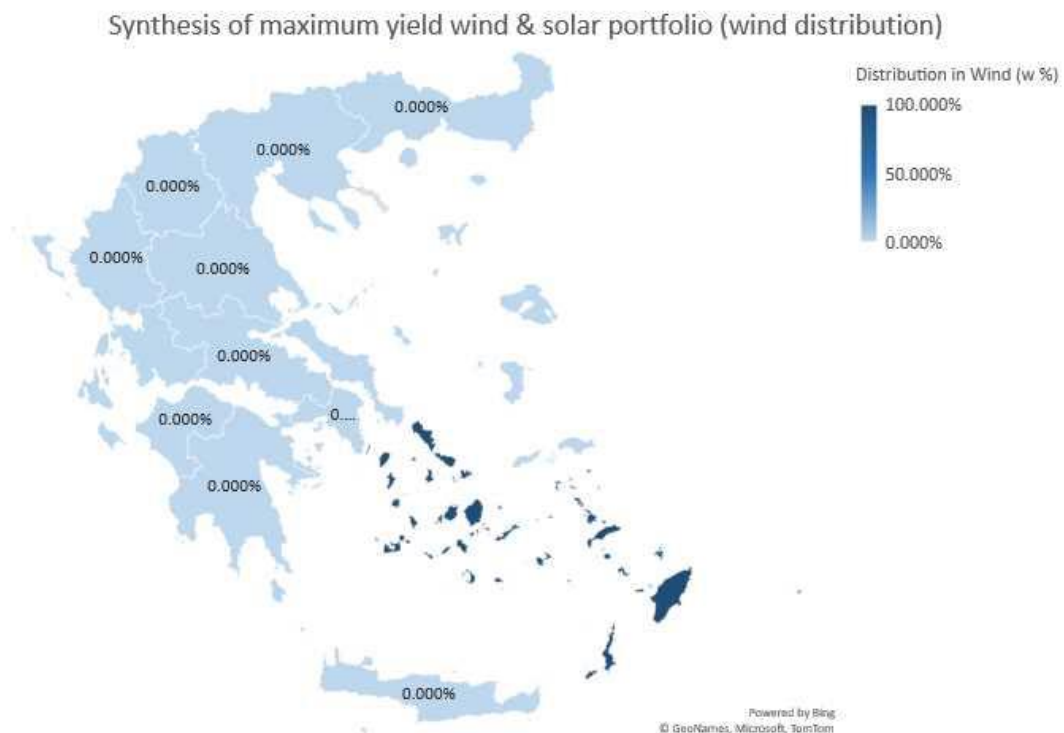


Figure 13 (a): Synthesis of the maximum yield wind and solar portfolio, wind distribution (map of Greece)

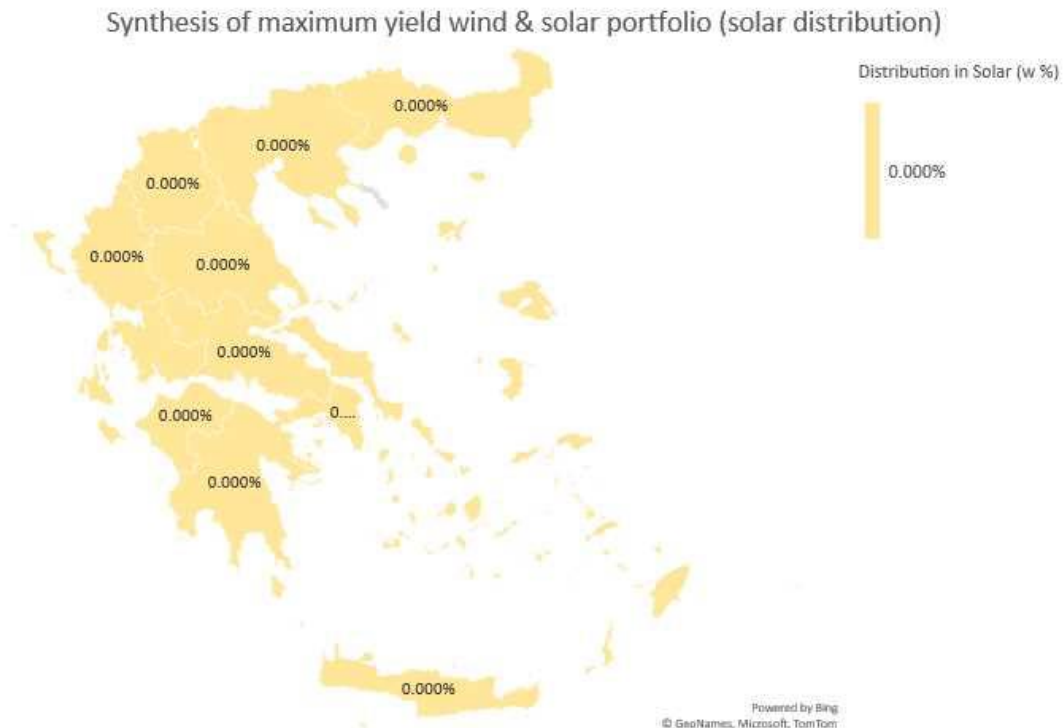


Figure 13 (b): Synthesis of the maximum yield wind and solar portfolio, solar distribution (map of Greece)

Figure 13 shows the distribution of the installed capacity for maximum yield portfolio combining wind and solar technologies. According to Fig. 13, a maximum yield allocation of the portfolio's installed capacity would put 100% to wind resources, especially in South Aegean (EL42) region. This maximum yield portfolio focuses on maximizing the mean output from combining wind and solar energy production. The optimization process shows that wind resources are the ideal choice when the concept is to maximize the expected yield, though with a significant presence of risk.

The maximum mean and its standard deviation for the maximum wind & solar portfolio are summarized in the following table:

Table 13: Expected yield &amp; risk of minimum risk wind &amp; solar portfolio

Portfolio's mean ( $\mu_p$ )	2586.372 MWh
Portfolio's standard dev. ( $\sigma_n$ )	207.4395 MWh

As a consequence, the expected yearly average wind and solar production of the maximum mean portfolio is equal to 2586.372 MWh with a standard deviation at 207.4395 MWh.

## 4.7 Minimizing risk by minimizing CV

### 4.7.1 Minimizing CV for wind power plants

Running the optimization process our goal is to minimize risk by minimizing the CV of the wind portfolio, therefore to minimize the wind portfolio's CV by using the Solver tool of Excel. The distribution of installed capacity for minimum CV wind portfolio is:

Table 14: Synthesis of the minimum CV wind portfolio

0%	$W_{EL30}$
0%	$W_{EL41}$
30.854%	$W_{EL42}$
0%	$W_{EL43}$
20.187%	$W_{EL51}$
0%	$W_{EL52}$
0%	$W_{EL53}$
0%	$W_{EL54}$
0%	$W_{EL61}$
0%	$W_{EL62}$
4.629%	$W_{EL63}$
0%	$W_{EL64}$
44.33%	$W_{EL65}$
100%	Total

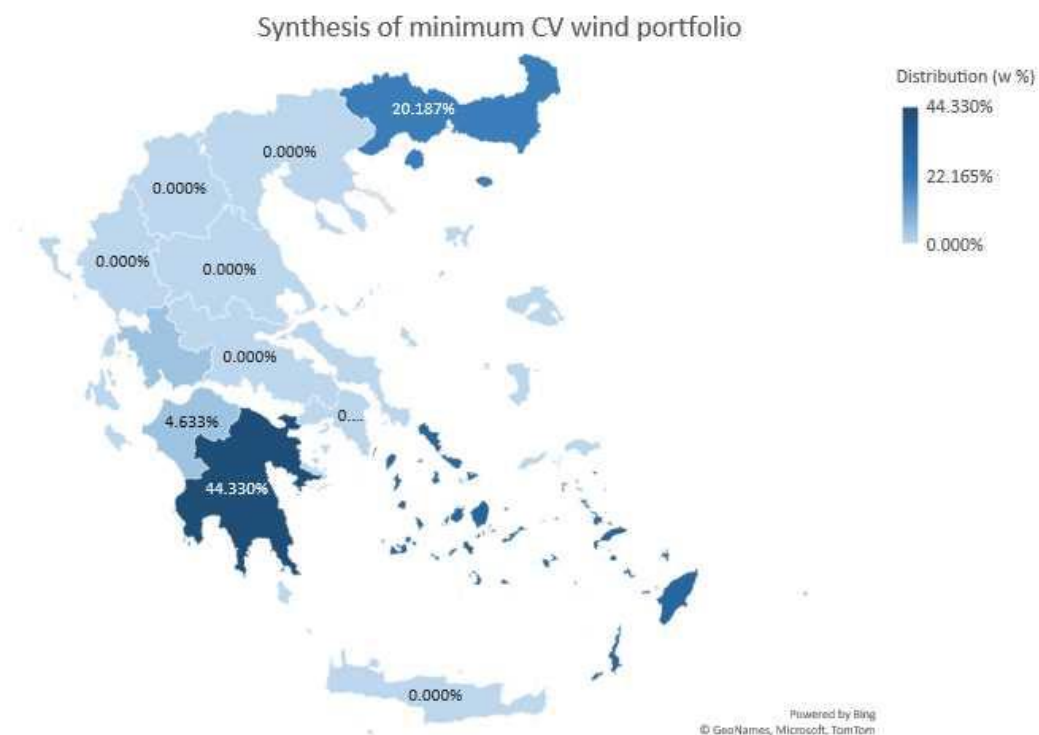


Figure 14: Synthesis of the minimum CV wind portfolio (map of Greece)

Figure 14 shows the distribution of the installed capacity for minimum risk by minimizing the CV of the wind portfolio. According to fig. 14, a minimum risk by minimizing CV allocation of the portfolio's installed capacity would put 44.33% in Peloponnese (EL65), 30.85% South Aegean (EL42) and 20.18% in Eastern Macedonia

& Thrace (EL51). The minimum risk by minimizing CV of wind portfolio achieves the best balancing between risk and yield.

Thus, minimizing the CV for the wind portfolio, the mean and standard deviation of portfolio are summarized in the following table:

Table 15: Expected yield & Standard deviation of minimum CV wind portfolio

Portfolio's CV ( $CV_p$ )	0.065 or 6.59%
Portfolio's mean ( $\mu_p$ )	2089.323 MWh
Portfolio's standard dev. ( $\sigma_p$ )	137.748 MWh

As a consequence, the expected yearly average wind production of the minimum CV wind portfolio is equal to 2089.323 MWh with a standard deviation at 137.748 MWh.

#### 4.7.2 Minimizing CV for solar power plants

Running the optimization process our goal is to minimize risk by minimizing the CV of the solar portfolio, therefore to minimize the solar portfolio's CV by using the Solver tool of Excel. The distribution of installed capacity for minimum CV solar portfolio is:

Table 26: Synthesis of the minimum CV solar portfolio

$W_{EL30}$	$W_{EL41}$	$W_{EL42}$	$W_{EL43}$	$W_{EL51}$	$W_{EL52}$	$W_{EL53}$	$W_{EL54}$	$W_{EL61}$	$W_{EL62}$	$W_{EL63}$	$W_{EL64}$	$W_{EL65}$	Total
0%	0%	21.398%	62.645%	0%	0%	0%	0%	0%	15.957%	0%	0%	0%	100%

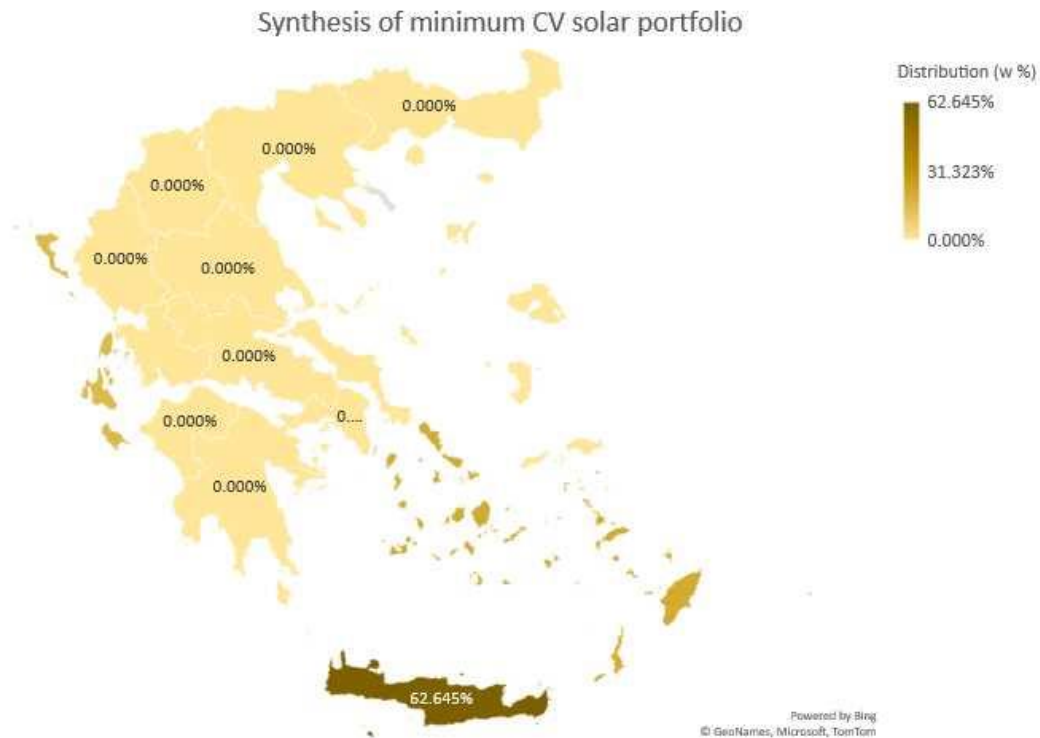


Figure 15: Synthesis of the minimum CV solar portfolio (map of Greece)

Figure 15 shows the distribution of the installed capacity for minimum risk by minimizing the CV of the solar portfolio. According to fig. 15, a minimum risk by minimizing CV allocation of the portfolio's installed capacity would put 62.64% in Crete (EL43), 21.39% in South Aegean (EL42) and 15.957% in Ionian Islands (EL62). The minimum risk by minimizing CV of solar portfolio achieves the best balancing between risk and yield.

Thus, minimizing the CV for the solar portfolio, the mean and standard deviation of portfolio are summarized in the following table:

Table 17: Expected yield & Standard deviation of minimum CV wind portfolio

Portfolio's CV ( $CV_p$ )	0.0184 or 1.84%
Portfolio's mean ( $\mu_p$ )	1681.876 MWh
Portfolio's standard dev. ( $\sigma_p$ )	31.018 MWh

As a consequence, the expected yearly average solar production of the minimum CV solar portfolio is equal to 1681.876 MWh with a standard deviation at 31.018 MWh.

Running the optimization process our goal is to minimize risk by minimizing the CV from combining wind & solar resources, therefore to minimize the wind & solar portfolio's CV by using the Solver tool of Excel. The distribution of installed capacity for minimum CV wind & solar portfolio is:

Solar	Wind	
0%	0%	W <sub>EL30</sub>
0%	0%	W <sub>EL41</sub>
38.015%	1.374%	W <sub>EL42</sub>
46.250%	0%	W <sub>EL43</sub>
0%	0%	W <sub>EL51</sub>
0%	0%	W <sub>EL52</sub>
0%	0%	W <sub>EL53</sub>
0%	0%	W <sub>EL54</sub>
0%	0%	W <sub>EL61</sub>
10.004%	0%	W <sub>EL62</sub>
0%	0.925%	W <sub>EL63</sub>
0%	0%	W <sub>EL64</sub>
0%	3.433%	W <sub>EL65</sub>
94.296%	5.731%	Total

Figure 16 (a): Synthesis of the minimum CV wind & solar portfolio, wind distribution (maps of Greece)

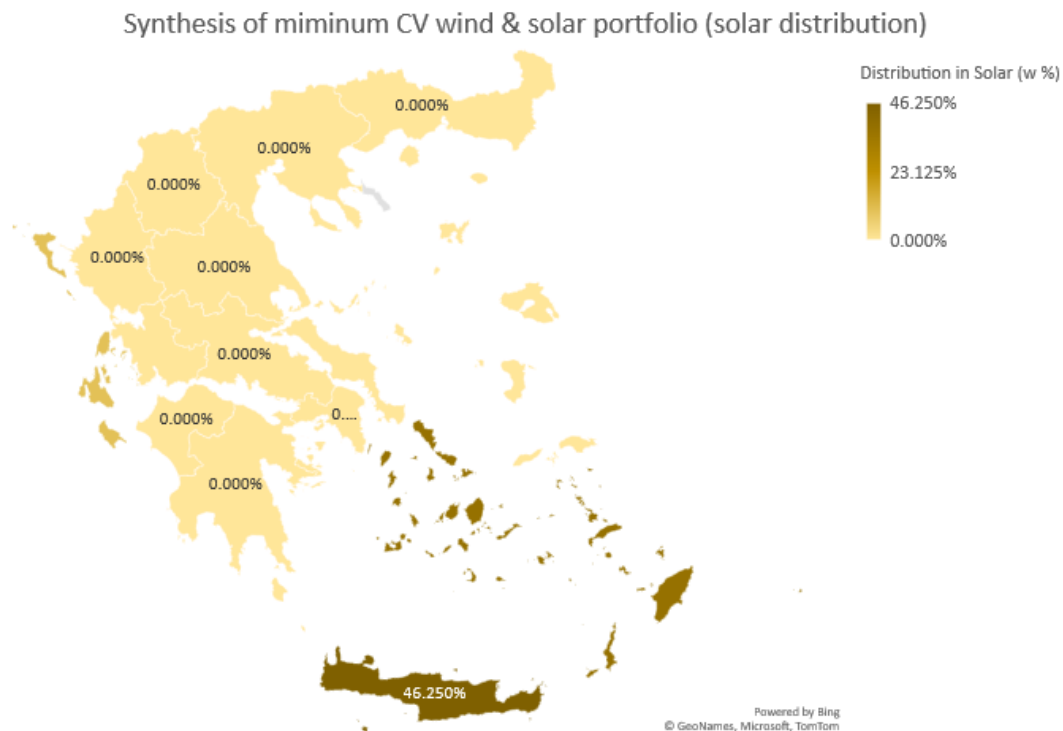


Figure 16 (b): Synthesis of the minimum CV wind & solar portfolio, solar distribution (maps of Greece)

Figure 16 shows the distribution of the installed capacity for minimum risk by minimizing the CV of portfolio from combining wind and solar technologies. According to Fig. 16, a minimum risk by minimizing portfolio's CV allocation of the portfolio's installed capacity would put 94.29% to solar resources and the rest 5.73% to wind resources.

Thus, minimizing the CV for the wind & solar portfolio, the mean and standard deviation of portfolio are summarized in the following table:

Table 19: Expected yield & Standard deviation of minimum CV wind & solar portfolio

Portfolio's CV ( $CV_p$ )	0.0179 or 1.79%
Portfolio's mean ( $\mu_p$ )	1706.312 MWh
Portfolio's standard dev. ( $\sigma_p$ )	30.579 MWh

As a consequence, the expected yearly average wind & solar production of the minimum CV wind & solar portfolio is equal to 1706.312 MWh with a standard deviation at 30.579 MWh.



This portfolio is the most advantageous choice compared to minimum CV wind portfolio and minimum CV solar portfolio, as its coefficient of variation is 1.79% which is the lowest. Moreover, this portfolio achieves the best tradeoff between risk and yield.

## 4.8 Comparison of portfolios

In this study we find optimal power portfolios according to aggregator's risk preferences, but the main purpose of this dissertation is to investigate if spatial and technological aggregation is effectiveness in managing the volumetric risk of renewable energy resources in our country. The results from our research are very encouraging, both strategies attain a satisfactory level of risk reduction. Comparing the optimal portfolios, we found out that the best option is the portfolio which combines distribution of wind and solar power plants rather than a single technology, as it has the minimum standard deviation (risk) among the optimal portfolios. On the other hand, the composite portfolio that focuses on maximizing yield has high standard deviation value, therefore it is more risky.

Furthermore, we create optimal risk portfolios by minimizing the CV. Minimizing portfolio's CV not only minimize risk but also maximizes yield (mean). Our results show that CV is more reliable measure of risk than standard deviation. We found out that the minimum risk by minimizing the CV in case of composite portfolio is the most advantageous selection an aggregator can make, as we have the minimum level of risk and we success a great yield, simultaneously.

Figure 17 shows a summary table of all optimal portfolios that we find in this chapter.

	Minimum risk wind portfolio	Maximum yield wind portfolio	Minimum risk solar portfolio	Maximum yield solar portfolio	Minimum risk wind & solar portfolio	Maximum yield wind & solar portfolio	Minimum risk (minimizing CV) wind portfolio	Minimum risk (minimizing CV) solar portfolio	Minimum risk (minimizing CV) wind & solar portfolio
Portfolio's Mean (MWh)	1238.143	2586.372	1670.051	1729.848	1638.138	2586.372	2089.32	1681.878	1706.31
Portfolio's St.Dev. (MWh)	103.798	207.440	30.955	34.199	30.161	207.440	137.748	31.018	30.579
Portfolio's CV	0.0838	0.0802	0.0185	0.0198	0.0184	0.0802	0.065	0.0184	0.0179

Figure 17: Summary table of optimal portfolios

We examine that choosing spatial and technological aggregation is the better option for controlling the volumetric risk but is not the only reason for choosing these strategies. Another crucial reason is the environmental footprint of RES, as wind and solar energy is growing very fast and as, we mentioned, they play important role to reduce the greenhouse gas emissions and implement the Goal 7 of E.U. For this reason, it is wise to highlight the environmental impact of wind and solar energy systems in relation to the use of land, visual and noise consequences, impact on biodiversity, consequences on microclimate of the country, safety issues etc. Even though the benefits of wind and solar energy are clear and magnificent, it is preferable for aggregators to disperse these technologies by the principle of a strategy plan and not with impulsion (Hamded, 2022).

## Chapter five: Conclusion

In this dissertation, our purpose was to examine the effectiveness of spatial and technological aggregation in managing the volumetric risk of renewable energy resources in Greece, specifically in wind and solar energy. To explore this, we applied the Modern Portfolio Theory (MPT) for finding optimal power portfolios.

Our empirical study based on two parts. In first part a descriptive statistical analysis was performed which helped us to extract useful information about the energy profile each region in Greece through 30 years. The second one, based on MPT model investigated optimal power portfolios for single wind, solar and the composite case of them. The generation of these portfolios grounded in three aspects: (i) focusing on minimizing portfolio risk; (ii) focusing on maximizing portfolio yield; and (iii) limiting the risk via inclusion of CV measure.

The descriptive statistical analysis showed that South Aegean region has the highest average total annual wind energy production, continuing with Eastern Macedonia & Thrace, North Aegean, and Attica. This indicates that, the wind pattern in these regions can be characterized as windiest through all the years of sample data. On the other hand, Western Macedonia as well as Thessaly and Epirus have the lowest average total annual wind production, so are less windy regions. Concerning the solar pattern in Greece, the descriptive statistical analysis showed that there are no big fluctuations in total annual solar energy production through the years. South Aegean and Crete regions have the highest total annual solar energy production, on contrary to Western Macedonia and Thessaly that have the lowest.

The spatially and technologically correlation among regions is a significant finding in this dissertation, as it is directly correlated with volumetric risk and the decision maker (aggregators). The positive correlation of pairs of regions that use single wind, solar or the composite case of them, maximizes the risk by investing in both. As expected by results from the production energy, regions with positive correlation show the same wind and solar pattern, while regions with negative correlation move in opposite direction, so aggregators are exposed to less risk.

Following, the optimization model was performed to create optimal power portfolios according to aggregator's preferences. In this research, we investigate portfolios, which minimize risk and maximize the yield for single wind, solar and the composite case (mixing wind and solar). The expectation is the portfolio with the lowest standard deviation. Comparing these portfolios, we found out that the best option is the composite case, as there is dispersion of volumetric risk in various regions in Greece by mixing wind and solar energy. Furthermore, we investigate portfolios by minimizing CV. The results showed that the composite portfolio is the best choice, since it has the lowest CV value. Such portfolios, minimizing portfolio's risk by minimizing CV, does not only minimize risk but also maximizes yield.

To conclude, the optimization model of this study emphasizes the value of making spatially and technologically diversified portfolios to manage volumetric risk. When it comes for optimal power portfolios, it is much more advantageous to invest by mixing wind and solar resources rather than single installations, since we demonstrated that this strategy has satisfactorily results in risk management. Above all, this dissertation shows the necessity our country to response in actions concerning the reduction of pollutant emission by investing strategically in clean energy, especially mixing wind and solar resources. A future challenge that arises from this research is to extend it in other forms of strategies for handling the volumetric risk of renewable energy resources. Future research could study the strategy of hedging, in other words using financial instruments that compensate aggregators from unexpected reduction in power delivery.

## References

- Allen, M.R., O.P. Dube, W. Solecki, F. Aragón-Durand, W. Cramer, S. Humphreys, M. Kainuma, J. Kala, N. Mahowald, Y. Mulugetta, R. Perez, M. Wairiu, and K. Zickfeld, (2018): Framing and Context. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 49-92
- Boreiko D and Massarotti F (2020) How Risk Profiles of Investors Affect Robo-Advised Portfolios. *Front. Artif. Intell.* 3:60.
- Campeciño, J. (2021). Portfolio Theory and Risk Analysis Using Coefficient of Variation: An Alternative to the Modern Portfolio Theory. Michigan State University, East Lansing, MI, p.1-10
- Castro, G.M. et al. (2022). Improvements to modern portfolio theory based models applied to electricity systems. *Energy Economics*, 111, p. 106047.
- Co-efficient of Variation Meaning and How to Use It (2023), Investopedia. Available at: <https://www.investopedia.com/terms/c/coefficientofvariation.asp> [accessed June 06 2023]
- Cunha, J., & Ferreira, P. (2014). Designing electricity generation portfolios using the mean-variance approach. *International Journal of Sustainable Energy Planning and Management*, 4, 17–30
- Energy Roadmap 2050 (2011) Europa. Available at: [https://energy.ec.europa.eu/system/files/201410/roadmap2050\\_ia\\_20120430\\_en\\_0.pdf](https://energy.ec.europa.eu/system/files/201410/roadmap2050_ia_20120430_en_0.pdf) [accessed: May 16 2023].

- F. J. Santos-Alamillos, N.S. Thomaidis, S. Quesada-Ruiz, J.A. Ruiz-Arias, D. Pozo-Vázquez (2016), “Do current wind farms in Spain take maximum advantage of the spatiotemporal balancing of the wind resource?”, *Renewable Energy* 96 (A), pp. 574-582.
- F. J. Santos-Alamillos, D. J. Brayshaw, J. Methven, N. S. Thomaidis, J. A. Ruiz-Arias, D. Pozo-Vázquez (2017), “Exploring the meteorological potential for planning a high performance European Electricity Super-grid: optimal power capacity distribution among countries”, *Environmental Research Letters* 12, 114030
- Gonzalez-Aparicio, I., Huld, T., Careri, F., Monforti, F., & Zucker Andreas. (2016). EMHIRE dataset—Part I: Wind power generation. European Meteorological derived High resolution RES generation time series for present and future scenarios.
- Gonzalez-Aparicio, I., Huld, T., Careri, F., Monforti, F., & Zucker Andreas. (2017). EMHIRE dataset—Part II: Solar power generation. European Meteorological derived High resolution RES generation time series for present and future scenarios. Part II: PV generation using the PVGIS model. Available at: [https://www.researchgate.net/publication/317304106\\_EMHIRE\\_dataset\\_-\\_Part\\_II\\_Solar\\_power\\_generation\\_European\\_Meteorological\\_derived\\_High\\_resolution\\_RES\\_generation\\_time\\_series\\_for\\_present\\_and\\_future\\_scenarios\\_Part\\_II\\_PV\\_generation\\_using\\_the\\_PVGIS\\_model](https://www.researchgate.net/publication/317304106_EMHIRE_dataset_-_Part_II_Solar_power_generation_European_Meteorological_derived_High_resolution_RES_generation_time_series_for_present_and_future_scenarios_Part_II_PV_generation_using_the_PVGIS_model) [accessed April 07 2023]. (Joint Research Centre Science for Policy Report). European Commission.
- Hamed, T. A., Alshare, A., (2022) Environmental Impact of Solar and Wind energy- A Review, *J. sustain. dev. energy water environ. syst.*, 10(2), 1090387.
- Hellenic Wind Energy Association. (2022). Spatial distribution of wind capacity. <https://eletaen.gr/d-t-statistiki-eletaen-first-semester-2022/>
- Θεσμικό Πλαίσιο Α.Π.Ε., Regulatory Authority for Energy. Available at: [https://www.rae.gr/thesmiko-plaisio-ape-2/#\\_ftn1](https://www.rae.gr/thesmiko-plaisio-ape-2/#_ftn1) [accessed June 18 2023]

SDG 7 - Affordable and clean energy (2023), Eurostat. Available at:

[https://ec.europa.eu/eurostat/statistics-explained/index.php?title=SDG\\_7\\_-\\_Affordable\\_and\\_clean\\_energy&oldid=361288#Affordable\\_and\\_clean\\_energy\\_in\\_the\\_EU:\\_overview\\_and\\_key\\_trends](https://ec.europa.eu/eurostat/statistics-explained/index.php?title=SDG_7_-_Affordable_and_clean_energy&oldid=361288#Affordable_and_clean_energy_in_the_EU:_overview_and_key_trends) [accessed June 05 2023]

SDG Progress Report (2023), United Nations. Available at:

[https://sdgs.un.org/sites/default/files/2023-04/SDG\\_Progress\\_Report\\_Special\\_Edition\\_2023\\_ADVANCE\\_UNEDITED\\_VERSION.pdf](https://sdgs.un.org/sites/default/files/2023-04/SDG_Progress_Report_Special_Edition_2023_ADVANCE_UNEDITED_VERSION.pdf) [accessed June 05 2023]

Suri, Marcel; Betak, Juraj; Rosina, Konstantin; Chrkavy, Daniel; Suriova, Nada; Cebecauer, Tomas; Caltik, Marek; Erdelyi, Branislav, (2020). Global Photovoltaic Power Potential by Country (English). Energy Sector Management Assistance Program (ESMAP) Washington, D.C. : World Bank Group.

The Intergovernmental Panel on Climate Change, ipcc. Available at:

[https://www.ipcc.ch/site/assets/uploads/sites/2/2022/06/SR15\\_Chapter\\_1\\_HR.pdf](https://www.ipcc.ch/site/assets/uploads/sites/2/2022/06/SR15_Chapter_1_HR.pdf) [accessed June 07 2023]

N.S. Thomaidis, Moukas, A.-I. Designing Efficient Renewable Energy Portfolios for Optimal Coverage of European Power Demand Under Transmission Constraints. *Energies* 2022, 15, 9375.

N.S. Thomaidis, F. J. Santos-Alamillos, D. Pozo-Vázquez, J. Usaola-García (2016), “Optimal management of wind and solar energy resources”, *Computers & Operations Research* 66, pp. 284-291.

N.S. Thomaidis, T. Christodoulou, F.J. Santos-Alamillos (2023) “Handling the risk dimensions of wind energy generation”, *Applied Energy* 339, 120925

Makri, I., (2019). Agenda 2030: Στο δρόμο προς την επίτευξη των στόχων βιώσιμης ανάπτυξης & η πορεία της Ελλάδας, Ινστιτούτο Μικρών Επιχειρήσεων. Available at: [https://imegsevee.gr/wp-content/uploads/2019/09/%CE%95%CE%A3\\_Agenda-2030\\_9-2019.pdf](https://imegsevee.gr/wp-content/uploads/2019/09/%CE%95%CE%A3_Agenda-2030_9-2019.pdf) [accessed June 03 2023]

Markowitz, H. (1952) 'Portfolio selection', The Journal of Finance, 7(1), p. 77.

doi:10.2307/2975974.



## Appendix A

Table 20: Total annual wind production

### TOTAL ANNUAL WIND PRODUCTION

YEAR	EL30	EL41	EL42	EL43	EL51	EL52	EL53	EL54	EL61	EL62	EL63	EL64	EL65
1986	2123.714	2441.505	2731.733	1846.257	2545.353	1718.352	891.351	1432.662	1123.429	2056.562	1580.379	2056.562	1580.379
1987	2064.648	2463.435	2983.507	2212.294	2398.066	1818.604	1239.142	1538.362	1135.836	2011.599	1567.750	2011.599	1567.750
1988	1885.534	2123.909	2677.557	2055.129	2179.793	1701.230	1222.667	1507.856	1177.576	1834.948	1614.672	1834.948	1614.672
1989	2128.585	2187.144	2494.281	1867.378	2275.206	1636.473	997.739	1493.907	1015.651	2031.034	1685.497	2031.034	1685.497
1990	2033.846	2343.699	2708.825	2018.379	2272.999	1589.357	905.714	1355.555	1021.905	1960.472	1435.996	1960.472	1435.996
1991	2222.857	2270.530	2648.679	2140.490	2347.220	1638.336	929.452	1503.444	1122.930	2074.930	1638.504	2074.930	1638.504
1992	2320.899	2273.667	2639.168	2082.888	2474.842	1861.563	1248.283	1692.324	1192.567	2180.380	1814.850	2180.380	1814.850
1993	2176.272	2279.201	2623.272	2015.032	2443.303	1764.618	1085.932	1667.527	1326.593	2067.215	1765.512	2067.215	1765.512
1994	2197.153	2313.360	2852.454	2299.599	2308.355	1665.080	1021.804	1525.925	1106.862	2054.335	1647.209	2054.335	1647.209
1995	1907.183	2160.219	2567.416	1870.196	2368.901	1705.637	1042.372	1483.937	1025.870	1885.657	1650.179	1885.657	1650.179
1996	1997.087	2227.287	2725.687	2097.853	2297.201	1592.652	888.102	1442.324	1304.160	1921.894	1800.992	1921.894	1800.992
1997	2065.189	2162.968	2639.784	1897.771	2367.178	1774.720	1182.262	1653.044	1315.369	2001.233	1829.447	2001.233	1829.447
1998	2049.775	2133.059	2550.271	1926.380	2487.610	1855.006	1222.402	1700.714	1128.209	2026.559	1768.010	2026.559	1768.010
1999	1699.912	1922.236	2485.698	1898.034	2107.478	1577.710	1047.941	1408.984	1091.867	1711.865	1576.940	1711.865	1576.940
2000	2041.285	2090.616	2687.352	2076.923	2176.049	1597.617	1019.185	1457.876	1045.558	1936.354	1594.852	1936.354	1594.852
2001	2259.038	2423.464	2793.518	2139.000	2754.303	1999.744	1245.184	1847.859	1299.791	2232.656	1909.338	2232.656	1909.338
2002	1528.952	1639.604	2142.739	1746.669	1974.097	1507.206	1040.314	1258.066	1068.730	1480.623	1469.143	1480.623	1469.143
2003	2407.425	2472.920	2938.525	2297.517	2578.900	1770.368	961.836	1575.799	1200.149	2239.629	1756.465	2239.629	1756.465
2004	2133.395	2302.195	2694.851	2077.121	2372.792	1760.924	1149.056	1593.019	1131.978	2037.388	1876.331	2037.388	1876.331
2005	1938.054	2148.040	2606.487	1947.322	2362.635	1662.735	962.834	1519.895	1073.141	1906.831	1639.291	1906.831	1639.291
2006	2226.931	2207.791	2537.915	1908.056	2344.220	1574.761	805.301	1451.059	923.685	2086.835	1586.394	2086.835	1586.394
2007	1907.563	2118.770	2496.044	1890.538	2250.141	1591.632	933.122	1367.640	1061.794	1839.609	1664.916	1839.609	1664.916

<b>2008</b>	2156.490	2152.825	2423.530	1813.749	2354.689	1682.775	1010.861	1438.262	1116.619	2031.801	1706.097	2031.801	1706.097
<b>2009</b>	2016.985	2124.762	2561.837	1997.469	2193.587	1521.368	849.148	1331.907	997.901	1923.912	1715.489	1923.912	1715.489
<b>2010</b>	1962.935	2089.258	2437.746	1849.622	2289.249	1670.032	1050.814	1552.796	1174.821	1941.653	1822.160	1941.653	1822.160
<b>2011</b>	2504.893	2209.105	2407.164	1731.728	2511.669	1675.012	838.355	1582.355	1199.209	2314.148	1778.479	2314.148	1778.479
<b>2012</b>	2416.933	2221.833	2581.031	2127.639	2602.375	1858.181	1113.986	1660.181	1209.581	2261.500	1777.740	2261.500	1777.740
<b>2013</b>	2192.893	2222.860	2682.067	2125.075	2246.288	1607.576	968.863	1463.840	1080.003	2087.986	1742.764	2087.986	1742.764
<b>2014</b>	1523.984	1677.586	1942.833	1334.896	1843.573	1295.582	747.590	1097.196	922.034	1500.133	1347.028	1500.133	1347.028
<b>2015</b>	2223.342	2141.953	2329.181	1724.128	2289.481	1564.307	839.133	1377.793	898.243	2094.433	1494.629	2094.433	1494.629

Table 41: Total annual solar production

**TOTAL ANNUAL SOLAR PRODUCTION**

<b>YEAR</b>	<b>EL30</b>	<b>EL41</b>	<b>EL42</b>	<b>EL43</b>	<b>EL51</b>	<b>EL52</b>	<b>EL53</b>	<b>EL54</b>	<b>EL61</b>	<b>EL62</b>	<b>EL63</b>	<b>EL64</b>	<b>EL65</b>
<b>1986</b>	1665.136	1727.223	1763.849	1713.747	1516.844	1436.595	1379.175	1461.350	1416.027	1575.947	1549.264	1495.047	1569.541
<b>1987</b>	1588.098	1643.856	1711.280	1676.342	1417.757	1398.628	1383.500	1452.541	1401.540	1539.658	1510.675	1445.462	1514.699
<b>1988</b>	1598.542	1626.571	1683.607	1658.551	1456.428	1467.486	1438.740	1474.140	1453.097	1572.305	1540.167	1483.587	1564.294
<b>1989</b>	1674.962	1721.293	1784.859	1708.952	1504.886	1547.685	1529.740	1569.956	1543.751	1670.607	1642.947	1552.973	1646.612
<b>1990</b>	1679.872	1733.300	1792.012	1719.753	1514.945	1546.389	1504.432	1517.738	1550.930	1641.455	1605.812	1552.933	1638.124
<b>1991</b>	1581.310	1621.920	1692.301	1667.989	1391.277	1402.721	1372.776	1455.208	1402.198	1586.348	1534.192	1423.131	1542.120
<b>1992</b>	1660.110	1718.371	1772.033	1718.985	1523.103	1529.384	1502.823	1528.319	1528.296	1617.324	1590.918	1539.803	1590.955
<b>1993</b>	1691.849	1737.497	1798.992	1773.627	1511.098	1524.452	1469.098	1564.384	1515.481	1673.282	1634.816	1561.640	1638.356
<b>1994</b>	1655.233	1645.170	1737.195	1727.987	1457.634	1463.424	1478.580	1504.732	1480.350	1612.323	1588.939	1521.859	1607.119
<b>1995</b>	1634.460	1657.785	1737.395	1722.417	1443.854	1447.563	1397.350	1430.831	1452.205	1561.125	1534.200	1491.272	1568.533
<b>1996</b>	1516.087	1598.871	1663.447	1615.330	1368.033	1330.040	1291.034	1347.505	1322.571	1484.885	1446.284	1368.402	1461.138
<b>1997</b>	1626.647	1659.466	1737.081	1688.760	1448.476	1473.444	1476.772	1526.800	1463.434	1613.397	1583.305	1500.444	1568.128
<b>1998</b>	1635.080	1626.227	1707.207	1688.648	1439.288	1464.998	1459.675	1516.857	1491.827	1606.965	1601.936	1519.605	1597.676

<b>1999</b>	1650.953	1654.622	1751.631	1725.496	1467.148	1470.156	1431.139	1446.194	1476.285	1564.543	1532.153	1512.814	1572.396
<b>2000</b>	1689.252	1746.418	1776.964	1704.841	1592.732	1573.664	1511.851	1579.538	1561.660	1642.884	1628.837	1571.303	1618.686
<b>2001</b>	1636.794	1646.443	1708.618	1687.834	1453.860	1462.197	1457.117	1482.130	1490.329	1598.905	1573.355	1521.330	1581.590
<b>2002</b>	1602.614	1622.814	1709.072	1683.596	1403.174	1397.968	1374.629	1449.414	1425.610	1563.339	1538.184	1479.785	1566.743
<b>2003</b>	1552.141	1647.034	1678.031	1631.397	1469.959	1456.521	1397.125	1491.908	1411.653	1553.122	1512.720	1423.445	1481.048
<b>2004</b>	1604.713	1678.413	1727.612	1701.988	1459.683	1456.661	1420.222	1446.217	1454.637	1558.209	1527.193	1474.246	1542.791
<b>2005</b>	1613.234	1650.515	1718.744	1682.584	1442.639	1481.321	1400.631	1467.823	1466.768	1562.534	1552.432	1478.597	1550.405
<b>2006</b>	1624.509	1642.495	1705.475	1664.834	1406.812	1424.027	1386.665	1482.254	1410.350	1604.271	1553.440	1447.312	1552.177
<b>2007</b>	1689.243	1710.268	1769.938	1697.077	1528.511	1503.580	1428.609	1488.633	1476.158	1616.648	1583.145	1533.771	1602.919
<b>2008</b>	1661.064	1678.020	1750.288	1703.332	1481.799	1472.382	1414.437	1453.520	1478.316	1593.501	1554.452	1513.968	1588.707
<b>2009</b>	1622.690	1612.735	1699.059	1661.611	1387.428	1421.231	1375.645	1396.857	1424.197	1539.346	1496.826	1463.064	1528.058
<b>2010</b>	1603.369	1604.501	1704.452	1708.898	1375.517	1415.658	1353.693	1377.038	1419.275	1530.905	1487.280	1459.550	1534.367
<b>2011</b>	1652.256	1718.812	1731.262	1651.563	1514.767	1509.666	1444.668	1568.439	1456.956	1648.174	1624.518	1489.906	1579.562
<b>2012</b>	1651.807	1674.319	1728.928	1682.279	1513.166	1499.242	1436.823	1503.340	1503.590	1607.139	1573.193	1527.661	1593.775
<b>2013</b>	1653.262	1661.172	1724.045	1713.927	1451.877	1461.676	1433.038	1428.915	1494.481	1563.819	1528.077	1512.715	1555.151
<b>2014</b>	1595.498	1615.147	1700.469	1645.516	1368.445	1378.469	1360.533	1427.565	1405.919	1546.377	1512.993	1459.645	1528.130
<b>2015</b>	1651.137	1676.319	1729.594	1642.385	1479.721	1482.483	1450.393	1539.482	1492.034	1636.945	1605.678	1511.876	1571.081

## Appendix B

Table 22: Descriptive statistical analysis for wind per region

DESCRIPTIVE STATISTICAL ANALYSIS FOR WIND PER REGION									
	EL30	EL41	EL42	EL43	EL51	EL52	EL53	EL54	EL61
<b>Mean</b>	2077.125	2184.860	2586.372	1967.171	2333.918	1674.638	1015.358	1499.404	1116.402
<b>Standard Error</b>	41.616	34.409	38.521	35.774	33.347	24.613	25.794	26.912	20.539
<b>Median</b>	2094.452	2197.468	2614.880	1972.396	2345.720	1667.556	1015.023	1498.676	1119.774
<b>Standard Deviation</b>	227.940	188.466	210.986	195.941	182.646	134.811	141.281	147.401	112.496
<b>Sample Variance</b>	51956.783	35519.254	44514.991	38393.009	33359.728	18173.951	19960.419	21726.957	12655.430
<b>Kurtosis</b>	0.954	2.761	2.350	2.465	1.353	1.524	-0.813	1.280	-0.242
<b>Skewness</b>	-0.689	-1.255	-0.947	-0.923	-0.344	-0.140	0.148	-0.234	0.074
<b>Range</b>	980.909	833.316	1040.674	964.703	910.730	704.162	500.693	750.663	428.350
<b>Minimum</b>	1523.984	1639.604	1942.833	1334.896	1843.573	1295.582	747.590	1097.196	898.243
<b>Maximum</b>	2504.893	2472.920	2983.507	2299.599	2754.303	1999.744	1248.283	1847.859	1326.593
<b>Sum</b>	62313.755	65545.801	77591.152	59015.132	70017.553	50239.149	30460.745	44982.109	33492.061
<b>Count</b>	30	30	30	30	30	30	30	30	30

Continuing the above table

	<b>EL62</b>	<b>EL63</b>	<b>EL64</b>	<b>EL65</b>
<b>Mean</b>	1991.139	1675.235	1991.139	1675.235
<b>Standard Error</b>	34.770	24.451	34.770	24.451
<b>Median</b>	2028.796	1675.207	2028.796	1675.207
<b>Standard Deviation</b>	190.442	133.923	190.442	133.923
<b>Sample Variance</b>	36267.990	17935.266	36267.990	17935.266
<b>Kurtosis</b>	1.778	-0.052	1.778	-0.052
<b>Skewness</b>	-1.010	-0.479	-1.010	-0.479
<b>Range</b>	833.525	562.310	833.525	562.310
<b>Minimum</b>	1480.623	1347.028	1480.623	1347.028
<b>Maximum</b>	2314.148	1909.338	2314.148	1909.338
<b>Sum</b>	59734.174	50257.057	59734.174	50257.057
<b>Count</b>	30	30	30	30

Table 23: Descriptive statistical analysis for solar per region

<b>DESCRIPTIVE STATISTICAL ANALYSIS FOR SOLAR PER REGION</b>									
	<b>EL30</b>	<b>EL41</b>	<b>EL42</b>	<b>EL43</b>	<b>EL51</b>	<b>EL52</b>	<b>EL53</b>	<b>EL54</b>	<b>EL61</b>
<b>Mean</b>	1632.064	1665.253	1729.848	1689.008	1459.695	1463.324	1425.364	1479.321	1462.331
<b>Standard Error</b>	7.526	7.896	6.351	6.148	10.004	9.828	9.857	10.385	9.598
<b>Median</b>	1635.937	1656.204	1728.270	1688.704	1457.031	1464.211	1429.874	1478.135	1465.101
<b>Standard Deviation</b>	41.222	43.248	34.783	33.674	54.792	53.830	53.989	56.879	52.573
<b>Sample Variance</b>	1699.262	1870.363	1209.880	1133.935	3002.175	2897.687	2914.845	3235.229	2763.928
<b>Kurtosis</b>	0.829	-0.957	-0.562	0.366	-0.224	0.283	0.022	-0.119	0.441
<b>Skewness</b>	-0.812	0.426	0.293	-0.038	0.138	-0.180	-0.127	-0.161	-0.270
<b>Range</b>	175.762	147.548	135.545	158.298	224.698	243.624	238.706	232.033	239.089
<b>Minimum</b>	1516.087	1598.871	1663.447	1615.330	1368.033	1330.040	1291.034	1347.505	1322.571
<b>Maximum</b>	1691.849	1746.418	1798.992	1773.627	1592.732	1573.664	1529.740	1579.538	1561.660
<b>Sum</b>	48961.923	49957.597	51895.437	50670.247	43790.860	43899.711	42760.911	44379.625	43869.924
<b>Count</b>	30	30	30	30	30	30	30	30	30

Continuing the above table

	<b>EL62</b>	<b>EL63</b>	<b>EL64</b>	<b>EL65</b>
<b>Mean</b>	1589.543	1558.264	1494.572	1568.496
<b>Standard Error</b>	8.017	8.635	8.342	7.760
<b>Median</b>	1589.924	1552.936	1497.745	1569.037
<b>Standard Deviation</b>	43.908	47.293	45.692	42.504
<b>Sample Variance</b>	1927.944	2236.671	2087.785	1806.624
<b>Kurtosis</b>	-0.145	-0.283	0.632	0.609
<b>Skewness</b>	-0.025	-0.108	-0.647	-0.403
<b>Range</b>	188.398	196.663	202.901	185.475
<b>Minimum</b>	1484.885	1446.284	1368.402	1461.138
<b>Maximum</b>	1673.282	1642.947	1571.303	1646.612
<b>Sum</b>	47686.283	46747.930	44837.147	47054.884
<b>Count</b>	30	30	30	30

## Appendix C

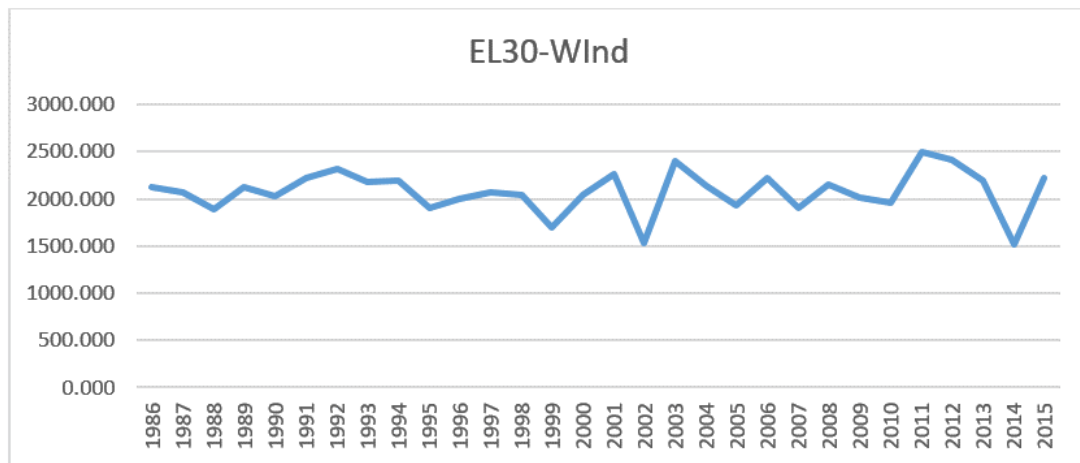


Figure 98: Total annual wind production of Attica from 1986 to 2015

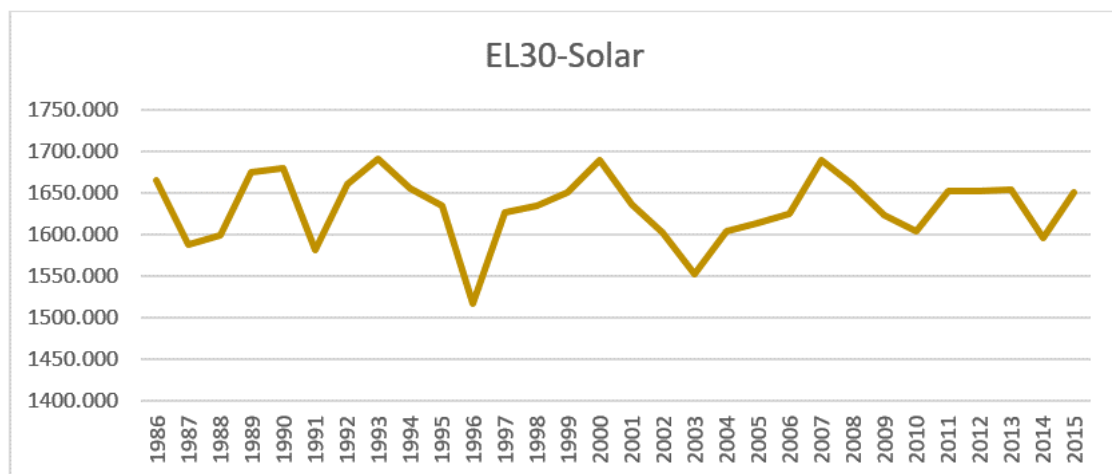


Figure 19: Total annual solar production of Attica from 1986 to 2015



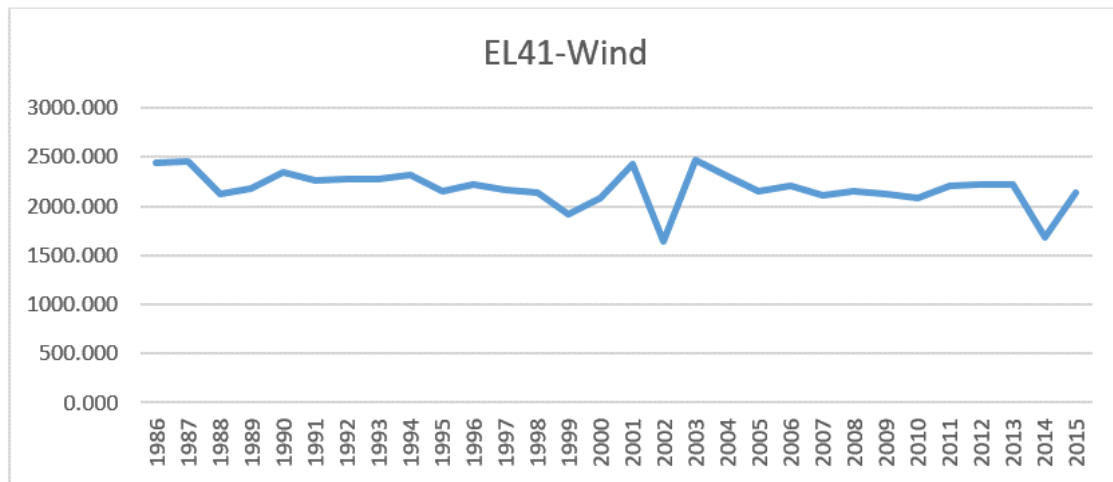


Figure 20: Total annual wind production of North Aegean from 1986 to 2015

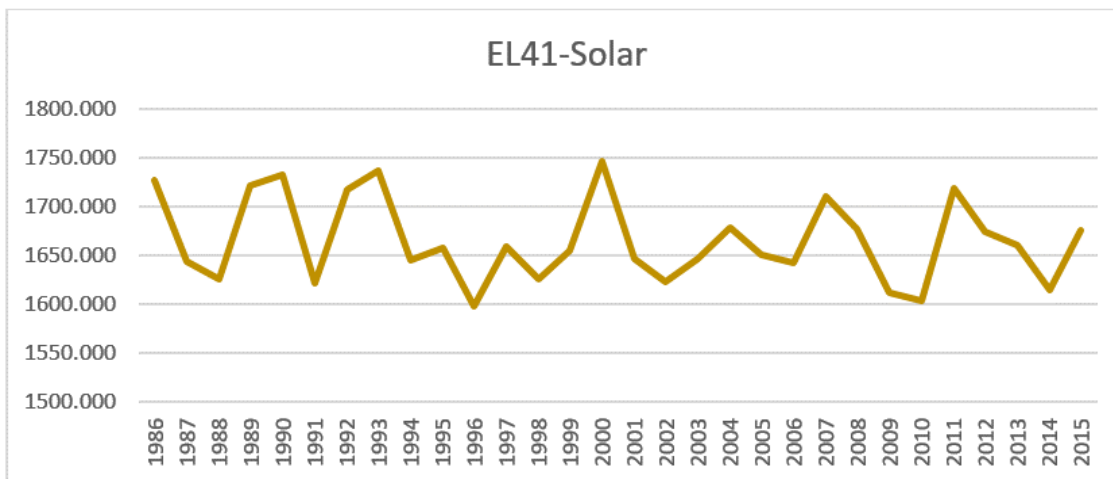


Figure 21: Total annual solar production of North Aegean from 1986 to 2015

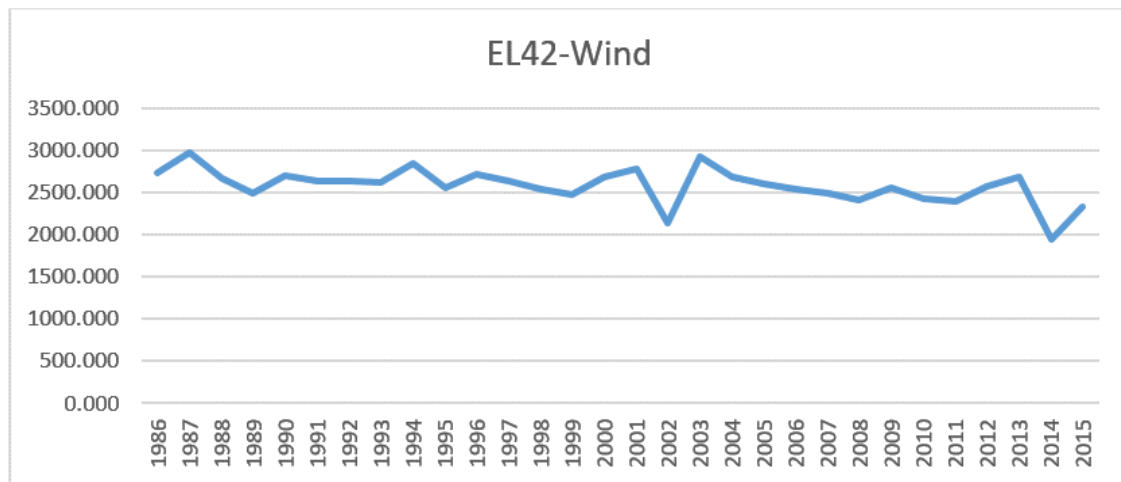


Figure 22: Total annual wind production of South Aegean from 1986 to 2015

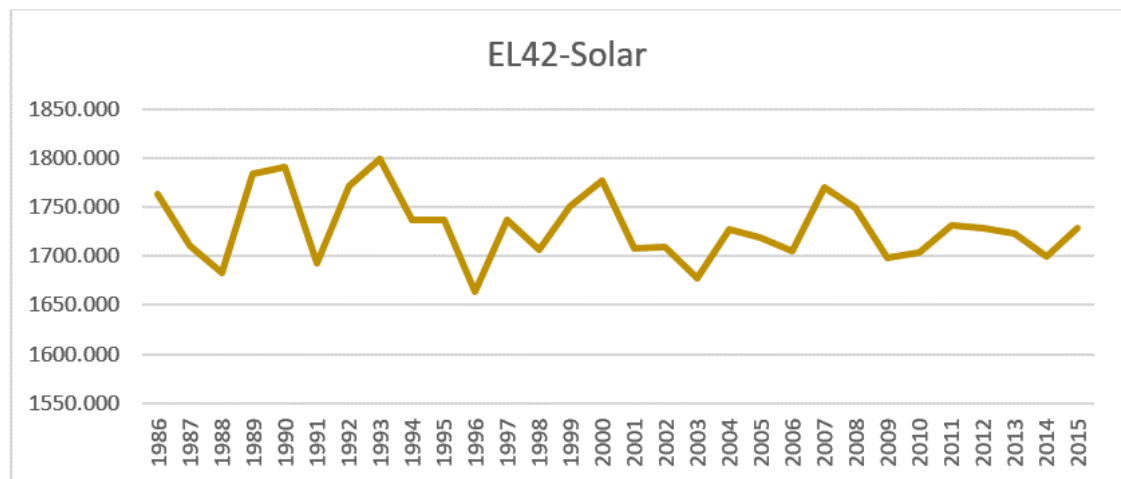


Figure 23: Total annual solar production of South Aegean from 1986 to 2015

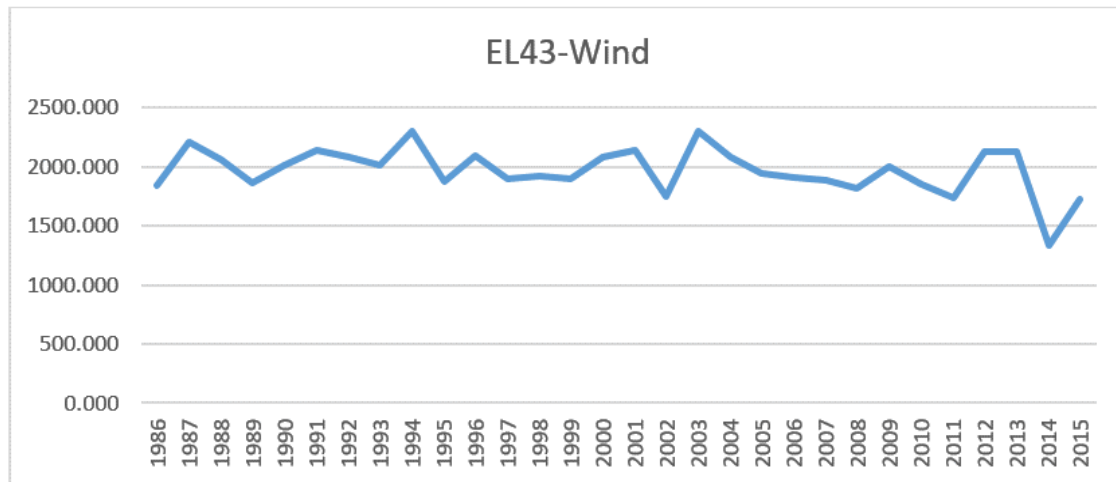


Figure 24: Total annual wind production of Crete from 1986 to 2015

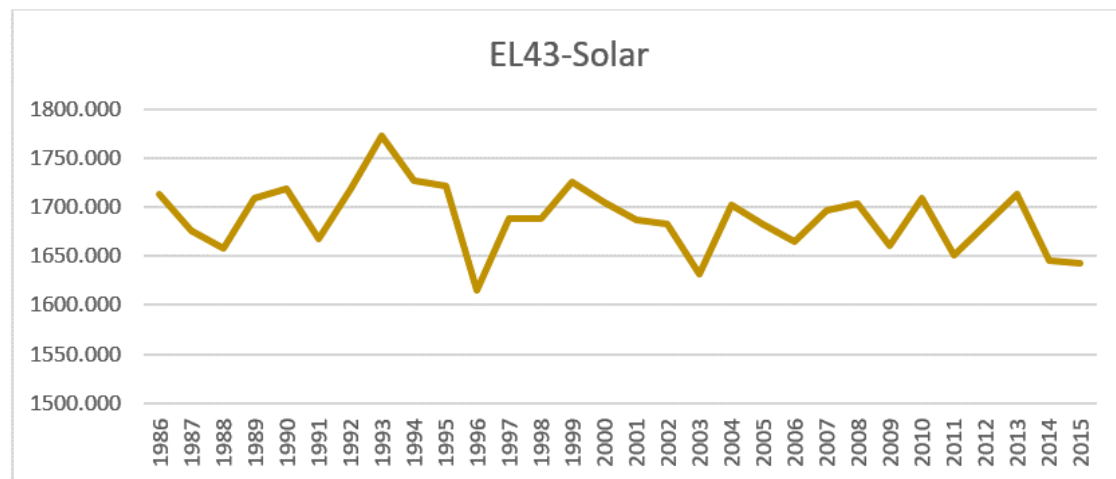


Figure 25: Total annual solar production of Crete from 1986 to 2015

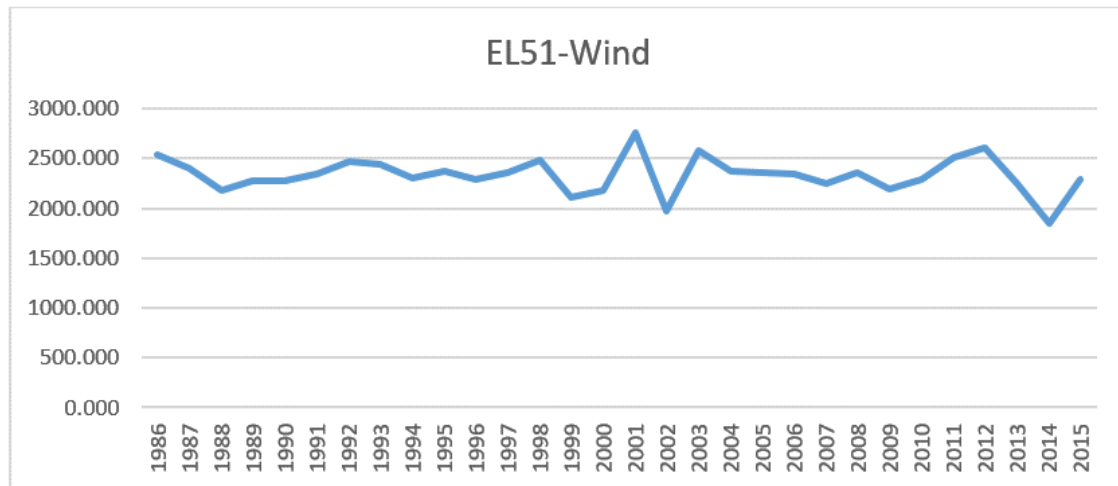


Figure 26: Total annual wind production of Eastern Macedonia & Thrace from 1986 to 2015

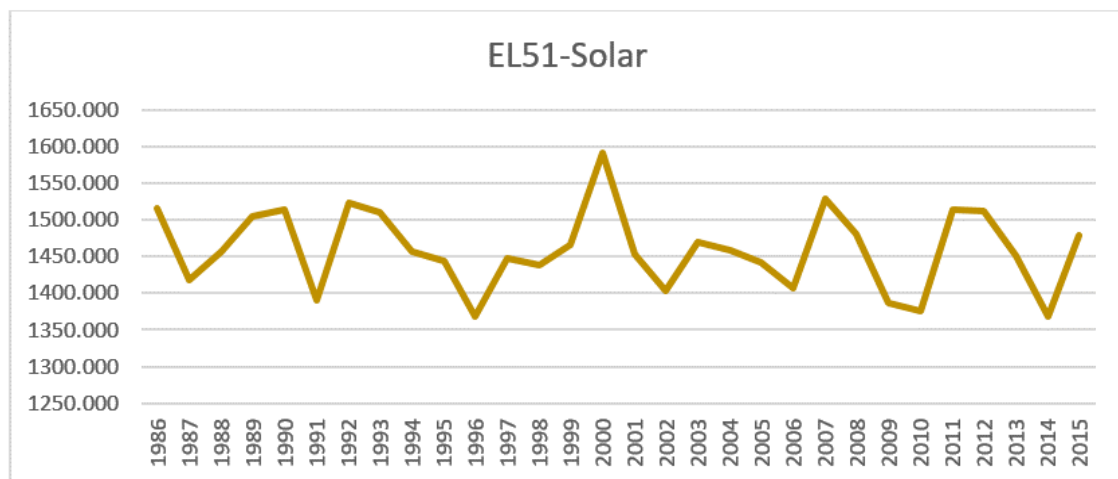


Figure 27: Total annual solar production of Eastern Macedonia & Thrace from 1986 to 2015

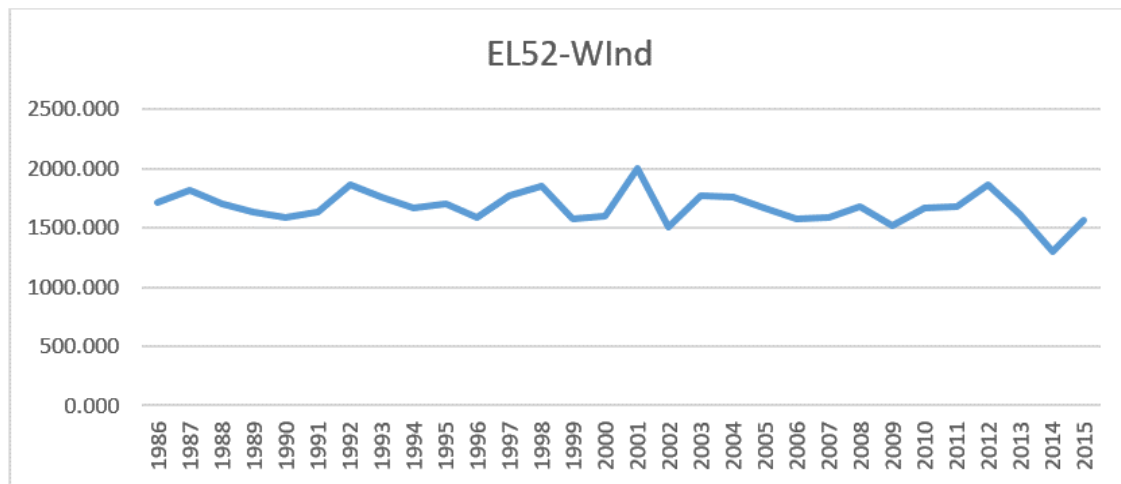


Figure 28: Total annual wind production of Central Macedonia from 1986 to 2015

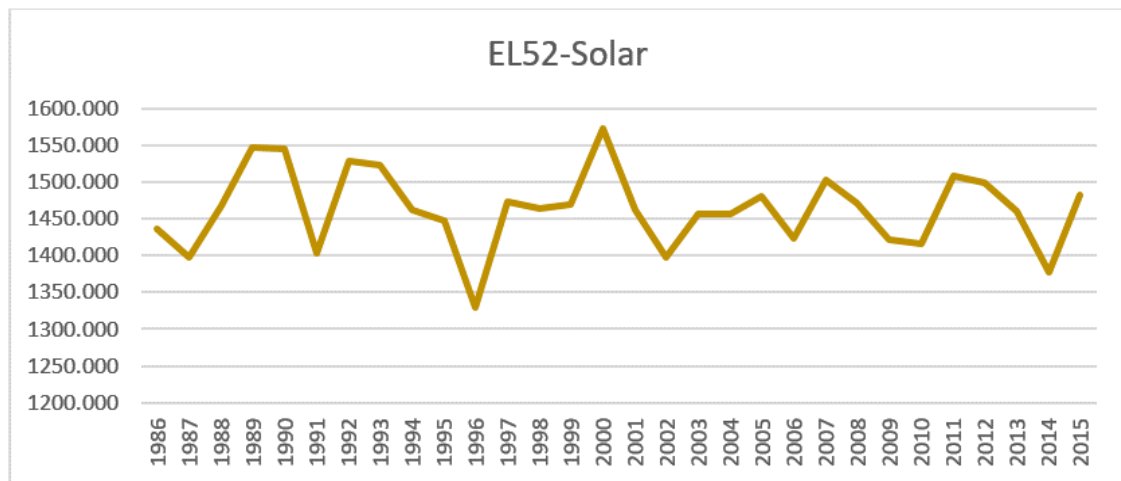


Figure 29: Total annual solar production of Central Macedonia from 1986 to 2015

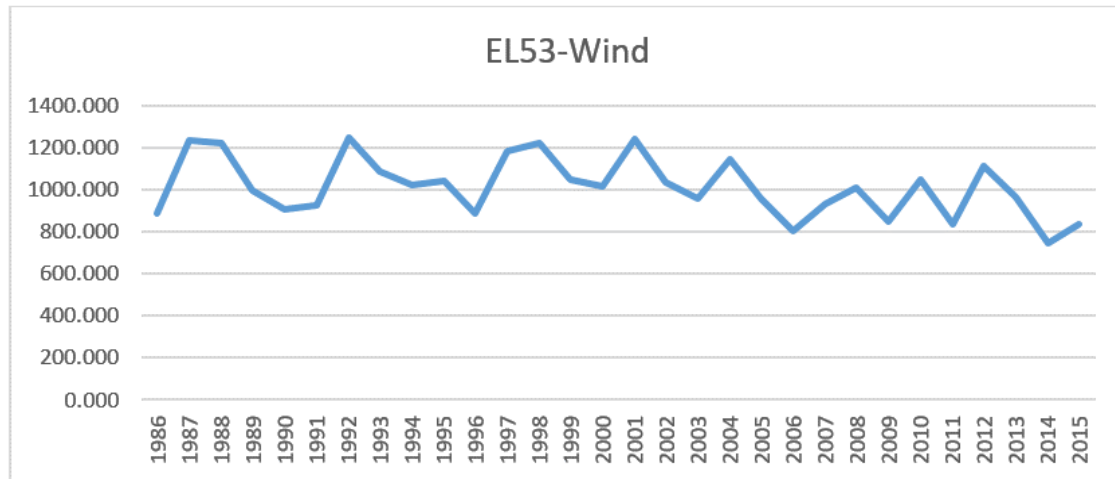


Figure 30: Total annual wind production of Western Macedonia from 1986 to 2015

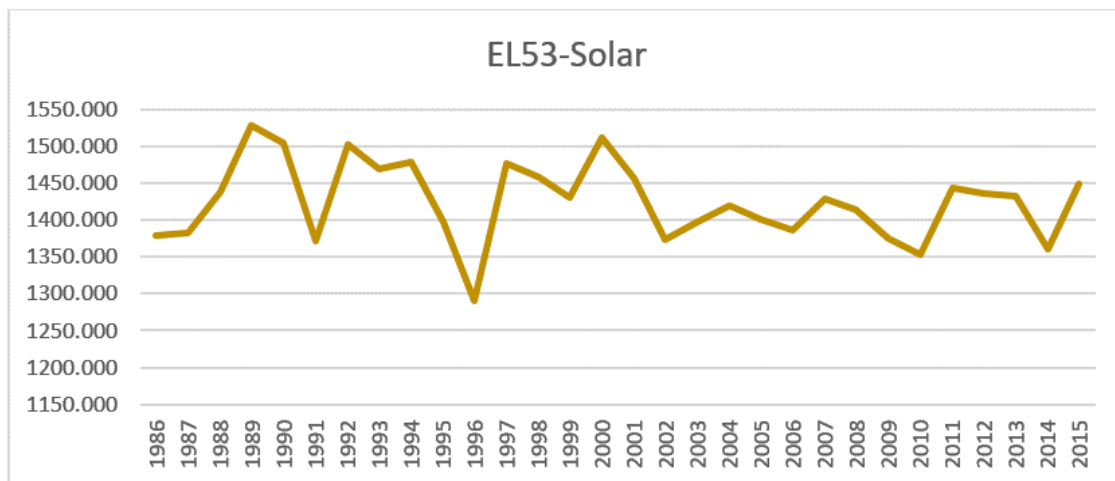


Figure 31: Total annual solar production of Western Macedonia from 1986 to 2015

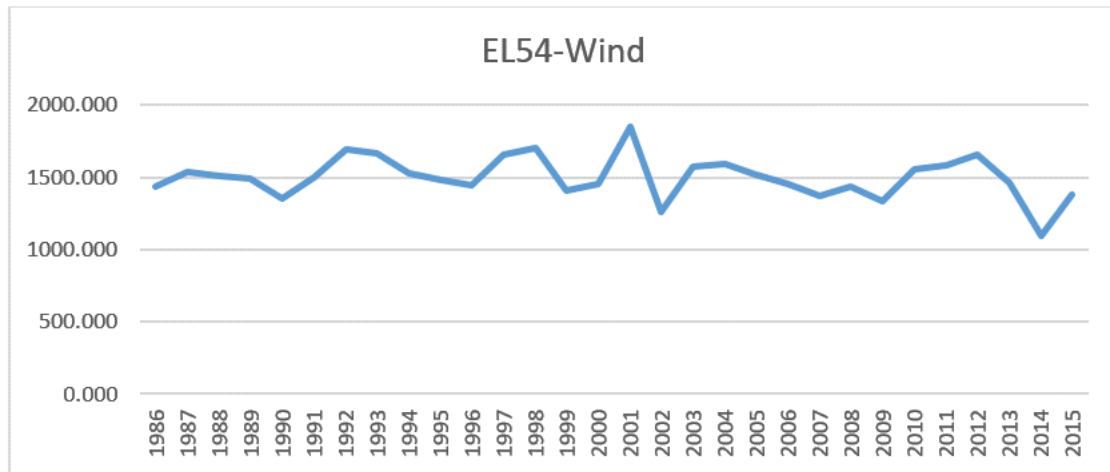


Figure 32: Total annual wind production of Epirus from 1986 to 2015

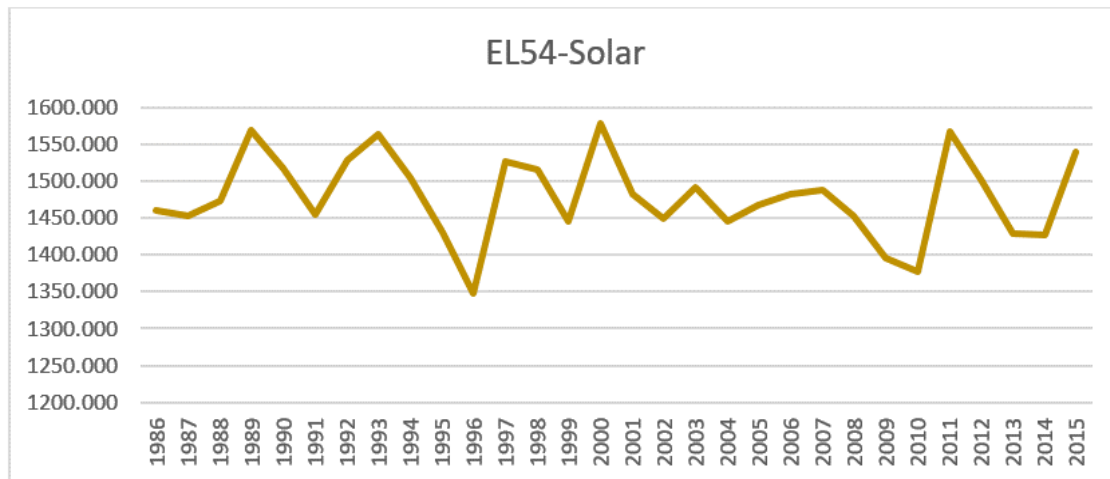


Figure 33: Total annual solar production of Epirus from 1986 to 2015

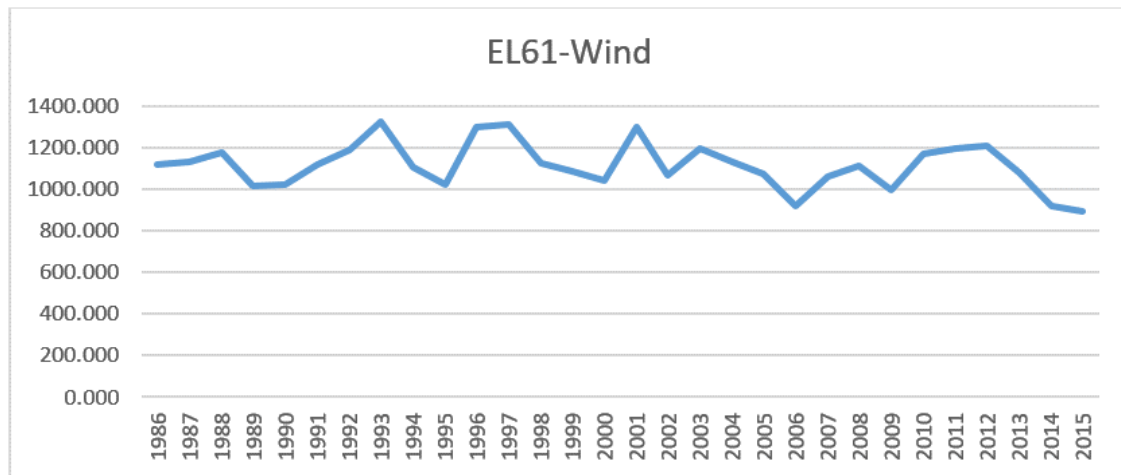


Figure 34: Total annual wind production of Thessaly from 1986 to 2015

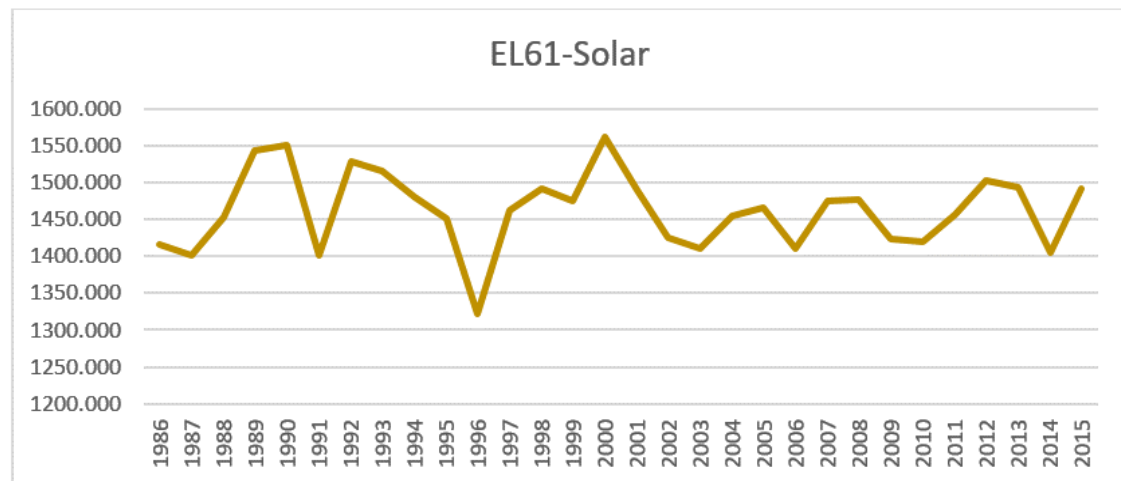


Figure 35: Total annual solar production of Thessaly from 1986 to 2015



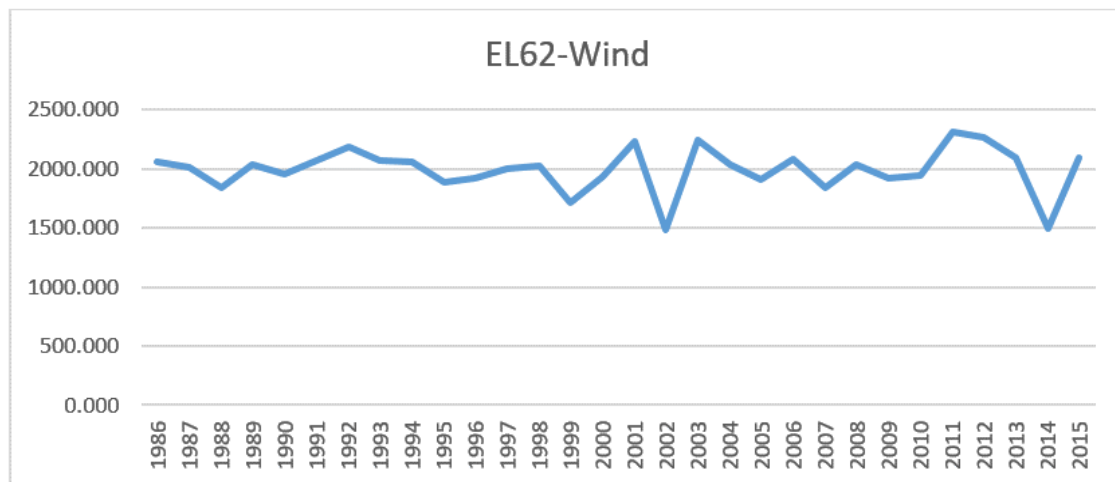


Figure 36: Total annual wind production of Ionian Islands from 1986 to 2015

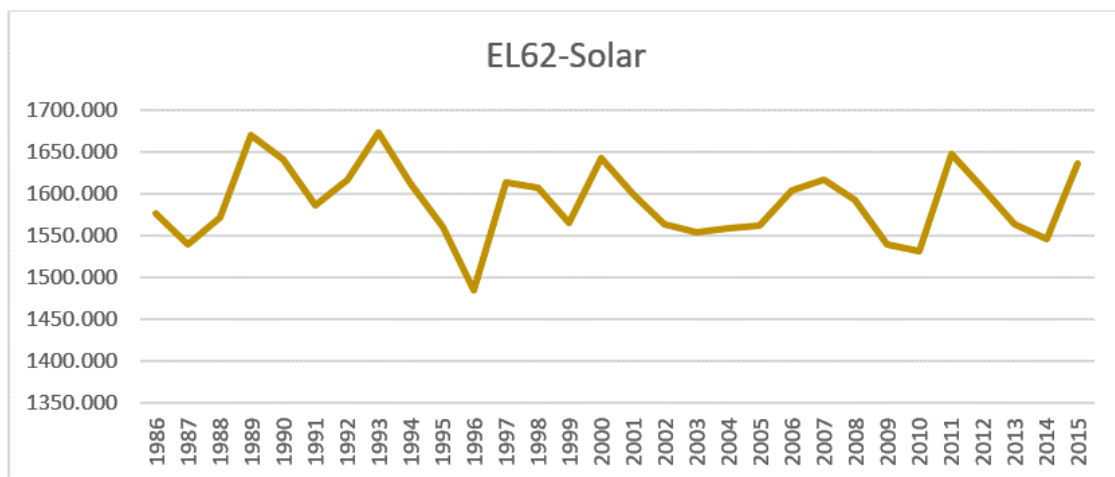


Figure 37: Total annual solar production of Ionian Islands from 1986 to 2015

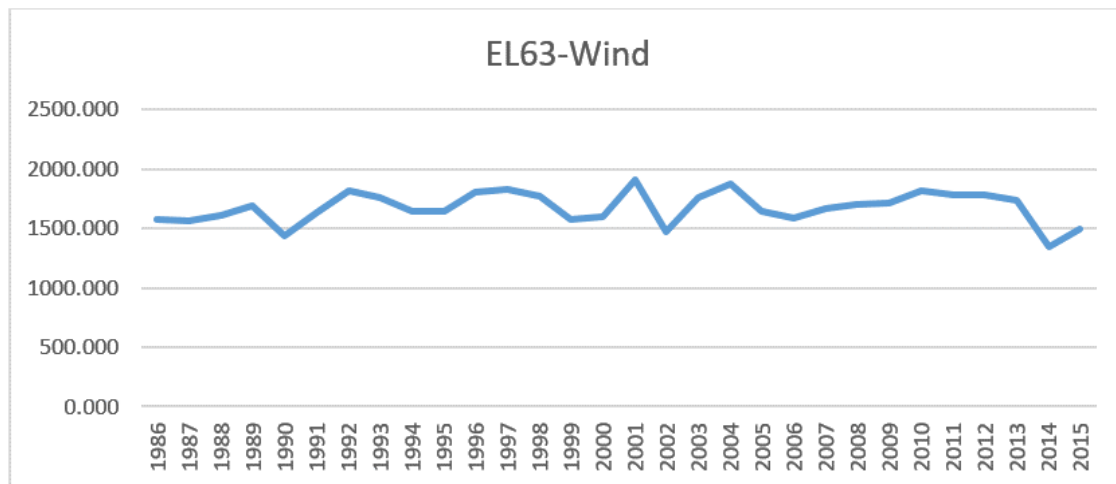


Figure 38: Total annual wind production of Western Greece from 1986 to 2015

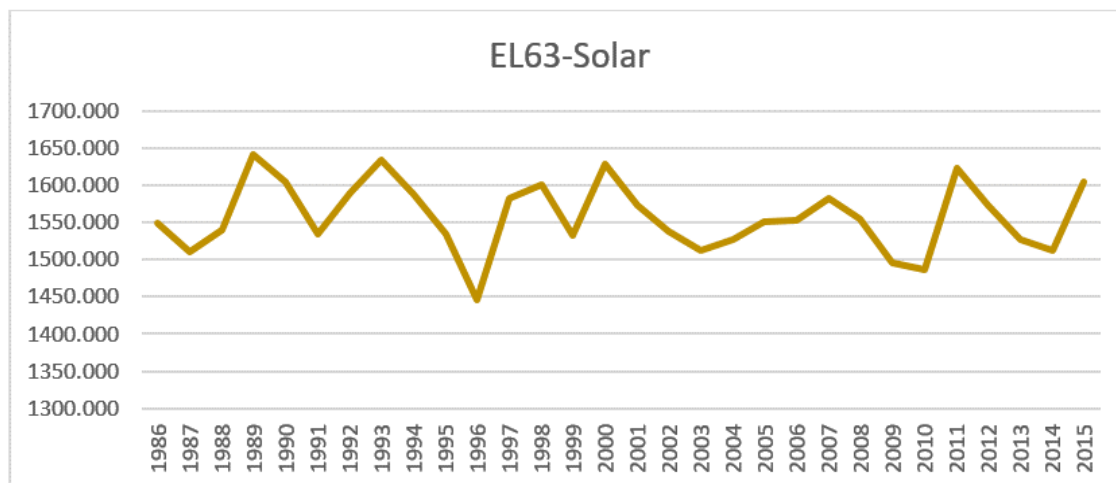


Figure 39: Total annual solar production of Western Greece from 1986 to 2015

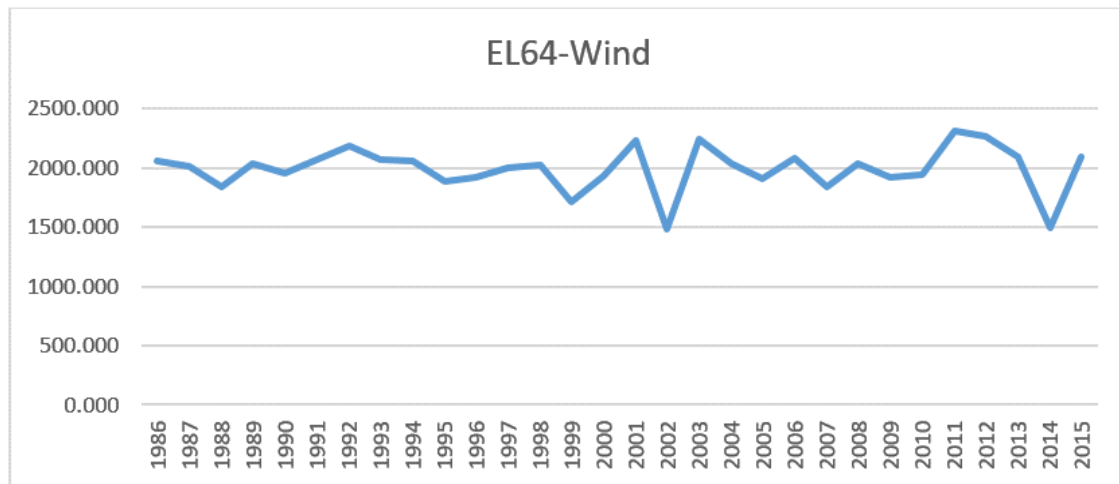


Figure 40: Total annual wind production of Central Greece from 1986 to 2015

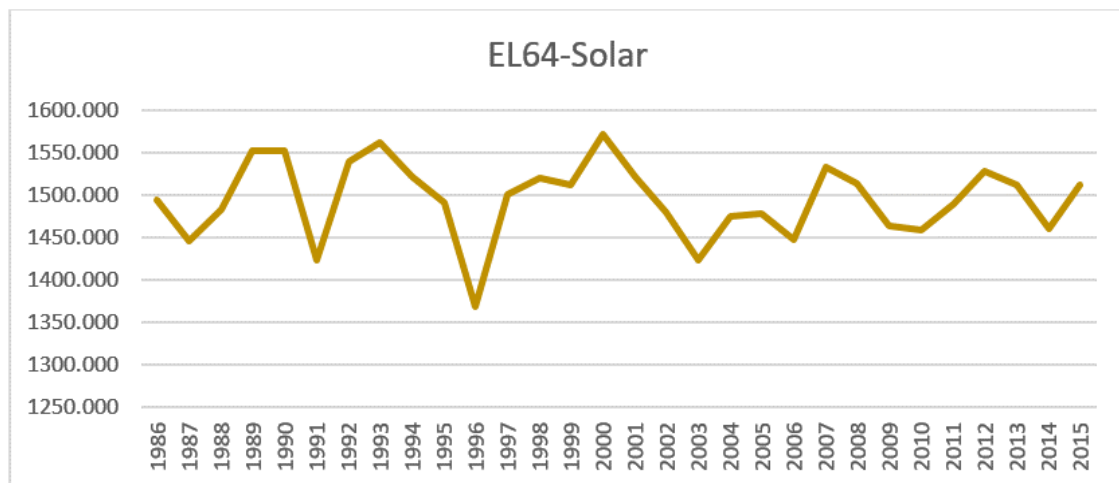


Figure 41: Total annual solar production of Central Greece from 1986 to 2015

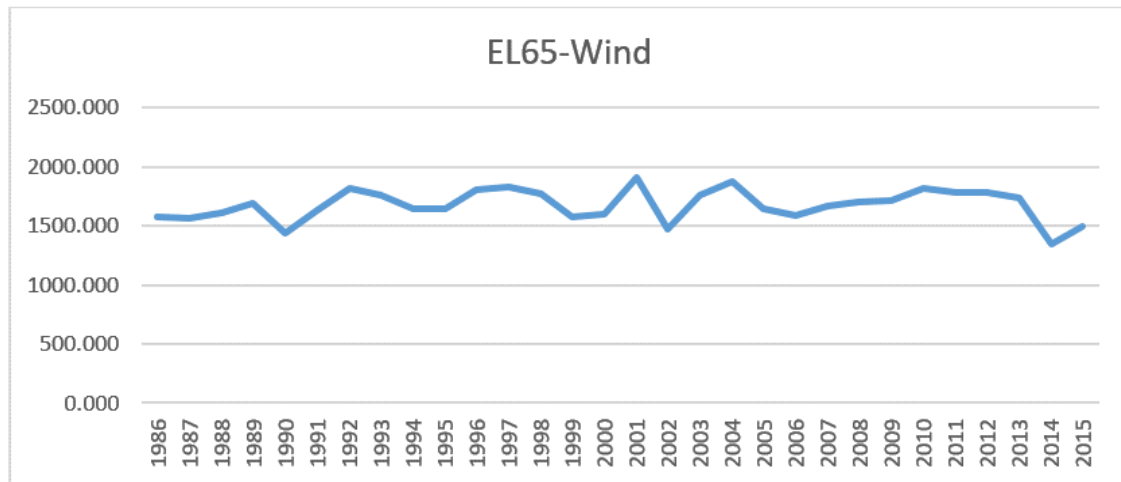


Figure 42: Total annual wind production of Peloponnese from 1986 to 2015

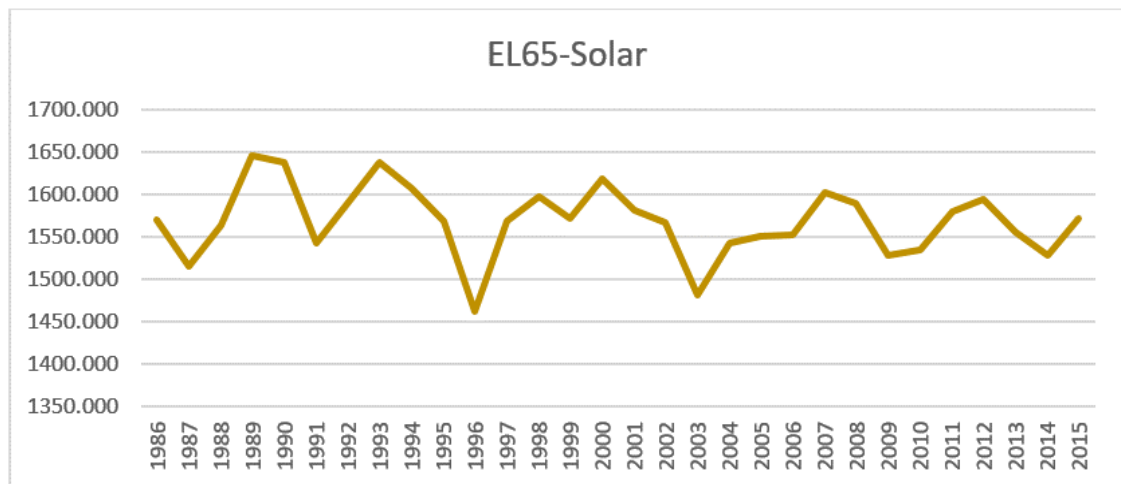


Figure 43: Total annual solar production of Peloponnese from 1986 to 2015

## Appendix D

	Variance - Covariance matrix of yearly wind & solar capacity factors																									
	EL30-W	EL41-W	EL42-W	EL43-W	EL51-W	EL52-W	EL53-W	EL54-W	EL61-W	EL62-W	EL63-W	EL64-W	EL65-W	EL30-S	EL41-S	EL42-S	EL43-S	EL51-S	EL52-S	EL53-S	EL54-S	EL61-S	EL62-S	EL63-S	EL64-S	EL65-S
EL30-W	50224.890	31822.639	24122.371	21845.879	32378.165	17542.438	2706.710	21063.520	8311.070	41345.051	16526.603	41345.051	16526.603	1476.573	3408.114	720.432	-241.737	4775.118	4251.897	3743.725	5387.703	2516.973	3836.096	3558.907	1049.823	997.083
EL41-W	31822.639	34335.279	33346.922	25232.874	26852.687	16487.185	6121.684	16542.157	8085.608	28151.747	11253.171	28151.747	11253.171	239.869	2336.871	627.005	611.551	2903.390	1891.541	1790.721	1898.790	618.946	1094.609	910.265	-86.424	-125.036
EL42-W	24122.371	33346.922	43031.158	36161.834	22658.845	17365.856	12072.867	17313.240	10511.371	22103.994	11515.450	22103.994	11515.450	-846.213	1104.159	-76.613	886.586	2385.991	1326.731	1727.647	754.286	281.729	-469.360	-432.702	-555.622	-910.218
EL43-W	21845.879	25232.874	36161.834	37113.242	17476.967	14825.958	12174.949	15733.565	9575.388	18853.335	11615.491	18853.335	11615.491	-1049.646	46.022	-597.261	782.776	1597.125	1176.518	1678.014	381.983	784.250	-466.730	-591.149	-387.785	-670.995
EL51-W	32378.165	26852.687	22658.845	17476.967	32247.737	20806.319	9364.902	21868.800	11093.626	29302.682	15717.361	29302.682	15717.361	609.983	1896.026	289.059	468.751	3027.761	2185.437	1790.840	2756.842	1128.835	1706.826	1885.303	645.730	500.961
EL52-W	17542.438	16487.185	17365.856	14825.958	20806.319	17568.153	14329.987	18045.619	9926.421	16901.502	12312.170	16901.502	12312.170	418.772	949.366	306.983	1059.583	2095.766	1840.022	2216.221	1976.441	1614.372	1012.053	1353.913	1184.786	805.043
EL53-W	2706.710	6121.684	12072.867	12174.949	9364.902	14329.987	19295.071	14222.437	8759.217	4500.323	8906.978	4500.323	8906.978	227.561	2.705	324.907	1650.414	1163.771	1494.606	2641.602	1196.040	2099.908	317.280	822.524	1723.841	1109.125
EL54-W	21063.520	16542.157	17313.240	15733.565	21868.800	18045.619	14222.437	21002.725	11441.415	19819.074	15403.534	19819.074	15403.534	470.413	902.073	238.995	1139.805	1993.884	2361.279	2829.438	2710.258	2008.122	1627.961	1956.848	1294.757	1024.406
EL61-W	8311.070	8085.608	10511.371	9575.388	11093.626	9926.421	8759.217	11441.415	12233.583	8009.211	10503.423	8009.211	10503.423	-849.488	35.855	-296.623	403.307	448.775	-33.692	99.693	160.370	-494.634	-224.106	-196.187	-342.586	-426.036
EL62-W	41345.051	28151.747	22103.994	18853.335	29302.682	16901.502	4500.323	19819.074	8009.211	35059.057	15219.345	35059.057	15219.345	1251.769	2684.200	585.208	51.142	3852.924	3523.773	3183.269	4187.611	2218.314	2961.255	2838.539	1015.622	844.690
EL63-W	16526.603	11253.171	11515.450	11615.491	15717.361	12312.170	8906.978	15403.534	10503.423	15219.345	17337.424	15219.345	17337.424	-405.485	-47.353	-435.756	444.279	483.524	702.393	641.948	-51.581	248.904	-101.066	-96.914	-109.312	-445.479
EL64-W	41345.051	28151.747	22103.994	18853.335	29302.682	16901.502	4500.323	19819.074	8009.211	35059.057	15219.345	35059.057	15219.345	1251.769	2684.200	585.208	51.142	3852.924	3523.773	3183.269	4187.611	2218.314	2961.255	2838.539	1015.622	844.690
EL65-W	16526.603	11253.171	11515.450	11615.491	15717.361	12312.170	8906.978	15403.534	10503.423	15219.345	17337.424	15219.345	17337.424	-405.485	-47.353	-435.756	444.279	483.524	702.393	641.948	-51.581	248.904	-101.066	-96.914	-109.312	-445.479
EL30-S	1476.573	239.869	-846.213	-1049.646	609.983	418.772	227.561	470.413	-849.488	1251.769	-405.485	1251.769	-405.485	1642.620	1354.193	1229.981	947.368	1665.583	1727.146	1600.719	1453.731	1751.201	1386.503	1499.216	1696.388	1529.768
EL41-S	3408.114	2336.871	1104.159	46.022	1896.026	949.366	2.705	902.073	35.855	2684.200	-47.353	2684.200	-47.353	1354.193	1808.018	1293.565	732.279	2101.789	1866.440	1550.983	1741.291	1553.459	1397.385	1499.952	1404.785	1259.215
EL42-S	720.432	627.005	-76.613	-597.261	289.059	306.983	324.907	238.995	-296.623	585.208	-435.756	585.208	-435.756	1229.981	1293.565	1169.551	872.757	1430.750	1421.698	1286.907	1178.166	1364.652	1086.560	1164.224	1301.748	1197.583
EL43-S	-241.737	611.551	886.586	782.776	468.751	1059.583	1650.414	1139.805	403.307	51.142	444.279	51.142	444.279	947.368	732.279	872.757	1096.137	785.678	897.296	898.455	509.287	1042.023	614.188	671.249	1052.812	964.662
EL51-S	4775.118	2903.390	2385.991	1597.125	3027.761	2095.766	1163.771	1993.884	448.775	3852.924	483.524	3852.924	483.524	1665.583	2101.789	1430.750	785.678	2902.102	2537.975	2144.541	2301.471	2144.218	1699.368	1899.747	1883.160	1570.339
EL52-S	4251.897	1891.541	1326.731	1176.518	2185.437	1840.022	1494.606	2361.279	-33.692	3523.773	702.393	3523.773	702.393	1727.146	1866.440	1421.698	897.296	2537.975	2801.097	2541.907	2450.306	2543.259	1909.784	2103.848	2066.209	1802.679
EL53-S	3743.725	1790.721	1727.647	1678.014	1790.840	2216.221	2641.602	2829.438	99.693	3183.269	641.948	3183.269	641.948	1600.719	1550.983	1286.907	898.455	2144.541	2541.907	2817.683	2519.687	2546.991	1939.077	2162.478	2074.693	1847.508
EL54-S	5387.703	1898.790	754.286	381.983	2756.842	1976.441	1196.040	2710.258	160.370	4187.611	-51.581	4187.611	-51.581	1453.731	1741.291	1178.166	509.287	2301.471	2450.306	2519.687	3127.388	2132.360	2244.852	2466.170	1767.643	1704.074
EL61-S	2516.973	618.946	281.729	784.250	1128.835	1614.372	2099.908	2008.122	-494.634	2218.314	248.904	2218.314	248.904	1751.201	1553.459	1364.652	1042.023	2144.218	2543.259	2546.991	2132.360	2671.797	1768.028	1984.280	2202.423	1890.601
EL62-S	3836.096	1094.609	-469.360	-466.730	1706.826	1012.053	317.280	1627.961	-224.106	2961.255	-101.066	2961.255	-101.066	1386.503	1397.385	1086.560	614.188	1699.368	1909.784	1939.077	2244.852	1768.028	1863.679	1961.030	1539.198	1573.141
EL63-S	3558.907	910.265	-432.702	-591.149	1885.303	1353.913	822.524	1956.848	-196.187	2838.539	-96.914	2838.539	-96.914	1499.216	1499.952	1164.224	671.249	1899.747	2103.848	2162.478	2466.170	1984.280	1961.030	2162.115	1735.392	1717.608
EL64-S	1049.823	-86.424	-555.622	-387.785	645.730	1184.786	1723.841	1294.757	-342.586	1015.622	-109.312	1015.622	-109.312	1696.388	1404.785	1301.748	1052.812	1883.160	2066.209	2074.693	1767.643	2202.423	1539.198	1735.392	2018.192	1751.218
EL65-S	997.083	-125.036	-910.218	-670.995	500.961	805.043	1109.125	1024.406	-426.036	844.690	-445.479	844.690	-445.479	1529.768	1259.215	1197.583	964.662	1570.339	1802.679	1847.508	1704.074	1890.601	1573.141	1717.608	1751.218	1746.403

Table 24: Variance-Covariance matrix of annual wind & solar capacity factors