Techno-Economic Assessment of Wind energy in Urban Environments: A Case Study in Pattaya, Thailand

Chatchawich Chaihong

A thesis Submitted in Partial Fulfillment of Requirements for the
Degree of Master of Engineering in Energy Technology
Prince of Songkla University
2023

Techno-Economic Assessment of Wind energy in Urban Environments: A Case Study in Pattaya, Thailand

Chatchawich Chaihong

A thesis Submitted in Partial Fulfillment of Requirements for the Degree of Master of Engineering in Energy Technology

Prince of Songkla University

2023

Thesis Title	Techno-Economic assessment of Wind energy in urban environments: A case study in Pattaya, Thailand
Author	Mr. Chatchawich Chaihong
Major Program	Energy Technology

Major Advisor

(Asst. Prof. Dr.Juntakan Taweekun)

Examining Committee

--Chairperson

(Assoc. Prof. Dr. Suttichai Premrudeeprechacharn)

--Committee

(Dr. Kittinan Maliwan)

--Committee

(Dr. Somchai Saeung)

--Committee

(Asst. Prof. Dr.Juntakan Taweekun)

The Graduate School, Prince of Songkla University, has approved this thesis as partial fulfillment of requirements for the degree of Master of Engineering Degree in energy technology.

(Asst. Prof. Dr. Thakerng Wongsirichot)

Acting Dean of Graduate School

This is to certify that the work here submitted is the result of the candidate's own investigations. Due acknowledgement has been made of any assistance received.

....Signature

(Asst. Prof. Dr.Juntakan Taweekun)

Major Advisor

....Signature

(Mr. Chatchawich Chaihong)

Candidate

I hereby certify that this work has not been accepted in substance for any degree and is not being currently submitted in candidature for any degree.

....Signature

(Mr. Chatchawich Chaihong)

Candidate

ชื่อวิทยานิพนธ์ การประเมินทางเทคนิค เศรษฐศาสตร์ของพลังงานลมในสภาพแวดล้อมในเมือง: กรณีศึกษาในพัทยา ประเทศไทย

ผู้เขียน นายชัชวิชญ์ ไชยหงษ์

สาขาวิชา เทคโนโลยีพลังงาน

ปีการศึกษา 2566

บทคัดย่อ

ความท้าทายของกลุ่มพลังงานสะอาดต่อเป้าหมายในการลดการปล่อยคาร์บอนไดออกไซด์ (CO_2) ที่เป็นเป้าหมายร่วมกันทั่วโลก โดยประเทศไทยได้มีแผนพัฒนาพลังงานทดแทน (AEDP) ของประเทศไทยในปี 2018 ถึงแม้ว่าจะไม่ได้รวมพลังงานนิวเคลียร์อยู่ในแผน แต่ 1 ใน 7 กลุ่มพลังงานสะอาด เป็นพลังงานลมที่มีการปล่อย CO_2 ต่ำที่สุดรองลงมาจากพลังงานนิวเคลียร์ การศึกษานี้จึงได้นำการวิเคราะห์พลังงานลมรายพื้นที่เพื่อแสดงคำตอบที่ชัดเจนต่อพื้นที่ โดยมีพื้นที่องค์กรปกครองส่วนท้องถิ่นรูปแบบพิเศษ เมืองพัทยา อำเภอบางละมุง จังหวัดชลบุรี ที่ได้อยู่ในแผนเขตพัฒนาพิเศษภาคตะวันออก (EEC) ในพื้นที่ 3 จังหวัดในภาคตะวันออก ได้แก่ ระยอง ชลบุรี และฉะเชิงเทรา ทั้งนี้เพื่อตอบคำถามถึงโอกาสในการจัดตั้งฟาร์มกังหันลมผลิตไฟฟ้า จึงได้เกิดการประเมินการสร้างพื้นฐานเพื่อรองรับการขยายตัวของเมืองและเศรษฐกิจที่กำลังเกิดขึ้นโดยวิเคราะห์เปรียบเทียบการผลิตพลังงานประจำปี (AEP) ของกังหันลม และ Economic analysis (public sector) สำหรับกรณีศึกษาเป็นพื้นที่ จากสถานีตรวจอากาศ อุตุนิยมวิทยา กรมอุตุนิยมวิทยา ในจังหวัดชลบุรี ประเทศไทย (สถานีชลบุรี, สถานีเกาสีชัง, และสถานีพัทยา) ในช่วงระยะเวลา 2019-2021 ปี ทุก ๆ 10 นาที ณ ความสูงที่ 10 เมตรเหนือพื้นดิน และนำเข้าโปรแกรม Wind Atlas Analysis and Application Program (WAsP) 12 เพื่อวิเคราะห์ความเร็วลมและทิศทางลม ณ ความสูงที่ 60 และ 90 เมตร เหนือระดับพื้นดิน และเฉลี่ยรายเดือน และจำลองการตั้งกังหันลมผลิตฟ้าที่มี High speed limit cut และ Low speed limit cut มีช่วงกว้างที่สุดเพื่อรองรับกำลังลมที่มีความผันผวนสูง, Rotor diameter ช่วงระหว่าง 60-90 เมตร, Default height ช่วงระหว่าง 60-90 เมตร พบว่า มีกังหันลม 3 รุ่นด้วยกันคือ 1. Bonus 1.3 MW, 2. SWT-1.3-62 และ 3. SWT-2.3-82 VS

จากผลวิจัยได้บ่งชี้ทรัพยากรในพื้นที่ที่ศึกษามีศักยภาพต่ำต่อการจัดตั้งฟาร์มกังหันลมผลิตไฟฟ้า โดยอยู่บน Wind Power Class 1, Resource Potential ระดับ Poor และรายละเอียดบนพื้นที่สถานีชลบุรี ทิศทางลมที่พัดปกคลุมอยู่ทางทิศตะวันออกเฉียงเหนือ และทิศตะวันตก Capacity factor สูงสุดที่ 10.2 %, บนพื้นที่สถานีเกาะสีชัง ทิศทางลมที่พัดปกคลุมอยู่ทางทิศ

ตะวันออกเฉียงใต้ Capacity factor สูงสุดที่ 19.6 %, และบนพื้นที่สถานีพัทยา ทิศทางลมที่พัดปกคลุมอยู่ทางทิศตะวันตกเฉียงใต้ และทิศตะวันตก Capacity factor สูงสุดที่ 1.6 %

ผลการวิจัยในประเด็นเศรษฐศาสตร์ พบว่า ค่า AEP ของกังหันลมผลิตไฟฟ้าที่สามารถแสดงผลตอบแทนได้สูงสุดไม่ใช่ตัวเลือกที่ดีที่สุดเสมอไป โดยสังเกตุได้จากผลการวิเคราะห์ของกังหันลมรุ่น SWT-2.3-82 VS (cluster Khao Kaya Sira Hill, Ko Sichang) ที่แสดงค่า AEP สูงถึง 3.366 GWh ซึ่งนั่นหมายถึงโอกาสในการทำ CO_2 emission ได้ 2,154.24 ton CO_2/GWh กลับกันเมื่อมองในประเด็นเศรษฐศาสตร์ทั้ง 5 ประเด็น ประเด็นแรก LOCE ของกังหันลมรุ่นนี้ไม่ได้เป็นค่าที่ต่ำสุดของกังหันทั้ง 3 รุ่น โดย LCOE ที่แสดงความคุ้มค่าที่สุดได้อยู่บนกังหันลมรุ่น SWT-1.3-62 จากทั้ง 3 ค่า Discount rates (5.0%, 5.4%, และ 7.0%), ประเด็นต่อมา NPV กังหันลมรุ่น SWT-1.3-62 ยังคงเป็นรุ่นที่สามารถแสดงค่าได้สูงที่สุดจากทั้ง 3 ค่า Discount rates (5.0%, 5.4%, และ 7.0%) และในกังหันลมรุ่น SWT-2.3-82 VS ยังคงไม่สามารถแสดงค่า NPV ที่สูงสุดได้ โดยมีจุดสังเกตุที่เมื่อ Discount rates เป็น 7.0% ผลของ NPV กลับติดลบถึง -262,599.01 USD, ประเด็นที่ 3 BCR โดยได้แสดงค่าแบบเดียวกับ NPV โดยเมื่อ Discount rates เป็น 7.0% ผลของ BCR ได้แสดงค่าติดลบถึง -14.74 และเป็นค่าต่ำสุดของทั้ง 3 พื้นที่, ในประเด็นที่ 4 PBP กังหันลมได้แสดงถึงระยะเวลาการคืนทุนภายในช่วงอายุเฉลี่ยของกังหันลม และทั้งนี้กังหันลมรุ่น SWT-1.3-62 ยังคงสามารถแสดงค่าที่ดีกว่าสำหรับพื้นที่ทั้งในรูปแบบ without O&M และ PBP with O&M, และในประเด็นสุดท้าย IRR , FIRR, EIRR ถึงแม้จะไม่ได้แสดงค่าที่เป็นลบเหมือนพื้นที่วิจัยสถานีชลบุรี และสถานีพัทยา แต่ค่าที่ออกมานั้นยังคงต่ำกว่ากังหันลมรุ่น SWT-1.3-62 ซึ่งทั้งหมดนี้จะช่วยแสดงให้เห็นว่า การลงทุนที่สูงขึ้นไม่ได้นำมาซึ่งผลตอบแทนที่สูงตาม

คำสำคัญ : ต้นทุนเฉลี่ยตลอดอายุโครงการ (Levelized Cost of Electricity: LCOE) มูลค่าปัจจุบันสุทธิ (Net Present Value หรือ NPV) อัตราส่วนต้นทุนผลประโยชน์ หรืออัตราผลตอบแทนต่อค่าใช้จ่าย (Benefit Cost ratio หรือ BCR หรือ B/C ratio) ระยะเวลาคืนทุน (Payback Period หรือ PBP) อัตราผลตอบแทนภายใน (Internal Rate of Return หรือ IRR), อัตราผลตอบแทนภายในทางการเงิน (FIRR), อัตราผลตอบแทนภายในทางเศรษฐศาสตร์ (EIRR) และการปล่อยคาร์บอนไดออกไซด์เทียบเท่า (CO_2e)

Thesis Title Techno-Economic assessment of Wind energy in urban environments: A case study in Pattaya, Thailand

Author Mr. Chatchawich Chaihong

Major Program Energy Technology

Academic Year 2023

ABSTRACT

Global clean energy is collectively calling on countries to set targets to reduce carbon dioxide (CO_2) emissions. Thailand has a renewable energy development plan (AEDP) for 2018, but it does not include nuclear power. In the clean energy sector, wind power has the second lowest CO_2 emissions. The study therefore summarizes an analysis of area-specific wind power to provide a clear answer for the area, including answering the question of whether a wind farm could be built to generate electricity. A comparative analysis of the annual energy production (AEP) of wind turbines and an economic analysis (public sector) is conducted using a case study of a specific area of local government organization in Pattaya City, Bang Lamung District. Chonburi Province, which is part of The Eastern Economic Corridor (EEC) Development Zone Plan, was analyzed using data from the meteorological weather stations of the Chonburi Meteorological Office (Pattaya station and comparative data from Chonburi and Ko Sichang stations) every 10 minutes at a height of 10 m above the ground during the period 2019-2021. The data were analyzed using Wind Atlas Analysis and Application Program (WAsP) 12 to predict the wind speed and direction at a height of 60 and 90 meters above the ground and simulate the installation of 3 wind turbines, namely: 1. Bonus 1.3 MW, 2. SWT-1.3-62, and 3. SWT-2.3-82 VS

According to the research results, the resources in the study area have low potential for the construction of wind farms for electricity generation. They are classified as wind power class 1, with low level resource potential, and information about Chonburi station area. The prevailing wind direction is northeast. The area around Ko Sichang Station in the west has the highest capacity factor of 10.2%. The prevailing wind direction is southeast, with the highest capacity factor of 19.6%, and in the Pattaya station area. The prevailing wind direction is southwest. and in the west, the highest capacity factor is 1.6%.

In economics, the AEP of a wind turbine that has the highest return is not always the best choice. From the analysis of the wind turbine SWT-2.3-82 VS (Khao Kaya Sira Hill cluster, Ko Sichang), it shows that it has an AEP of 3.366 GWh, which means a CO_2 emission potential of 2,154.24 tons. CO_2/GWh, which is reversed when considering the five economic points. First, the LCOE of this turbine model is not the lowest of the three turbine models. The SWT-1.3-62 wind turbine model has the most economic LCOE at all three discount rates (5.0%, 5.4%, and 7.0%). The SWT-1.3-62 wind turbine model is still the model that shows the highest value at all 3 discount rates. The wind turbine model SWT-2.3-82 VS still failed to demonstrate the highest NPV, observing that at a discount rate of 7.0%, the NPV result was negative at -$262,599.01 and output 3 BCR showed the value as NPV. The BCR results showed a negative value of -14.74 when the discount rates were set at 7.0%, the lowest value of all three ranges. In point 4, the PBP wind turbines showed a payback period within the average lifetime of wind turbines. And the SWT-1.3-62 wind turbine model still shows a better value for the area without O&M and with O&M, and in the last point, IRR, FIRR, EIRR although it does not show negative values like the Chonburi. and Pattaya Station research area, the value that came out was still lower than that of the SWT-1.3-62 wind turbine. Higher investment does not bring high returns.

Keywords : Levelized Cost of Electricity (LCOE), Net Present Value (NPV), Benefit Cost ratio (BCR or B/C ratio), Payback Period (PBP), Internal Rate of Return (IRR), Financial Internal Rate of Return (FIRR), Economics Internal Rate of Return (EIRR) and carbon dioxide (CO_2) emissions

ACKNOWLEDGMENT

A techno-economic assessment of wind energy in urban environments: A case study in Pattaya, Thailand, was successfully conducted for research purposes. Thanks to the great courtesy and support of my advisor, Asst. Prof. Dr. Juntakan Taweekun, who kindly gave me advice, suggestions, and improved various shortcomings until this research was successful. The researcher would like to take this opportunity to express his deepest gratitude to the Faculty of Engineering, Prince of Songkhla University, which has approved the scholarship for engineering graduates from the research fund of the Faculty of Engineering. I would like to thank Miss Yosita Laomanaswee (Nook), an academician of the Energy Technology Program, and Miss Pavinee Intharit (Koi), an academician of the Energy Technology Program, for their help in education and research. For the assistance in editing documents in the faculty and graduate school, I would like to personally thank you for supporting my mind. Thank you for the playlists of Northeastern and Southern Thai songs that kept me awake while writing my research paper. Finally, the researcher hopes that this research will be useful to the relevant authorities and those who are interested in further studies

Chatchawich Chaihong

LIST OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

WAsP	Wind Atlas Analysis and Application Program
AEP	Annual Energy Production
LCOE	Levelized Cost of Electricity
NPV	Net Present Value
BCR or B/C ratio	Benefit Cost ratio
PBP	Payback Period
IRR	Internal Rate of Return
FIRR	Financial Internal Rate of Return
EIRR	Economics Internal Rate of Return
CO_2	Carbon Dioxide
MW	Megawatts
GW	Gigawatt
MWh	Megawatt-Hour
GWh	Gigawatt-Hour
CO_2/GWh	Carbon Dioxide Per Gigawatt Hour
m/s	Meters Per Second
W/m^2	Watts Per Square Meter

LIST OF PAPER AND PROCEEDINGS

1. Chaihong, Chatchawich, and Juntakan Taweekun. 2023. “Techno-Economic Assessment of Wind Energy in Urban Environments: A Case Study in Pattaya, Thailand”. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 104 (1):169-84. https://doi.org/10.37934/arfmts.104.1.169184.

REPRINTS WERE MADE WITH PERMISSION FROM THE PUBLISHERS/SUBMITTED MANUSCRIPT

[J. Adv. Res. Fluid Mech. Therm. Sc.] Editor Decision

NA

Nor Azwadi <azwadi@akademiabaru.com>

ถึง: Chatchawich Chaihong (6410120004); Juntakan Taweekun (จันทกานต์ ทวีกุล)   พ 12/4/2023 7:52

chatchawich chaihong, Juntakan Taweekun:

We have reached a decision regarding your submission to Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, "Techno-Economic assessment of Wind energy in urban environments: A case study in Pattaya, Thailand".

Our decision is to: Accept Submission

CHAPTER 1.
INTRODUCTION

1.1. Research motivation/Rationale/Introduction

One of the seven categories of clean energy listed in Thailand's Renewable Energy Development Plan (AEDP) is wind power, which in 2018 consumed a total of 12,996 thousand tons of oil-equivalent in renewable energy. In terms of electricity, heat, and biofuels, the target levels for the proportion of renewable energy and alternative energy both are 30% of final energy consumption in 2037 from 15.48% of final energy consumption in 2018, an increase of 10.8% from the previous year, with the performance of renewable energy and alternative energy in 2016–2018, with the size of wind power being 507.00, 627.80, and 1,102.82 megawatts, respectively [1] Thailand's energy consumption is anticipated to increase by 1.18 % on average by 2036. Integrated Energy Blueprint (THAIB) with Potential Risk at 2.13 % (RISK) [2]

Approximately 513,115 km² compensate Thailand [3] The Indochina Peninsula in Southeast Asia is divided into 77 administrative provinces. also some have ties to the Malay Peninsula Additionally, each region has a varied terrain. It is a complicated, high-mountainous terrain in the north. Most of the northeast is made up of dry highlands. The area in the middle is a floodplain. The sea surrounds the southern portion of the Malay Peninsula on all sides. Mountain ranges and valleys can be found in the western region. which runs from the westernmost point of the north in the sea, there are 23 provinces [4]. and it is a fascinating region Bangkok region and Pattaya city have a unique type of local government organization (Chonburi province) [5]. via Pattaya City It is a city located in The Eastern Economic Corridor (EEC) Development Zone Plan, which includes the provinces of Rayong, Chonburi, and Chachoengsao. [6]

Thailand has objectives from the AEDP 2018 plan to increase the share of renewable energy. Consequently, this study will investigate Thailand's potential for expanding wind energy. for Thailand, and the previous article discussed "Assessment of onshore wind energy potential using regional atmospheric modeling system (rams) for Thailand." [7] It is a study of available wind energy resources in the area. According to studies, the mountainous regions of Thailand's western, southern, and eastern regions have higher sources of wind energy than other regions at an altitude of 120 meters above ground level (agl), and the article "Investigation of PV and wind hybrid system for building rooftop" [8] , which evaluates the generation of electrical power for use inside buildings. from clean energy sources with significant potential to reduce dependence on the basic grid.

From an economic perspective, the study "Wind resource assessment and economic viability of conventional and unconventional small wind turbines: A case study of Maryland" found that the technical and economic viability of more than 150 small wind turbines at an average annual wind speed of about 3 m/s would generate 1990 kWh of electricity per year with a payback period of 13 years[9]

And in the study "Evaluation of wind and solar energy investments in Texas", the break-even point between the benefits of wind and solar energy was reached. When the size of the wind turbine system is 50 kW and the photovoltaic system is 42 kW, it was found that the photovoltaic system is in the range of 2-20 years and about 13 years for the wind system [10]

In the study "Wind resource assessment of the southernmost region of Thailand using atmospheric and computational fluid dynamics wind flow modeling" [11] , study results were obtained. Installing wind turbines in areas with high wind energy potential above 8.0 m/s, capable of generating 690 GWh/year of electricity, will reduce CO2eq emissions to the atmosphere by 1.2 million tons per year. In areas with low wind resources at 6-7 m/s but easier access, nearly 3000 GWh/year of energy can be generated and 5 million tons of CO_2eq emissions avoided.

In the nearby area, "Wind atlas of Chanthaburi and Trat provinces, Thailand" [12] was studied using Computational Fluid Dynamics (CFD) technique. Wind data were obtained over a 5-year period from MERRA. 200 m. The simulation results show that the area between 40-100 m above the ground has the potential to generate electricity. Three potential areas with average wind speed more than 6 m/s were proposed: Khao Khitchakut at 40 m, between Chanthaburi and Khlung at 65 m, and Ko Chang at 80 m.

Consequently, this study will compare several forms of wind energy that generate electricity. Levelized Cost of Electricity (LCOE), Net Present Value (NPV), Benefit Cost Ratio (BCR or B/C ratio), Payback Period (PBP), Internal Rate of Return (IRR), Financial Internal Rate of Return (FIRR), Economics Internal Rate of Return (EIRR) and the calculation of the carbon dioxide equivalent (CO_2e) emissions that will be reduced as a direct consequence of the installation of wind turbines are all factors that affect a project's economic viability. For a Pattaya City, Bang Lamung District, Chonburi case study

1.2. Research objectives

1) To determine the levelized cost of electricity (LCOE), net present value (NPV), benefit cost ratio (BCR or B/C ratio), payback period (PBP), and internal rate of return (IRR) Financial Internal Rate of Return (FIRR), Economics Internal Rate of Return (EIRR) for the electricity generated from wind energy sources
2) To assess wind energy and determine how the installation of wind turbines will reduce carbon dioxide equivalent (CO_2e) emissions.
3) To create annual maps utilizing the weather station's Wind Atlas Analysis and Application Program (WAsP). meteorology Chonburi Province, Thailand's Meteorological Department

1.3. Research scope

This study aims to assess the potential of wind energy resources in Thailand by collecting wind speed data from the Thai Meteorological Department [13] in Chonburi Province for 3 years from January 1, 2019, to December 31, 2021. The data were collected every 10 minutes at a height of 10 meters above the ground and analyzed using the Wind Atlas Analysis and Application Program (WAsP) to estimate the wind speed at a height of 60 and 90 meters above ground level and calculate the monthly average. The wind direction distribution was also analyzed to assess the potential wind energy production of different types of wind turbines and draft a wind map for the region.

1.4. Benefits anticipated

1) Economic analysis of wind power generation in terms of levelized cost of energy (LCOE), net present value (NPV), cost-benefit ratio or benefit-cost ratio (BCR or B/C ratio), payback period (PBP) internal rate of return (IRR) Financial Internal Rate of Return (FIRR), Economics Internal Rate of Return (EIRR) as a decision component for the construction of wind power plants
2) The results of the analysis of wind energy and the computation of the decrease in carbon dioxide equivalent (CO_2e) emissions caused by the installation of wind turbines.

3) Results of yearly mapping utilizing the weather station's Wind Atlas Analysis and Application Program (WAsP). meteorology Chonburi Province, Thailand's Meteorological Department

1.5. Thesis organization

This chapter provides background information on the basic principles, history, and applications of wind energy. It also describes the specific area in Chonburi Province, Thailand, that is the focus of this study. The second part of this chapter outlines the objectives of the study, which include conducting a comparative analysis of the annual energy production (AEP) of wind turbines and conducting an economic analysis. The final section summarizes the main methods used in this study. Chapters 2–3 provide an overview of the theoretical basis and related research on renewable energy, specifically wind energy in Thailand. Chapter 4 describes the evaluation and management of wind energy projects through simulation results and project management calculations in the local area. Chapter 5 discusses the results of the simulations and provides suggestions for improvement. Data on comparative wind turbines and analysis of wind resources at heights of 60, 90, and 120 meters above the ground can be found in the annex.

CHAPTER 2.
LITERATURE REVIEWS

2.1. Status of renewable energies in power generation in the system of Thailand

Thailand Energy Balance Report 2020 by the Department of Alternative Energy Development and Efficiency (DEDE), Ministry of Energy. Includes a report showing the results of fuel consumption for power generation in 2016 - 2020 [14]

Table 2-1 *Utilization / installed capacity of the system and production of the system*

ITEMS	2016	2017	2018	2019	2020
National grid installed capacity (MW)1/	42,982	49,472	51,392	52,254	54,790
Peak generation of national grid (MW)1/	30,972	30,303	29,968	37,312	30,342
National grid generation (Gwh)1/	187,640	185,510	187,366	197,267	185,602
Electric consumption (Gwh)1/	190,504	193,860	197,214	203,714	196,706

Sources: DEDE, EGAT, MEA, PEA, OERC, SEW, DOPA, IPP, SPP, and VSPP.

Note: 1/Since 2015 including private generation for own use.

(Source: dede.go.th, page 46, 2022)

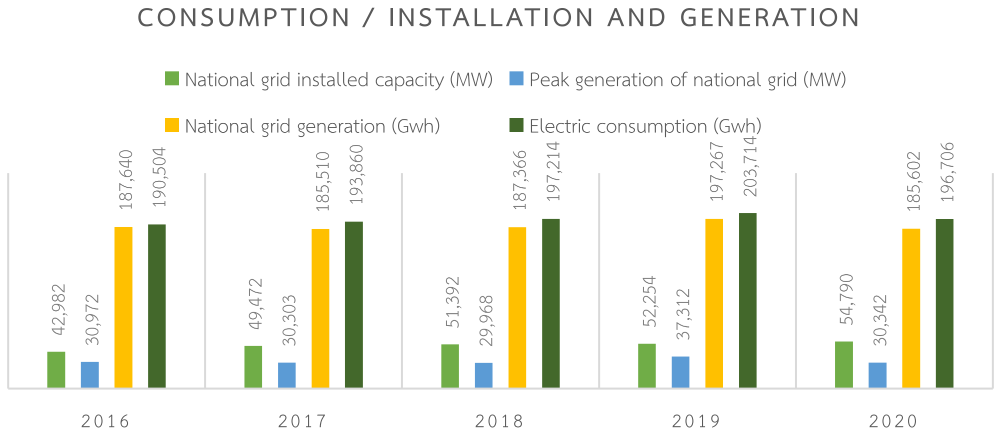


Figure 2-1 *Comparison of installed power generation, peak power generation, production and power consumption.*

(Source: dede.go.th, page 46, 2022)

Table 2-2 Use of renewable energy in 2020

Alternative Energy	2020				
	MW	Gwh	Million Liters	Thousand Ton	ktoe
ELECTRICITY* (Solar, Wind, Hydro, Biomass, MSW, Biogas and Geothermal Power)	12,005	34,074	-	-	2,903
HEAT (Solar, Biomass, MSW and Biogas)	-	-	-	-	6,717
BIOFUEL	-	-	3,370	-	2,377
ETHANOL	-	-	1,500	-	765
BIODIESEL	-	-	1,870	-	1,612
GRAND TOTAL	12,005	34,074	3,370	-	11,997

* Including off grid power generation.

(Source: dede.go.th, page 52, 2022)

Table 2-3 The use of renewable energy fuels to generate electricity into the system

RENEWABLE ENERGY TYPE unit : ktoe	2016	% change from previous year	2017	% change from previous year	2018	% change from previous year	2019	% change from previous year	2020	% change from previous year	% average change
1.Solar	288.00	-	387.00	34.38	387.00	-	438.00	13.18	429.00	(2.05)	9.10
2.Wind	29.00	-	95.00	227.59	140.00	47.37	313.00	123.57	274.00	(12.46)	77.21
3.Small hydro power 1/	27.00	-	43.00	59.26	52.00	20.93	38.00	(26.92)	30.00	(21.05)	6.44
4.Large hydro power 2/	284.00	-	369.00	29.93	611.00	65.58	511.00	(16.37)	369.00	(27.79)	10.27
5.Geothermal	0.10	-	0.10	-	0.10	-	0.10	-	0.10	-	-
6.Paddy husk	802.00	-	837.00	4.36	691.00	(17.44)	717.00	3.76	698.00	(2.65)	(2.39)
7.Bagasse	3,184.00	-	3,852.00	20.98	4,365.00	13.32	4,786.00	9.64	4,165.00	(12.98)	6.19
8.Agricultural waste	5,370.00	-	1,957.00	(63.56)	2,334.00	19.26	2,587.00	10.84	2,672.00	3.29	(6.03)
9.MSW	29.00	-	36.00	24.14	67.00	86.11	102.00	52.24	144.00	41.18	40.73
10.Biogas	238.00	-	525.00	120.59	590.00	12.38	653.00	10.68	522.00	(20.06)	24.72

Sources: DEDE, EGAT, PEA, IPP, SPP, and VSPP.

Notes: 1/ Including hydro power plant s 12 MW & hydro power plant using the water downstream.

2/ Including hydro power plant > 12 MW & hydro power plant (Lamtakhong Dam).

3/ Including black liquor and residual gas.

(Source: dede.go.th, page 50, 2022)

The information in Tables 2-1, 2-2, 2-3 and Chart 1 shows how the system produces electricity. as the cost of electricity continues to rise. However, the data show that production capacity is insufficient to meet demand, so energy must be imported to meet the demand for electricity. The information in Table 2-3 on the historical use of renewable energy in electricity generation shows that the three sources with the highest average rate of change are wind resources, waste, and biogas. and are often consistent with Thailand's 2018 Renewable Energy Development Plan (AEDP) [1] with a view to increasing fuel usage in accordance with Table 2-4.

Table 2-4 *AEDP 2015 and AEDP 2018 Plans' Power Generation Status and Targets by Fuel Type*

TYPE	Installed capacity (MW)			
	AEDP2015		AEDP2018	
	Target[(a)]	bound[(b)]	PDP2018[(c)]	Total (cumulative)[(d)]
1. Solar energy	6,000	2,849	9,290	12,139
2. Floating solar energy	-	-	2,725	2,725
3. Biomass	5,570	2,290	3,500	5,790
4. Wind power	3,002	1,504	1,485	2,989
5. Biogas (wastewater/waste/energy plants)	1,280	382	1,183	1,565
6. Community waste	500	500	400	900
7. Industrial waste	50	31	44	75
8. Small hydro power	376	239	69	308
9. Large hydro power	2,906	2,920	-	2,920
Total installed capacity (megawatts)	19,684	10,715	18,696	29,411
Able to generate electricity (million units)	65,582	32,757	52,894	85,652
Electricity demand (million units)	326,119	326,119	250,204	250,204
Renewable energy electricity to electricity demand (%)	20.11	10.04	21.14	34.23
Renewable energy electricity to final energy (%)	4.27	2.13	3.55	5.75

Notes: (a) The AEDP 2015 target is installed capacity, in addition to contract capacity.
(b) Projects with government commitments include projects that have already supplied electricity to the electrical system. Projects with power purchase agreements and projects that have already accepted the purchase of electricity

(c) Target of contracted capacity of renewable and alternative energy power plants to purchase electricity according to PDP2018 during 2018 – 2037

(d) The cumulative sum is the contracted capacity of projects already bound to the government. Combined with the contracted capacity target of renewable and alternative energy power plants to purchase electricity according to PDP2018

(Source: dede.go.th, page 17, 2022)

The information in Tables 2-3 and 2-4 reveals some fascinating energy sources, including hydro, wind, and solar resources. It is not necessary to import energy or increase the country's production capacity to generate energy. Therefore, it is considered a very clean and sustainable energy.

2.2. Wind and wind energy

There are two different ways air can move: "wind" is the movement of air that is parallel to the surface of the earth. "Air current" is a vertical movement of air at the same instant. and the wind system that blows across the earth The "Coriolis force" which is a product of the earth's rotation and affects the flow of air currents, is one of the variables [15]

Wind energy is currently being used more and more as a renewable energy source. In order to generate electricity, wind farms are primarily built, combined with other energy sources such as solar energy [16] , hydropower [17] and wave energy [18], from which the development has emerged. In addition, technological competition today has led to faster payback times and lower costs than in the past. as well as significant reductions in equivalent CO_2 emissions.

The calculation equation can be used to estimate wind energy

1) Average distribution of wind speed

In dispersing the wind frequency data in the measuring region, it is possible to calculate the average wind speed from the collection of wind data over time [19], [20] based on the equation (1)

$$V_m = \frac{1}{N}\sum_{i=1}^{\infty} n_i v_i \qquad (1)$$

Therefore:

V_m = mean wind speed over time (m/s)

N = total number of hours (hours)

n_i = number of hours (hours)
v_i = mid-range wind speed (m/s)

2) Examination of the average wind direction

analysis of the average wind direction utilizing the frequency distribution of wind direction data. The wind direction angle value is used to express the wind direction [21] according to equation (2)

$$WD_m = \frac{1}{N}\sum_{i=1}^{\infty} n_i d_i \qquad (2)$$

Therefore:

WD_m = average wind direction over time (degree angle)
N = total number of hours (hours)
n_i = number of hours (hours)
d_i = center of wind direction (degree angle)

3) Weibull Distribution Parameters

Wind is a random variable and a highly volatile parameter that changes with the time of day, day of the year, and from year to year [22] to build an accurate model to characterize wind speed data [23], [24] to evaluate the economic feasibility [24]. It was found that the PDF probability distribution function considering the data parameters from Weibull distribution is the most suitable to describe the frequency of wind speed. and the distribution function of wind energy density [25], [26] can be analyzed by Weibull equations with 2 parameters: the c-scale parameter and the k-shape parameter [27], [28]. According to the equation (3)

$$f(V) = \frac{k}{c}\left(\frac{V}{c}\right)^{k-1} exp\left[-\left(\frac{V}{c}\right)^{k}\right], k > 0, v > 0, c > 1 \qquad (3)$$

Therefore:

$f(V)$ = probability of observing wind speed v
V = wind speed (m/s)
k = shape parameter
c = level parameter value (m/s)

A cumulative distribution function can be created from equation (3) using equation (4).

$$f(V) = 1 - exp\left[-\left(\frac{V}{c}\right)^k\right] \qquad (4)$$

Therefore:

$f(V)$ = probability of observing wind speed
V = wind speed (m/s)
k = shape parameter
c = level parameter value (m/s)

4) Wind Power Density (WPD), W/m^2

A measure of the site's potential for wind energy is called wind power per area. The amount of energy that is accessible per square meter of space at a given height [29]–[31] were examined using equation (5).

$$WPD_{wind} = \frac{1}{2}\rho V_m^3 \qquad (5)$$

Therefore:

ρ = Air density (Choose a value equal to 1.225 kilograms per cubic meter)
V = the collection of wind speed data's hourly average

When we compare the positive influencing factors with the hindering factors, we find that the benefits and expansion of wind energy outweigh the limitations or obstacles. The obstacles and uncertainties that have influenced the development of the sectors are related to strict legislation to protect ecosystems and limited spatial opportunities for new projects. Conversely, wind energy tends to benefit from new opportunities such as climate change. Abolition of nuclear power and coal, and industry-specific strengths such as wind energy's competitiveness in the power generation market. In addition, low greenhouse gas emissions and wind energy's competitiveness in the electricity market help make wind energy the largest renewable energy source. [32]

2.3. Thai Wind Power Status

The seasonal average wind speed of Thailand will influence the monsoon most involved in the northeast monsoon. and the next is the southwest monsoon. There is a tendency to strengthen high-wind power [33], and data from the Ministry of Energy in Thailand provides a detailed topography of Thailand's wind resources. There is high potential in some areas according to their characteristics, especially in high or narrow areas such as hills, gorges, or peaks. The average wind speed at an altitude of 90 meters is 4-5 m/s [1] from "Assessment of onshore wind energy potential using the regional atmospheric modeling system (RAMS) for Thailand," a map of wind resources at an altitude of 120 meters above ground level (AGL) with a resolution of 9 km. The results show that the average annual wind speed is in the range of 1.60–5.83 m/s and that the high wind power is in the mountainous areas of the western South. and the eastern part of Thailand. Further assessments have been recommended to determine whether onshore wind energy resources can be developed and utilized. to achieve national renewable energy policy goals in Thailand or not [7].

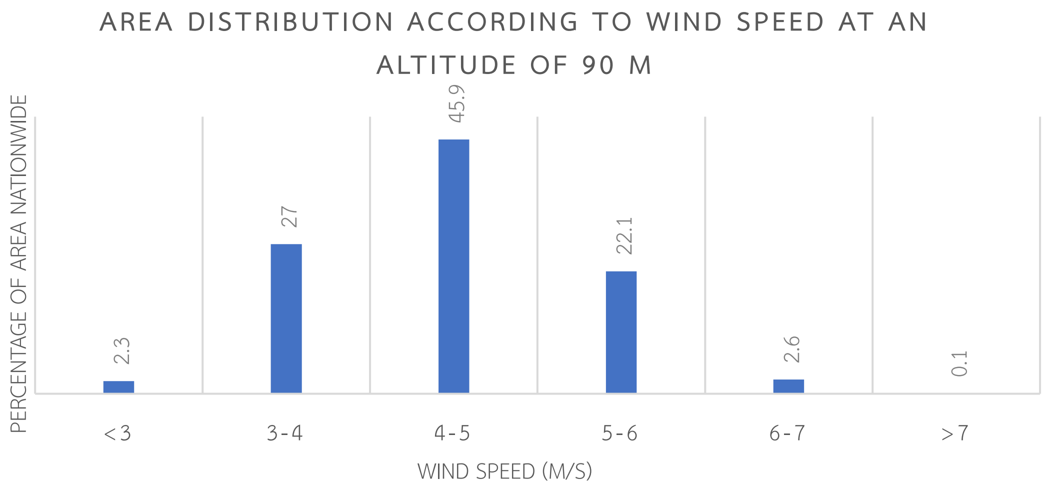


Figure 2-2 *At a height of 90 meters, the area distribution according to wind speed*
(Source: dede.go.th, page 7, 2022)

From the data in Chart 3, it shows that the average wind speed in Thailand is 6-7 m/s and will be in the southern area of the country. and the western part of the upper south, and the northeastern region in the upper and eastern regions of the region [1]. The Department of Alternative Energy Development and Efficiency

(DEDE), Ministry of Energy, Thailand's Energy Balance Report 2020, has shown the results of an increase in the use of wind energy to produce more electricity each year. In the years 2016-2020, there is an expansion at 383, 1,109, 1,641, 3,670, and 3,220 million kilowatt hours (GWh), according to Sequence [14].

According to the Meteorological Department, the region is divided into six regions: the North, the Northeast, the Central, the East, the South (east coast), and the South (west coast). There are 128 weather stations listed with details from the weather report. Table 2-5 [13]: Meteorological Department weather report for each weather station

Table 2-5 *Meteorological Department weather report each weather station*

Daily Observation Report

Friday, June 17, 2022 at 7AM

Issued On : 6/17/2022 5:00:37 PM

No	Station	PPP	T	R24hr	R1Jan	RH	Wind	
		(hPa)	(c)	(mm)	(mm)	(%)	(deg)	(knot)
Northern Part								
1	MAE HONG SON	1009.46	24.9	12		94	C	0
2	MAE SARIANG	1009.81	25.1	0		95	C	0
3	CHIANG RAI	1009.23	24.5	7.9		93	C	0
4	CHAING RAI AGROMET.	1009.04	23.8	4.3		96	C	0
5	PHAYAO	1009.31	24.2	0		92	C	0
6	DOI ANG KANG	1009.21	18	19.4		98	NW	6
7	CHIANG MAI	1009.09	25.8	0		85	C	0
8	LAMPANG	1009.49	24.8	1		95	C	0
9	THOEN	1009.57	24.7	4		97	C	0
10	LAMPANG AGROMET.	1009.21	24	28		96	C	0
11	LAMPHUN	1008.76	25.7	0.6		93	NNE	2
12	PHRAE	1009.21	24.2	11.5		95	N	2
13	NAN	1009.74	24	22.7		96	C	0
14	NAN AGROMET.	1010.01	23.2	31.4		95	C	0
15	THA WANGPHA	1010.39	23.7	9.9		95	W	2
16	THUNG CHANG	1009.8	22.8	2.3		97	C	0
17	UTTARADIT	1008.85	24.7	1.7		90	C	0
18	SUKHOTHAI*	1008.46	25.5	0		93	C	0
19	SI SAMRONG AGROMET.	1009.35	25	0		94	C	0
20	TAK	1009.64	27.7	0		79	C	0
21	MAE SOT	1008.17	25.5	0		92	C	0
22	BHUMIBOL DAM	1009.28	25.6	0		88	C	0

Daily Observation Report

Friday, June 17, 2022 at 7AM

Issued On : 6/17/2022 5:00:37 PM

No	Station	PPP (hPa)	T (c)	R24hr (mm)	R1Jan (mm)	RH (%)	Wind (deg)	Wind (knot)
23	DOI MU SOE AGROMET.	1009.93	21.7	0		94	SW	4
24	UMPHANG	1009.96	23	0		96	C	0
25	PHITSANULOK	1009.57	26.4	0		96	C	0
26	PHETCHABUN	1008.45	25	"T"		92	C	0
27	LOM SAK	1009.92	25	1.2		94	C	0
28	WICHIAN BURI	1009.32	26.9	"T"		87	C	0
29	KAMPHAENG PHET	1009.37	26.9	"T"		93	C	0
30	PICHIT AGROMET	1007.49	27.6	4		88	C	0
Northeastern Part								
31	NONG KHAI	1008.87	26.3	0.2		89	W	2
32	LOEI	1009.31	23.7	22.6		94	C	0
33	LOEI AGROMET.	1008.81	23.8	14.7		97	C	0
34	UDON THANI	1009.7	25.7	16.4		97	C	0
35	SAKON NAKHON	1008.67	25.9	0		93	SE	2
36	SAKON NAKHON AGROMET.	1008.97	24.8	0		92	C	0
37	NAKHON PHANOM	1009.3	26.2	0		90	C	0
38	NAKHON PHANOM AGROMET.	1009.69	26	0.3		96	C	0
39	NONG BUA LAM PHU	1008.32	24.6	2.2		98	C	0
40	Bueng Kan	1009.11	25.6	1.8		93	C	0
41	KHON KAEN	1008.18	25	2.3		92	WNW	1
42	THA PHRA AGROMET.	1009.22	25.4	0.7		92	C	0
43	MUKDAHAN	1008.3	27.5	0		88	C	0
44	MAHASARAKHAM	1009.2	26.7	0		86	C	0
45	KALASIN	1008.49	26.2	0		92	C	0
46	Amnat Charoen	1009.27	27	0		93	C	0
47	CHAIYAPHUM	1009.07	26.1	0		91	W	2
48	ROI ET	1008.66	26.7	0		88	C	0
49	ROI ET AGROMET.	1008.81	26.2	0		89	C	0
50	Yasothon	1008.9	27.2	0		95	C	0
51	UBON RATCHATHANI AGROMET.	1009.74	26.5	0		93	S	2
52	UBON RATCHATHANI	1009.09	27.5	0.9		88	C	0
53	SI SAKET AGROMET.	1008.66	27.8	0		88	C	0
54	NAKHON RATCHASIMA	1009.51	26.5	"T"		86	C	0

Daily Observation Report

Friday, June 17, 2022 at 7AM

Issued On : 6/17/2022 5:00:37 PM

No	Station	PPP	T	R24hr	R1Jan	RH	Wind	
		(hPa)	(c)	(mm)	(mm)	(%)	(deg)	(knot)
55	PAKCHONG AGROMET.	1010.06	24.5	0.1		90	C	0
56	CHOK CHAI	1008.77	26	0		92	C	0
57	SURIN	1009.31	27	9.8		91	C	0
58	SURIN AGROMET.	1009.69	26.4	0.3		93	C	0
59	THA TUM	1009.29	26.8	0		90	C	0
60	BURIRUM	1009.85	26.5	0		88	#Error	0
61	NANG RONG	1009.32	26.2	0		89	S	2
Central Part								
62	NAKHON SAWAN	1009.07	26.1	0.9		95	C	0
63	TAKFA AGROMET.	1009.15	27.2	0		89	C	0
64	CHAINAT AGROMET.	1009.57	27	0		92	C	0
65	UTHAITHANI	1009.06	27.5	0		93	C	0
66	AYUTTHAYA	1009.33	27.3	3		91	SSE	2
67	PATHUMTHANI	1009.57	28.3	0		98	E	1
68	RATCHA BURI	1010.58	26.4	0		94	C	0
69	SUPHAN BURI	1009.53	28.6	0		87	S	2
70	U THONG AGROMET.	1009.12	27.1	0		87	C	0
71	LOP BURI	1008.88	27	2.1		92	C	0
72	BUA CHUM	1009.22	25.8	0		95	WSW	2
73	PILOT STATION	1009.62	28.7	10		82	S	8
74	Samut Prakarn	1009.64	26.5	2.2		86	C	0
75	SUVARNABHUMI AIRPORT	1010.1	27.4	6.4		75	SSE	4
76	SAMUTSONGKRAM	1009.34	28.1	0		87	C	0
77	KANCHANA BURI	1009.67	27.5	0		84	WSW	5
78	THONG PHAPHUM	1010.54	25	0.4		93	C	0
79	NAKHONPATHOM	1009.3	27	0		88	W	2
80	BANGKOK METROPOLIS	1009.26	27.8	47.3		89	SSW	2
81	BANGKOK PORT (KLONG TOEI)	1009.37	28	44.6		94	C	0
82	BANG NA AGROMET.	1009.65	27.7	1.8		81	C	0
83	DON MUANG AIRPORT	1010.08	28.4	"T"		95	ESE	3
Eastern Part								
84	NAKORNNAYOK	1009.89	19.8	0		97	SSW	3
85	CHACHOENGSAO	1011.53	25.9	2.3		96	C	0
86	PRACHIN BURI	1009.18	27.5	0		90	E	5

Daily Observation Report

Friday, June 17, 2022 at 7AM

Issued On : 6/17/2022 5:00:37 PM

No	Station	PPP	T	R24hr	R1Jan	RH	Wind	
		(hPa)	(c)	(mm)	(mm)	(%)	(deg)	(knot)
87	KABIN BURI	1009.65	26.5	0		93	#Error	0
88	ARANYA PRATHET	1010.05	27.6	0		85	C	0
89	SA KAEW	1009.79	26	"T"		93	C	0
90	CHON BURI	1009.53	29.2	"T"		81	C	0
91	KO SICHANG	1009.45	28.7	0		83	E	3
92	PHATTHAYA	1009.58	28.5	7.4		86	C	0
93	SATTAHIP	1008.49	28.8	0		86	S	2
94	LAEM CHABANG	1010.42	28.8	0		83	SSW	5
95	RAYONG	1009.35	29.8	0		79	SSW	2
96	HUAI PONG AGROMET.	1009.47	28.8	0		84	SW	2
97	CHANTHA BURI	1009.88	27.4	"T"		93	C	0
98	PHLIU AGROMET.	1009.98	26.5	0		92	C	0
99	TRAD	1009.79	26.7	29.5		91	C	0
Southern Part (East Coast)								
100	PHETCHA BURI	1009.82	26.8	0		90	#Error	0
101	PRACHUAP KHIRIKHAN	1009.81	27.5	0		86	C	0
102	HUA HIN	1009.68	27.3	0		86	C	0
103	NONG PHLUB AGROMET.	1010.02	24.7	5.6		94	C	0
104	CHUMPHON	1010.17	26.2	0		92	C	0
105	SAWI AGROMET.	1010.53	25.5	0		94	C	0
106	SURAT THANI	1010.47	25.5	0		96	C	0
107	KO SAMUI	1010.32	27.8	0		88	C	0
108	SURAT THANI AGROMET.	1012.3	24.8	0		97	C	0
109	PHRA SANG	1010.29	25.3	0		96	C	0
110	NAKHONSI THAMMARAT	1010.01	25.2	0		94	C	0
111	NAKHONSI THAMMARAT AGROMET.	1009.83	25.2	0		97	C	0
112	CHAWANG	1010.14	25.5	14.6		96	C	0
113	PHATTHALUNG AGROMET.	1009.41	25	0		98	C	0
114	KHO HONG AGROMET.	1009.82	25.6	0		93	C	0
115	SA DAO	1009.59	25.1	0		97	C	0
116	SONGKHLA	1009.88	27	0		84	WSW	2
117	HAT YAI AIRPORT	1010.1	25.1	0		97	C	0

	Daily Observation Report Friday, June 17, 2022 at 7AM Issued On : 6/17/2022 5:00:37 PM							
No	Station	PPP (hPa)	T (c)	R24hr (mm)	R1Jan (mm)	RH (%)	Wind (deg)	Wind (knot)
118	PATTANI AIRPORT	1009.55	25	0		93	C	0
119	YALA AGROMET.	1010.24	25.2	0		93	SW	7
120	NARATHIWAT	1010	25.6	1.2		88	C	0
Southern Part (West Coast)								
121	RANONG	1011.04	26	0		88	C	0
122	TAKUA PA	1009.84	26	0		93	C	0
123	PHUKET	1009.98	25.5	2.4		93	C	0
124	PHUKET AIRPORT	1009.54	24.9	2.8		89	C	0
125	KO LANTA	1010.55	25.7	0		92	C	0
126	KRABI	1010.23	24.1	0		96	C	0
127	TRANG AIRPORT	1010.18	24.6	27.9		97	C	0
128	SATUN	1010.13	25.6	0.5		93	C	0

Remarks

- "T" - Trace (< 0.1 millimeter)
- T, Tmax, Tmin for dry, maximum (7 AM yesterday - 7 AM today), minimum temperature respectively
- dTmax, dTmin for maximum, mininum temperature change in 24 hours
- R24hr for amount of rainfall within 24 hours
- R1Jan for the accumulative rainfall since January 1st of this current year

(Source: tmd.go.th, page 1-4, 2022)

2.4.Wind Atlas Analysis and Application Program (WAsP)

The Wind resource assessment using the WAsP software manual describes WAsP tools as [34] Wind resource assessment is a critical component in the development of wind energy projects. It involves the estimation of the wind resource or wind power potential at one or several sites, or over an area. Wind resource maps are commonly used to show the variation in mean wind speed or power density over an area. While this may provide a good indication of the relative magnitude of the wind resource, a more realistic estimate is obtained when the sector-wise wind speed distributions are combined with the power curve of a given wind turbine to obtain a power production map. The result of wind resource assessment is an estimate of the mean wind climate at one or a number of sites, which includes wind direction probability distribution (wind rose) and sector-wise wind speed probability distribution functions.

Wind resource assessment provides important inputs for the siting, sizing, and detailed design of wind farms. WAsP software is a commonly used tool for wind resource assessment, which provides important inputs for the design of wind energy projects. When it comes to the siting of individual wind turbines, a site assessment (IEC 61400-1) is typically carried out to obtain additional information such as extreme wind, vertical wind profile shear, flow and terrain inclination angles, free-stream turbulence, wind speed probability distribution, and added wake turbulence. The WAsP Engineering software can be used to obtain this additional information. In summary, wind resource assessment is a critical component in the development of wind energy projects, and WAsP software is a valuable tool for this purpose.

2.4.1. Observation-based wind resource assessment

Wind resource assessment is an important step in wind energy project development, and it is conventionally based on wind data measured at or near the wind farm site. The WAsP software is a commonly used tool for wind resource assessment, which implements the wind atlas methodology. This methodology involves using meteorological models to calculate the generalised wind climatology from measured data, and then applying this data to calculate the wind climate at a specific site. The WAsP software assumes that the generalised wind climate is nearly the same at the predictor and predicted sites, and that past wind data is representative of future wind data. The reliability of WAsP predictions depends on the extent to which these assumptions are fulfilled. The wind farm assessment tool (WAT) contains simple tools to aid in these calculations. Overall, WAsP is a valuable tool for wind resource assessment, but its reliability depends on the accuracy of its assumptions. Further research may be needed to improve the accuracy of wind resource assessment and wind farm calculations.

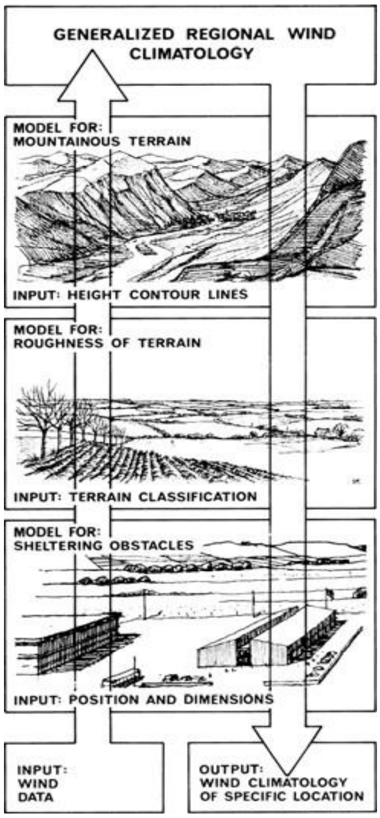


Figure 2-3 *Observation-based wind resource assessment*

(Source: Wind resource assessment using the WAsP software (DTU Wind Energy E-0174) , page 6)

WAsP analysis: from wind data to generalised wind climate

1. Time-series of wind speed and direction observed wind climate (OWC)
2. OWC + met. mast site description generalised wind climate (wind atlas)

WAsP application: from generalised to predicted wind climate

3. Generalised wind climate + site description predicted wind climate (PWC)
4. PWC + power curve annual energy yield of wind turbine

Wind farm production: from predicted wind climate to gross yield

5. PWC + wind turbine (WTG) characteristics 'WAsP gross' wind farm yield
6. PWC + WTG characteristics + wind farm layout wind farm wake losses
7. 'WAsP gross' yield – wake losses 'WAsP net' wind farm yield

Post-processing: from 'WAsP net' yield to net yield (P_{50} and P_x)

8. 'WAsP net' yield – technical losses net annual energy yield (P_{50})
9. Net yield – uncertainty estimate Net yield P_x

2.4.2. Numerical wind atlas methodologies

The wind atlas methodology framework, which includes mesoscale modeling and satellite imagery analysis, has been developed over the past two decades to assess wind resources in regions where high-quality, long-term measurement data is not available and regional-scale topography affects flow features. The numerical wind atlas methodology provides reliable data for physical planning on national, regional, or local scales, wind farm siting, project development, wind farm layout design, and micro-siting of wind turbines. However, additional on-site wind measurements for one or more years are required to produce bankable estimates of power production from prospective wind farms. The present course notes mainly focus on the observational wind atlas methodology, including different inputs to the WAsP modeling, modeling errors and uncertainties, types of additional losses in the wind farm, and a brief cookbook approach to site assessment using WAsP Engineering.

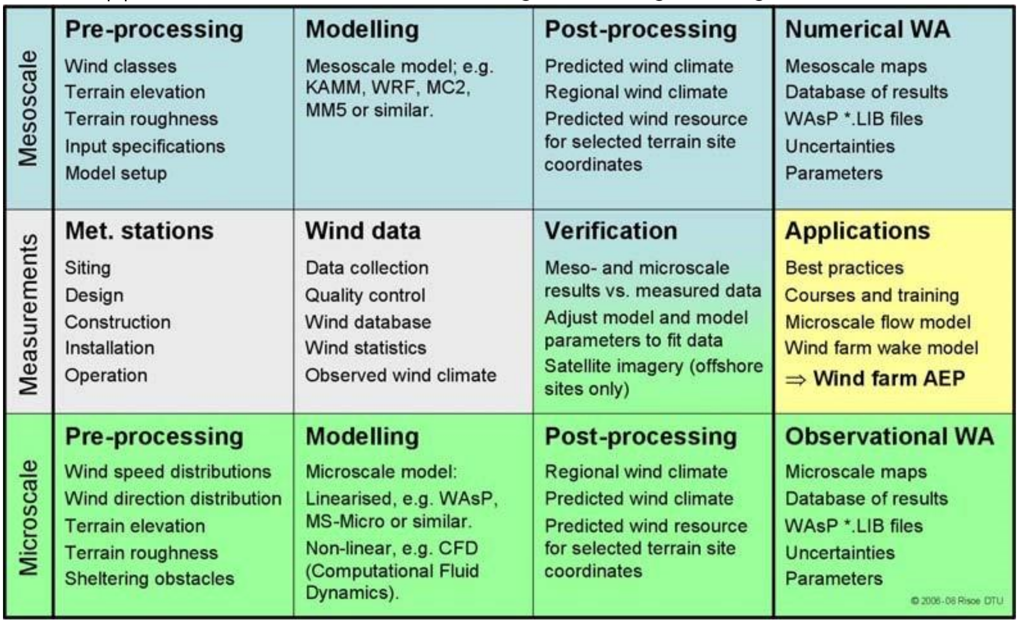


Figure 2-4 *Overview of state-of-the-art wind atlas methodologies*

(Source: Wind resource assessment using the WAsP software (DTU Wind Energy E-0174) , page 7)

2.4.2.1. Vertical Extrapolation of Wind Speed with Height

In the WAsP model [35], wind speed is extrapolated for turbines with heights starting from 10 m above ground level (a.g.l.) at a meteorological station upward to the hub height of the turbine using the following equation:

$$V_2 = V_1 \frac{\ln\left(\frac{h}{Z_{o1}}\right)}{\ln\left(\frac{h}{Z_{o2}}\right)} \qquad (6)$$

where:

V_2 = the wind speed at height h (in m/s)

V_1 = the wind speed at height Z_{o1} (in m/s)

Z_{o1} = the roughness length of the lower height (in meters)

Z_{o2} = the roughness length of the higher height (in meters)

h = the height at which the wind speed is to be extrapolated.

This equation is analogous to the logarithmic wind profile equation, where the wind speed at a higher height is estimated based on the wind speed at a lower height and the roughness lengths of the two heights.

For instance, if one needs to estimate the wind speed at a height of 80 meters, the value of "h" would be 80.

The equation enables one to extrapolate the wind speed from a lower height (Z_{o1}) to a higher height (h) based on the roughness lengths of the two heights (Z_{o1} and Z_{o2}) and the wind speed at the lower height (V_1).

It should be noted that the accuracy of the equation depends on the assumption that the logarithmic wind profile is valid and that the roughness lengths are accurately known or can be estimated.

2.4.2.2. The power law wind profile relationship

To estimate wind speeds [36] at heights of 60 m and 90 m from measurements taken at a height of 10 m, the following equation is used in the WAsP software:

$$V_2 = V_1 \times \left(\frac{h_1}{h_2}\right)^{\left(\frac{1}{7}\right)} \qquad (7)$$

where:

V_1 = the wind speed at height h1 (10 m)

V_2 = the wind speed at height h2 (60 m or 90 m)

h_1 = the lower height (10 m)

h_2 = the higher height (60 m or 90 m)

This equation assumes a logarithmic wind profile and uses the 1/7 power law exponent, which is based on the assumption that the wind shear exponent is constant and independent of wind speed. The power law wind profile relationship states that the wind speed at any height above the ground is related to the wind speed at a reference height through a power law relationship. The power law exponent varies depending on the surface roughness and atmospheric stability conditions. For neutral atmospheric conditions over flat, open terrain, the power law exponent is typically 1/7.

The equation is based on the concept of turbulence, which causes the wind speed to increase with height above the ground. It can be used to estimate wind speeds at a given height based on measurements or estimates of wind speeds at a reference height. However, the accuracy of the equation depends on the accuracy of the wind speed measurements and the assumptions made about the wind shear exponent. It should be noted that the power law wind profile is an empirical relationship and may not hold under all atmospheric conditions and terrain types. The power law exponent may also vary depending on specific atmospheric and terrain conditions and may need to be adjusted accordingly.

It should be noted that the equation assumes that the wind direction distribution is independent of height, which may not be true in reality. Therefore, caution should be exercised when applying this equation in areas with complex terrain or changing atmospheric stability conditions.

2.4.2.3. Rayleigh Distribution

The accuracy of the Weibull distribution [35] in wind regime analysis depends on the precise estimation of the shape parameter (K) and scale parameter (A). However, in many cases, adequate wind data, collected over shorter time intervals, may not be available to accurately estimate these parameters. Instead, simplified versions of the Weibull model can be used, such as the Rayleigh distribution which approximates K as 2.

The Rayleigh distribution is a special case of the Weibull distribution, where the shape parameter (k) is equal to 2. It is often used when there is a lack of sufficient wind data to estimate the shape parameter accurately. The Rayleigh distribution requires only the scale parameter (Vm) to be estimated, and its probability density function (PDF) and cumulative distribution function (CDF) are given by:

PDF:

$$f(V) = \frac{\pi}{2}\frac{V}{V_m^2}e^{-\left[\frac{\pi}{4}\left(\frac{V}{V_m}\right)^2\right]} \tag{8}$$

CDF:

$$f(V) = 1 - e^{-\left[\frac{\pi}{4}\left(\frac{V}{V_m}\right)^2\right]} \tag{9}$$

where:

V = wind speed
V_m = the mean wind speed and
π = the mathematical constant pi (3.14159...)

It is important to note that the Rayleigh distribution assumes isotropic wind speeds, meaning that wind speeds are equally likely in all directions. However, this assumption may not hold in all situations, but it is often used as a simplifying assumption when directional wind data is not available.

In contrast, the equation V2 = V1 * (h2 / h1)^(1/7) is used to extrapolate wind speed from one height to another using the power law relationship. This empirical relationship assumes a logarithmic wind profile and is commonly used in wind energy applications.

The main difference between the two equations is that V2 = V1 * (h2 / h1)^(1/7) is an empirical relationship used to estimate wind speed, while the Rayleigh distribution is a statistical model used to describe the probability distribution of wind speeds. The Rayleigh distribution can be used to estimate the wind speed distribution at heights other than the measurement height and is often used in wind resource assessment.

2.4.3. Wind resource assessment procedure and Energy yield assessment procedure

2.4.3.1. Wind resource assessment procedure

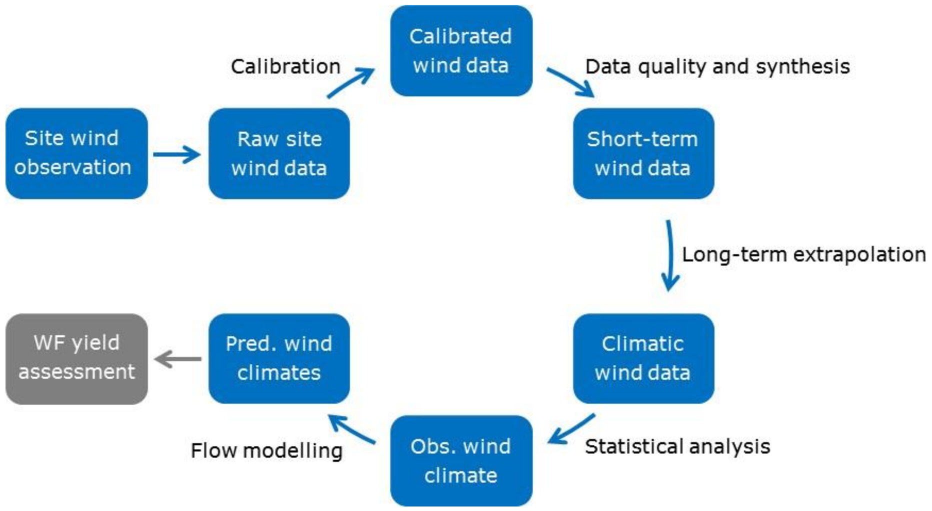


Figure 2-5 *Overview of the steps in the wind resource assessment procedure. (Source: Wind resource assessment using the WAsP software (DTU Wind Energy E-0174) , page 8)*

The wind resource assessment procedure, which involves a series of steps to evaluate the wind energy potential of a particular site. The procedure starts with the installation of met. Mast(s) at the wind farm site to measure wind data every 10 minutes, all year round. The raw data is then converted into calibrated wind data using calibration expressions for each individual instrument, and the quality and integrity of the data are assessed by visual inspection of the time-series and data analyses. Missing data may be substituted with values derived from other similar or redundant sensors.

Once the most accurate, reliable, and complete data set for the site mast is established, it is seen in the context of the long-term wind climate at the site, and an adjusted data set representing the long-term climatology is developed. This data set is then used to calculate the statistics of the wind climate, such as wind speed and direction distributions, mean values, standard deviations, and other statistics.

The last step in the wind resource assessment procedure involves predicting or estimating the long-term wind climates at the prediction sites, which are typically the turbine sites in a wind farm. This is done using a microscale flow model that has the ability to extrapolate the observed wind climate from the met. Mast to those sites. The predictions or estimations made assume that the predicted wind climate is representative of what is going to happen in the future, over the lifetime of the wind turbines.

2.4.3.2. Energy yield assessment procedure

The wind energy yield assessment procedure. The process includes several steps such as

1. Site wind climate = site wind data ± [long-term extrapolation effects]
2. Reference yield = wind climate at hub height plus [power curve]
3. Gross yield = reference yield ± [terrain effects]
4. Potential yield = gross yield – [wake losses]
5. Net yield = potential yield – [technical losses]
6. P90 yield = p50 yield – 1.282×[uncertainty estimate]

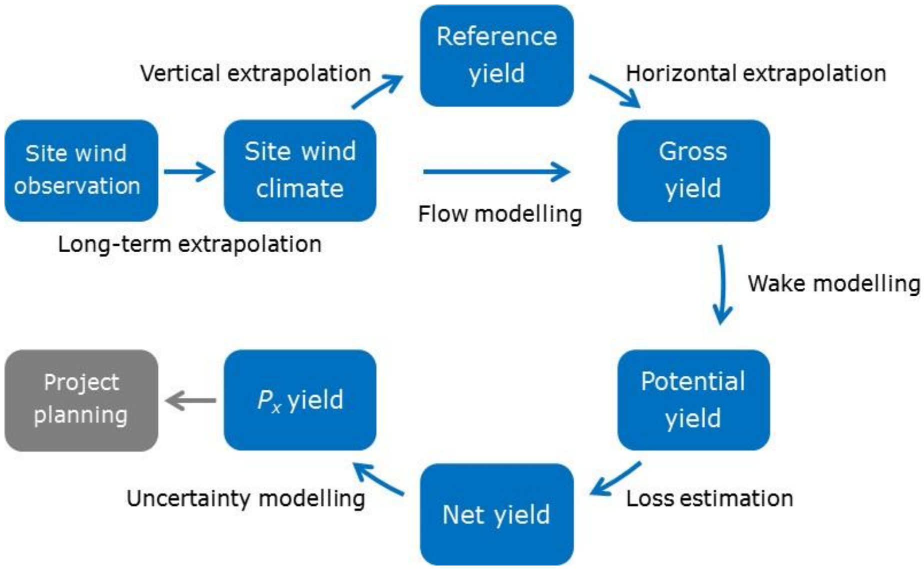


Figure 2-6 *Overview of steps in the wind farm energy yield assessment procedure.*

(Source: Wind resource assessment using the WAsP software (DTU Wind Energy E-0174) , page 9)

Site wind climate determination, reference yield calculation, gross yield estimation, potential yield determination, and net yield calculation. How the observed wind data are referenced and adjusted according to the long-term climatology of the area to predict the wind climate at the hub height of the mast location. The predicted wind climate, along with the site-specific wind turbine power curve, is used to calculate the reference yield. The gross yield is then estimated by adjusting the reference yield for terrain effects using a flow model. Wake losses at each turbine site are estimated and subtracted from the gross yield to determine the potential yield, which is then further adjusted for technical losses to obtain the net yield at the point of common coupling. Additionally, the aggregate uncertainty of the entire process is estimated to obtain the p_{90} value. And emphasizes the importance of breaking down the prediction process into these steps to facilitate comparison of different methods and models. Finally, these steps and their definitions are not universally agreed or even used; however, iec and measnet working groups are addressing these issues at the moment.

2.4.4. Wind-climatological inputs

The wind-climatological inputs required for the Wind Atlas Analysis and Application Program (WAsP) software. The wind climate data contains the wind direction distribution (wind rose) and sector-wise distributions of mean wind speed (histograms) which are provided in the observed wind climate file. The file should also include the wind speed sensor height above ground level in meters and geographical coordinates of the mast site. The latitude is used by WAsP to calculate the Coriolis parameter. Wind speeds must be given in meters per second and wind directions in degrees clockwise from north. The observed wind climate is usually given for 12 sectors and the wind speed histograms using 1 ms^{-1} wind speed bins.

The wind data analysis and calculation of the observed wind climate can be done using the WAsP Climate Analyst. To ensure accurate analysis, several data characteristics such as the data file structure, time stamp definition, data resolution, calm thresholds, and any flag values used for calms and missing data must be known. The Climate Analyst checks the time stamps, observation intervals and missing records in the data series. However, the main quality assurance is done by visual inspection of the time series and polar plot.

The observed wind climate must represent the long-term wind climate at anemometer height at the position of the meteorological mast, and an integer number of full years must be used to calculate it to avoid seasonal bias. Wind data series from prospective wind farm sites must be evaluated within the context of the long-term wind climate to avoid any long-term or climatological bias. WAsP uses Weibull distributions to represent the sector-wise wind speed distributions and the emergent distribution for the total distribution. The difference between the fitted and observed wind speed distributions should be less than about 1% for mean power density and less than a few percent for mean wind speed.

2.4.5. Wind farm inputs

The inputs required for using Wind Atlas Analysis and Application Program (WAsP) for wind farm analysis. The inputs consist of wind farm layout and characteristics of wind turbine generators such as hub height, rotor diameter, site-specific power and thrust curves. While WAsP does not have advanced layout design tools, the layout can be done manually or calculated in MS Excel and then imported to WAsP. The use of site-specific wind turbine generator data is crucial for calculating the yield of the wind farm, and WAsP can interpolate or extrapolate to representative performance tables if an air density correction policy has been selected. Basic data tables corresponding to specific values of air density and/or noise level must be obtained from the wind turbine manufacturer. Overall, the text emphasizes the importance of accurate inputs for reliable wind farm analysis using WAsP.

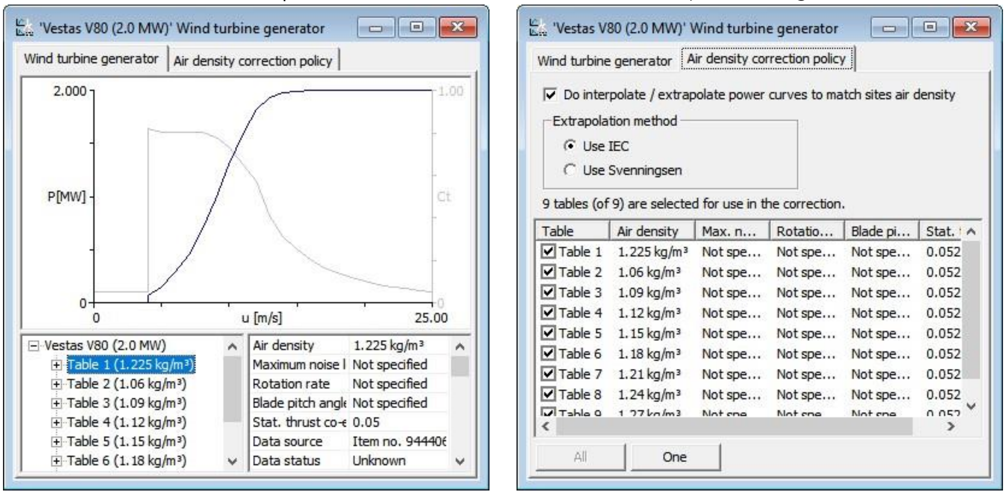


Figure 2-7 *Power and thrust curves for a sample Vestas V80 2-MW wind turbine. Different tables (lower left) may correspond to different air densities or sound levels. (Source: Wind resource assessment using the WAsP software (DTU Wind Energy E-0174) , page 17)*

2.4.6. WAsP modelling

Two separate issues related to the use of the WAsP software in wind power calculations. The first issue pertains to the estimation of air density, which is essential for calculating realistic wind power density and annual energy yield. The density of dry air can be calculated using atmospheric pressure and air temperature measurements, but WAsP 12 offers an alternative method using a global model based on CFSR reanalysis data. The model takes into account air humidity and gives more accurate air density values. The second issue concerns the default parameters of WAsP, which have been widely used in past studies. However, with the introduction of WAsP 12, more users have been modifying the heat flux values to improve the accuracy of the vertical wind profiles. Moreover, while the software does not contain advanced layout design tools, the wind farm layout can be established quickly by copying and pasting turbine site coordinates into WAsP or by using MS Excel. Finally, site-specific power and thrust curves of wind turbine generators must be obtained from the manufacturer to accurately estimate the wind farm yield.

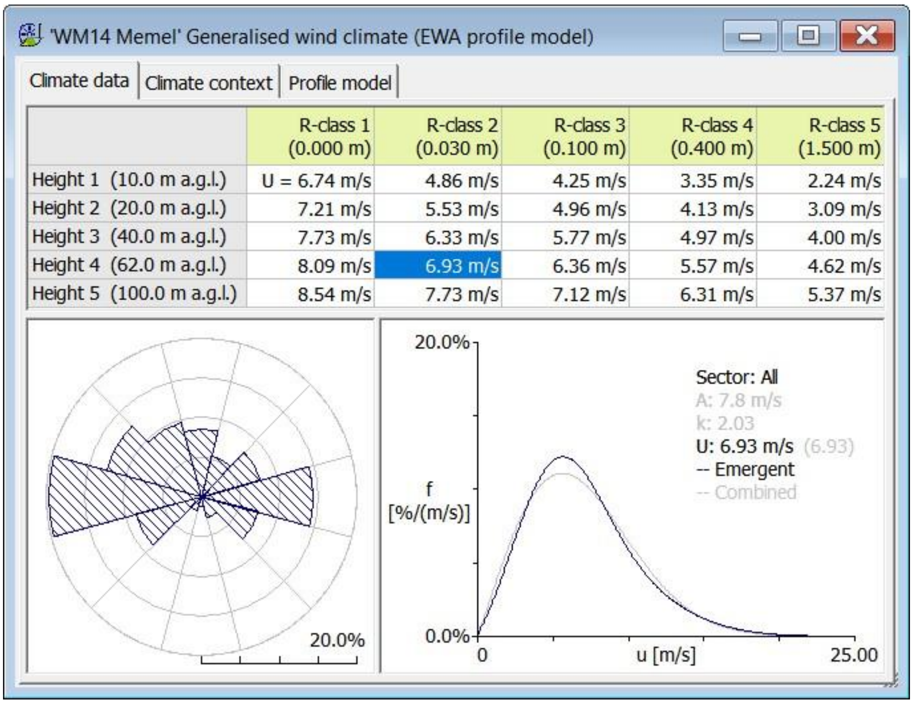
the need to estimate site air density for wind power calculations and the method for calculating air density using atmospheric pressure and temperature measurements.

$$\rho = \frac{B \times 100}{R \times (T + 273.15)} \qquad (10)$$

First, air density estimation is critical for calculating wind power density and annual energy yield for a given wind turbine site. Second, the formula for calculating dry air density from atmospheric pressure and temperature is provided, where ρ represents air density (kg m−3), B represents atmospheric pressure(hPa), R represents the gas constant for dry air (287.05 J kg−1 K−1), and T represents air temperature (°C). This formula can be used to estimate air density at any met. mast or wind turbine site where measurements of atmospheric pressure and temperature are available.

2.4.6.1. Modelling parameters

The modelling parameters that can be adjusted during the early stages of the WAsP calculations. The generalised wind climate data set is specified for five standard heights and five land cover classes. These standard conditions can be adjusted to the project in question. The default heights in the WAsP wind atlas are 10, 25, 50, 100, and 200 m above ground level, and if the wind turbine hub or anemometer heights are between these values, they may be adapted to the project characteristics. The default roughness classes correspond to roughness lengths of 0, 0.03, 0.10, 0.40, and 1.5 m, but can be adjusted if the terrain has a roughness length outside of these values.



'WM14 Memel' Generalised wind climate (EWA profile model)

Climate data | Climate context | Profile model

	R-class 1 (0.000 m)	R-class 2 (0.030 m)	R-class 3 (0.100 m)	R-class 4 (0.400 m)	R-class 5 (1.500 m)
Height 1 (10.0 m a.g.l.)	U = 6.74 m/s	4.86 m/s	4.25 m/s	3.35 m/s	2.24 m/s
Height 2 (20.0 m a.g.l.)	7.21 m/s	5.53 m/s	4.96 m/s	4.13 m/s	3.09 m/s
Height 3 (40.0 m a.g.l.)	7.73 m/s	6.33 m/s	5.77 m/s	4.97 m/s	4.00 m/s
Height 4 (62.0 m a.g.l.)	8.09 m/s	6.93 m/s	6.36 m/s	5.57 m/s	4.62 m/s
Height 5 (100.0 m a.g.l.)	8.54 m/s	7.73 m/s	7.12 m/s	6.31 m/s	5.37 m/s

Figure 2-8 *Sample wind atlas data set where the heights are adapted to site conditions. Data courtesy of the Wind Atlas for South Africa (WASA) project. (Source: Wind resource assessment using the WAsP software (DTU Wind Energy E-0174) , page 19)*

Additionally, the article discusses the atmospheric stability model used in WAsP, which employs separate mean and RMS heat flux values for over-land and over-water conditions. The default heat flux values were originally determined for the European Wind Atlas but have been successful in other regions as well. The mean heat flux value may be adjusted to site conditions to tweak the wind profiles, but only after careful analysis and improvement of the elevation and land cover map. The article suggests evaluating mast flow distortion to account for any potential discrepancies in the analysis. Since the WAsP heat flux values cannot be objectively determined in the current version, they must be based on careful wind profile analysis.

2.4.6.2. WAsP analysis

The wasp analysis, which is a crucial step in wind resource assessment. The wasp analysis involves converting the wind climate observed at a meteorological station to the generalised wind climate, which can be either static or dynamic. If the generalised wind climate is dynamic, it may contain a map that is specific to the met. Station site, as well as an obstacle group that is specific to the met Mast.

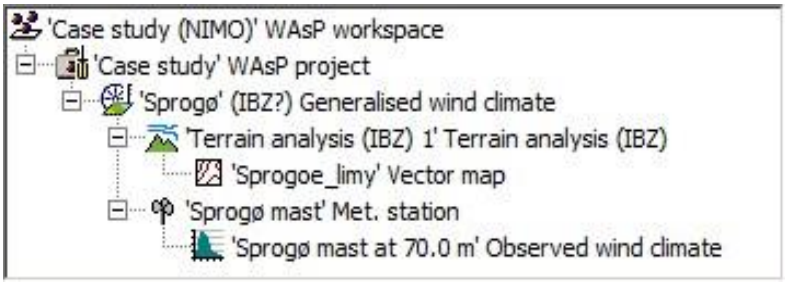


Figure 2-9 *In the workspace hierarchy, the observed wind climate is always child of a met. Station, which is always child of a generalised wind climate (wind atlas).*

(Source: Wind resource assessment using the WAsP software (DTU Wind Energy E-0174) , page 20)

And it must be emphasized the importance of using dynamic generalized wind climates, as they are better able to reflect changes over time. This can be particularly important in wind resource assessment, as wind patterns may change over time due to factors such as climate change or changes. in local land use.

2.4.6.3. WAsP application

The section describes the WAsP analysis and application, which are two crucial steps in wind resource assessment using WAsP software. WAsP analysis is the conversion of wind climate data observed at a meteorological station to the generalised wind climate (GWC) using the WAsP hierarchy.

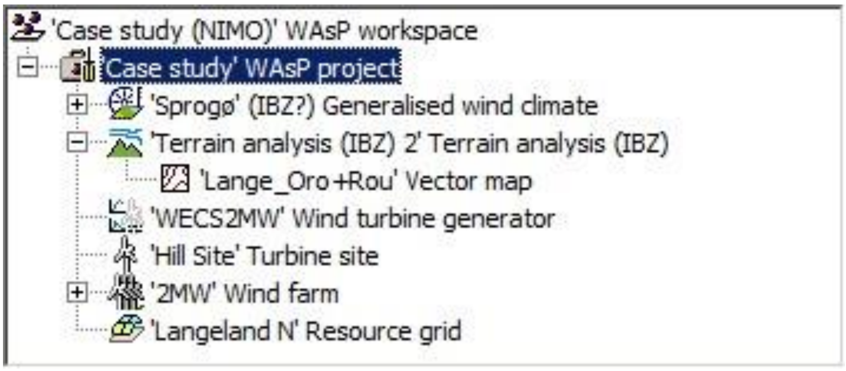


Figure 2-10 *The generalised wind climate, a terrain analysis with vector map, and a wind turbine generator are inputs to the application procedure; the turbine site, wind farm and resource grid contain the prediction results or outputs.*

(Source: Wind resource assessment using the WAsP software (DTU Wind Energy E-0174) , page 20)

The GWC can be either dynamic or static, with the dynamic GWC preferred due to its ability to reflect changes directly. On the other hand, WAsP application is the conversion of the GWC to the predicted wind climate at one or more sites using the WAsP hierarchy. A wind farm is a collection of wind turbines arranged in turbine site groups, and the Park wake model is invoked automatically for the wind turbines in a wind farm. WAsP 12 features an updated default wind farm wake model referred to as Park2. The reference site member is used to relate wind farm power production to the wind speed and direction measured at a nearby mast, while the wind resource grid corresponds to a regular grid of wind turbines, but no wake calculations are done. The paper highlights the importance of fulfilling map requirements for all sites in a resource grid.

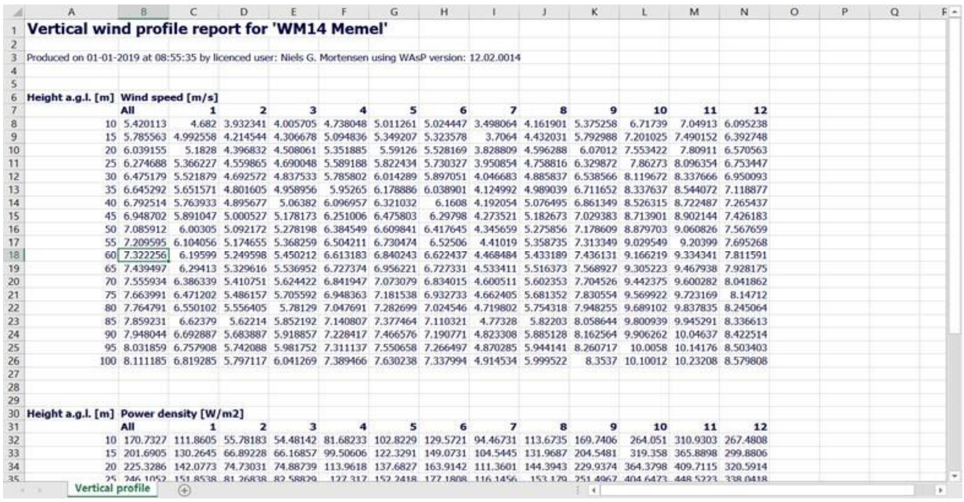
2.4.6.4. Validation of the modelling

The importance of additional instruments in wind farm projects for predicting wind speed variations across the site. In order to adjust terrain descriptions and atmospheric stability settings, it is essential to validate the modeling with the help of multiple sets of instruments. The procedure for evaluating the vertical wind profile requires measurements at two or more heights along the mast, and the comparison can be used to adjust the terrain descriptions and atmospheric stability settings. The study recommends using the top anemometer as the reference for yield calculations as it faces the least flow distortion. The process involves using the observed wind climate (owc) to calculate the generalized wind climate (gwc), inserting a turbine site at the meteorological mast location, setting the calculation height to the height of the reference anemometer, updating all calculations, invoking the "turbine site vertical profile" script, and plotting the wind speed profile graph. The wind speed profile graph can be adjusted by changing the heat flux values in the profile model tab of the generalized wind climate window. Cross predictions between masts can be made if wind speed and direction have been measured at two or more masts within the wind farm site or a similar region. The procedure involves making a WAsP project for each meteorological mast, inserting all mast positions and heights as turbine sites in the projects, using each mast to predict the wind climates at other mast sites, and making a table with the results of the cross prediction. The study concludes that it is essential to use multiple sets of instruments to validate the modeling, which can further improve the accuracy of wind speed predictions in wind farm projects.

The procedure for evaluating the vertical wind profile is then:

1. Use the observed wind climate (OWC) from the reference anemometer to calculate the generalised wind climate (GWC).
2. Insert a *Turbine site* in the map at the location of the meteorological mast.
3. Set the calculation height to the height of the reference anemometer.
4. Update all calculations (right-click menu or press the F9 function key).
5. Select the *Turbine site* and go to **Tools** > **Utility scripts** menu.
6. Invoke the “Turbine site vertical profile (Excel)” script.

MS Excel will now start and show WAsP predictions for several levels between 5 and 100 m a.g.l. at the site of the mast:



Vertical wind profile report for 'WM14 Memel'

Produced on 01-01-2019 at 08:55:35 by licenced user: Niels G. Mortensen using WAsP version: 12.02.0014

Height a.g.l. [m]	Wind speed [m/s]												
	All	1	2	3	4	5	6	7	8	9	10	11	12
10	5.420113	4.682	3.932341	4.005705	4.738048	5.011261	5.024447	3.498064	4.161901	5.375258	6.71739	7.04913	6.095238
15	5.785563	4.992558	4.214544	4.306678	5.094836	5.349207	5.323578	3.7064	4.432031	5.792988	7.201025	7.490152	6.392748
20	6.039155	5.1828	4.396832	4.508061	5.351885	5.59126	5.528169	3.828809	4.596288	6.07012	7.553422	7.80911	6.570563
25	6.274688	5.366227	4.559865	4.690048	5.589188	5.822434	5.730327	3.950854	4.758816	6.329872	7.86273	8.096354	6.753447
30	6.475179	5.521879	4.692572	4.837533	5.785802	6.014289	5.897051	4.046683	4.885837	6.538566	8.119672	8.337666	6.950093
35	6.645292	5.651571	4.801605	4.958956	5.95265	6.178886	6.038901	4.124992	4.989039	6.711652	8.337637	8.544072	7.118877
40	6.792514	5.763933	4.895677	5.06382	6.096957	6.321032	6.1608	4.192054	5.076495	6.861349	8.526315	8.722487	7.265437
45	6.948702	5.891047	5.000527	5.178173	6.251006	6.475803	6.29798	4.273521	5.182673	7.029383	8.713901	8.902144	7.426183
50	7.085912	6.00305	5.092172	5.278198	6.384549	6.609841	6.417645	4.345659	5.275856	7.178609	8.879703	9.060826	7.567659
55	7.209595	6.104056	5.174655	5.368259	6.504211	6.730474	6.52506	4.41019	5.358735	7.313349	9.029549	9.20399	7.695268
60	7.322256	6.19599	5.249598	5.450212	6.613183	6.840243	6.622437	4.468484	5.433189	7.436131	9.166219	9.334341	7.811591
65	7.439497	6.29413	5.329616	5.536952	6.727374	6.956221	6.727331	4.533411	5.516373	7.568927	9.305223	9.467938	7.928175
70	7.555934	6.386339	5.410751	5.624422	6.841947	7.073079	6.834015	4.600511	5.602353	7.704526	9.442375	9.600282	8.041862
75	7.663991	6.471202	5.486157	5.705592	6.948363	7.181538	6.932733	4.662405	5.681352	7.830554	9.569922	9.723169	8.14712
80	7.764791	6.550102	5.556405	5.78129	7.047691	7.282699	7.024546	4.719802	5.754318	7.948255	9.689102	9.837835	8.245064
85	7.859231	6.62379	5.62214	5.852192	7.140807	7.377464	7.110321	4.77328	5.82203	8.058644	9.800939	9.945291	8.336613
90	7.948044	6.692887	5.683887	5.918857	7.228417	7.466576	7.190771	4.823308	5.885128	8.162564	9.906262	10.04637	8.422514
95	8.031859	6.757908	5.742088	5.981752	7.311137	7.550658	7.266497	4.870285	5.944141	8.260717	10.0058	10.14176	8.503403
100	8.111185	6.819285	5.797117	6.041269	7.389466	7.630238	7.337994	4.914534	5.999522	8.3537	10.10012	10.23208	8.579808

Height a.g.l. [m]	Power density [W/m2]												
	All	1	2	3	4	5	6	7	8	9	10	11	12
10	170.7327	111.8605	55.78183	54.48142	81.68233	102.8229	129.5721	94.46731	113.6735	169.7406	264.051	310.9303	267.4808
15	201.6905	130.2645	66.89228	66.16857	99.50606	122.3291	149.0731	104.5445	131.9687	204.5481	319.358	365.8898	299.8806
20	225.3286	142.0773	74.73031	74.88739	113.9618	137.6827	163.9142	111.3601	144.3943	229.9374	364.3798	409.7115	320.5914
25	246.1052	151.8538	81.26838	82.58829	127.317	152.2418	177.1808	116.1456	153.179	251.4967	404.6473	448.5223	338.0418

Vertical profile

Figure 2-11 *Results of running the "Turbine site vertical profile (Excel)" script in WAsP are shown in MS Excel. The "All" column is the omni-directional wind profile; sectorwise wind profiles (here, 1-12) and power densities are also calculated.*

(Source: Wind resource assessment using the WAsP software (DTU Wind Energy E-0174) , page 22)

2.4.6.5. Special considerations

Special considerations for three types of terrains in wind resource assessment modeling using the Wind Atlas Analysis and Application Program (WAsP). The first type is offshore and near-shore conditions, which are generally within the operational envelope of WAsP models. However, adjustments need to be made to the roughness length of the sea surface, wake decay constant, and vertical reference levels used offshore. WAsP expects to encounter elevation or roughness change lines within 20 km from any site, but for sites far offshore, this may not occur, and the model may throw an error, which can be remedied by changing the model interpolation radius or adding a combined elevation/roughness change line around the wind farm site itself. There are no standard procedures for modelling tidal flats or sea ice, and different kinds of reanalysis data or numerical wind atlas data may be used to reference short-term measurements at an offshore site to the long-term climatology. The Fuga wake model is designed to handle large offshore wind farms.

The second type is forested terrain, which does not have specific models or procedures for modelling wind flow in, above and around forests.

Forests are specified in the vector map by roughness change lines, and the effective modelling height should be taken as the nominal height minus a displacement length, which is a function of the height of the trees and the stand density, but is often around 2/3 of the tree heights. Close to the forest edge, the flow may be quite complicated, and WAsP cannot be expected to provide entirely reliable results.

The third type is steep terrain, which was not originally designed for by WAsP. In steep terrain, where flow separation occurs, the flow modelling results will be biased. WAsP evaluates the steepness of the terrain using the ruggedness index, which is defined as the fraction of the terrain around a given site steeper than a critical slope. The relation between prediction error and difference in ruggedness indices has been used to correct WAsP predictions in steep and complex terrain, where the local slope of the fitted line can be established. Access to computational fluid dynamics (CFD) calculations has been implement

in WAsP from version 11, which is strongly recommended to employ in complex terrain.

2.4.7. Additional technical losses

The calculation of energy yield or potential annual energy production (AEP) of wind farms using the Wind Atlas Analysis and Application Program (WAsP) software. The AEP is the maximum energy that could potentially be produced by the wind farm, taking into account only wake losses. However, additional technical losses occur between the wind turbine rotor(s) and the point of common coupling (PCC) where the electricity is fed into the grid. These losses are not taken into account by WAsP and must be estimated for each project and subtracted from the AEP calculated by WAsP to obtain the metered production at the PCC.

Table 2-6 *Additional technical losses, which are not taken into account by WAsP, may be grouped into the following five categories (European Wind Energy Association, 2009). Typical values for an onshore wind farm in NW Europe are listed too. Range values from Brower et al. (2012) suggest that typical values may sometimes be too optimistic.*

	Loss category	Technical loss type	Typical	Range
1	Availability	• turbine availability	> 3% <	2-10%
		• balance of plant availability	1%	
		• grid availability	< 1%	
2	Electrical	• operational electrical losses • wind farm consumption	1-2%	2-3%
3	Turbine performance	• power curve adjustments • high-wind hysteresis • control losses (SCADA)	1-2%	0-5%
4	Environmental	• blade degradation and fouling • degradation due to icing • high and low temperature	1-2%	1-6%
5	Curtailments	• wind sector management • grid curtailment • noise, visual and environmental	Design dependent	0-5%

The additional losses are grouped into five categories: availability, electrical, turbine performance, environmental, and curtailments. The losses vary greatly but are often about 5-10% of the WAsP AEP in total. Therefore, it is crucial to know which production statistic is being used for a WAsP validation study. The article provides a detailed description of the steps involved in the prediction procedure using WAsP and the results that WAsP provides directly is then:

- Site wind climates – the observed, generalised and predicted wind climates
- Wind farm gross yield – the ‘WAsP gross’ annual energy production
- Wind farm potential yield – the ‘WAsP net’ annual energy production

2.4.8. Modelling error and uncertainty

WAsP prediction and reference values are subject to modelling error and uncertainty, which should always be estimated to determine the likely distribution of the modelling errors. The modelling uncertainty is composed of all the uncertainties related to the entire assessment procedure, and the different uncertainty factors tend to be random in nature and are often not correlated. Additionally, the modelling results may be biased, representing any systematic deviation of the modelling result from the reference value. Accurate estimates have low uncertainty and trueness values. The normal distribution can be used to plot exceedance probability curves as a function of the annual energy production. Different standard deviations of the normal distribution will result in different exceedance curves, where the steeper the central part of the curve, the smaller the standard deviation.

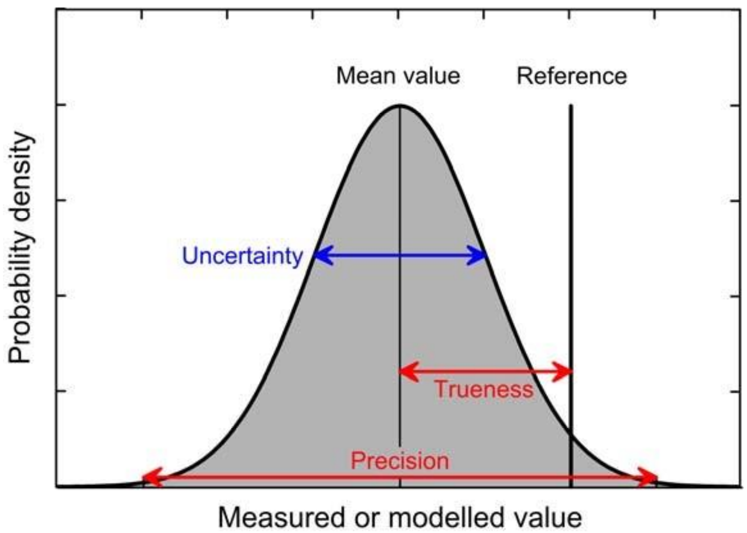


Figure 2-12 *Modelling uncertainty and bias. The 'Mean value' might correspond to the WAsP prediction (P50); the 'Reference' is the correct value we are trying to predict. The standard deviation of the normal distribution shown is 10% and the bias shown is 20%.*

(Source: Wind resource assessment using the WAsP software (DTU Wind Energy E-0174) , page 27)

The normal distribution shown in Figure 2-12 can be plotted to show excess probabilities as a function of annual energy production, see Figure 2-13.

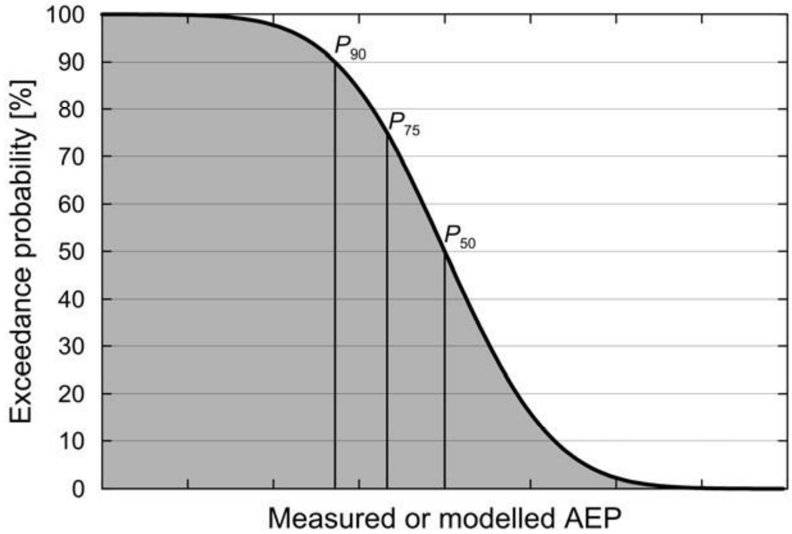


Figure 2-13 *Excess probability curve corresponding to the normal distribution. (Source: Wind resource assessment using the WAsP software (DTU Wind Energy E-0174) , page 27)*

Furthermore, shown in Figure 2-13 are the P90, P75 and P50 values, corresponding to probabilities exceeding 90%, 75% and 50%, respectively, different standard deviations of the normal distribution. (different uncertainty estimates) will result in different excess curves. when there is a large standard deviation (Uncertainty) The difference between P90, P75 and P50 values is large with a small standard deviation. The difference will be small. See Figure 2-14.

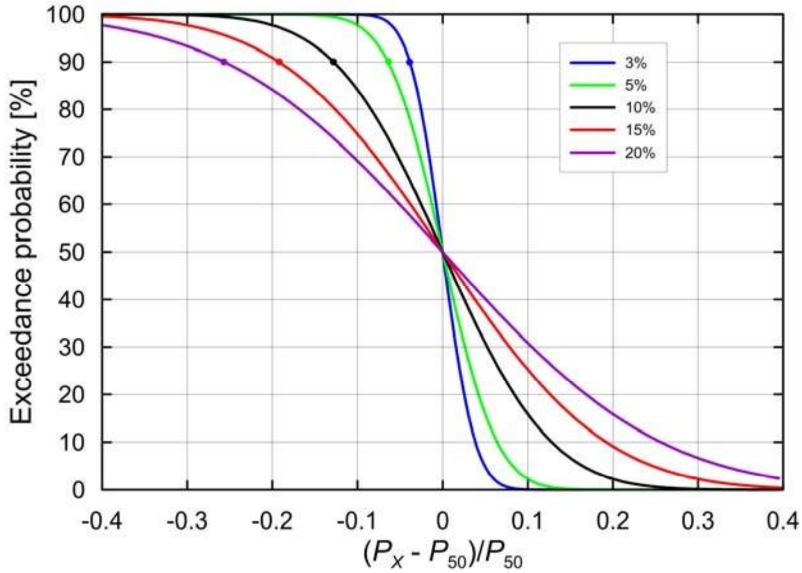


Figure 2-14 *Excess probability curves corresponding to the normal distribution with different standard deviations: 20, 15, 10, 5 and 3%, respectively. The smaller the standard deviation, the P90 value is also specified.*

(Source: Wind resource assessment using the WAsP software (DTU Wind Energy E-0174) , page 28)

2.4.8.1. Prediction biases

Modeling errors and WAsP (Wind Atlas Analysis and Application Program) forecast uncertainties. For example, mean wind speeds measured with cup anemometers are inherently biased. Due to the instrument's behavior in turbulent flows, however, these turbulent biases are often viewed as only part of the overall measurement uncertainty.

A large bias can occur in complex (steep) topography where |ΔRIX| is approximately 5% larger. ΔRIX of the turbine site The forecasts may need to be corrected using RIX analysis or WAsP CFD models.

2.4.8.2. Sensitivity analysis

This section describes the sensitivity analysis performed on a microscale modeling system, WAsP, used to estimate the annual energy production (AEP) of a wind turbine (An example is the wind farm in NE China). Sensitivity analysis involves studying the variation in the output of a mathematical model based on changes in the input data and parameters. The purpose of this analysis is to investigate the robustness and uncertainty of the microscale modeling.

In order to minimize uncertainty, the sensitivity analysis was performed by changing the input parameters such as U calibration, anemometer height, adapted atlas heights, direction offset, air density, stability, heat flux, BG roughness, the position of the mast, and elevation detail. Results of the sensitivity analysis are presented in Table 2-7, showing the change in predicted AEP at various heights due to changes in input parameters. that it may not always be possible or necessary to perform a comprehensive sensitivity analysis; however, identifying the factors or parameters contributing to the sensitivity of a modeling result is important.

Table 2-7 *Comprehensive sensitivity analyses for a 70-m mast on a hill in Northern China.*

Parameter	Input change	Change in predicted AEP @ h		
		75 m	100 m	125 m
U calibration	+1%	1.5%	1.4%	1.3%
Anemometer height	−1%	0.3%	0.3%	0.3%
Adapted atlas heights	Standard h	0.9%	0.0%	1.8%
Direction offset	+10°	0.7%	0.2%	0.0%
Air density	−2.5%	−1.4%	−1.3%	−1.2%
Stability	neutral	−1.4%	−6.1%	−9.0%
Heat flux	+10 Wm−2	0.2%	1.1%	1.7%
BG roughness	half of 5 cm	0.4%	0.4%	0.2%
BG roughness	double of 5 cm	0.0%	−0.4%	−0.5%
Position of mast	±10 m	0.2%	0.2%	0.1%
Elevation detail	SRTM 3 only	−0.2%	−0.6%	−0.8%

2.4.8.3. Uncertainty estimation

This section focuses on the estimation of uncertainty in wind farm energy production. The "3% vision" proposed by TPWind is discussed, which aims to improve techniques so that wind farm energy production predictions can be made with less than 3% uncertainty. Sources of uncertainty in wind farm energy production are then discussed, and it is noted that there is no systematic classification for these sources. Table 2-8 lists the generally accepted sources of uncertainty, which include wind data, future wind variability, spatial variation, power conversion, plant performance and losses, and other factors such as air density. and the emphasizes that every wind farm yield assessment report should contain an estimation of the uncertainty of the energy yield estimation. The overall uncertainty of energy yield predictions is often calculated using equations for independent stochastic processes to include the principal uncertainties. The paper notes that the aggregate uncertainty for the estimation of the yield of an onshore wind farm in Europe is often between 10 and 15% of AEP, and any estimated uncertainties outside of this range should be highlighted and discussed. Overall, this section provides important information for wind farm developers and stakeholders on the sources and estimation of uncertainty in wind farm energy production predictions.

Table 2-8 *Commonly used sources of uncertainty by category and type.*

Uncertainty category	Uncertainty type	Typical values
1 Wind data	• wind measurements • long-term extrapolation	2-5% on wind speed 1-3% on wind speed
2 Future wind variability	• inter-annual variability • climate change	2-6% on wind speed
3 Spatial variation (flow modelling)	• vertical extrapolation • horizontal extrapolation	0-5% on wind speed 0-5% on wind speed
4 Power conversion	• power curve • metering	5-10% on AEP 0-2% on AEP
5 Plant performance and losses	• wake effects • technical losses	0-5% on AEP 0-2% on AEP
6 Other	• air density	0-2% on AEP

2.4.9. Wind conditions and site assessment

This chapter focuses on the assessment of wind conditions at potential wind farm sites. The WAsP software can estimate the mean wind climate at any site, including wind farms. However, calculating parameters such as the 50-year extreme wind speed and turbulence intensity at turbine sites requires the use of additional tools such as WAsP Engineering and Windfarm Assessment Tools. It is important to note that this chapter provides only a brief introduction to these software packages as the focus of the course is on the principles of the IEC 61400-1 standard.

One approach to estimating the 50-year extreme wind speed is through measurements at a meteorological mast. The Climate Analyst tool in WAsP can provide the observed extreme wind climate, which can be used to derive the necessary parameters. The turbulence intensity can also be calculated from wind speed measurements and standard deviation. However, it is important to consider the location of the mast and the similarity of the terrain to the wind farm site as observed extreme winds and turbulence intensities may not be representative of turbine sites if the mast is not at hub height or situated in different terrain.

2.4.9.1. Extreme wind and turbulence intensity

The use of WAsP Engineering to estimate extreme wind and turbulence intensity at the turbine sites in a wind farm. The process involves creating input files for WAsP Engineering by calculating and saving the observed extreme wind climate in Climate Analyst, and exporting different site locations and generalised wind climate to files in WAsP. A project is set up in WAsP Engineering by defining the flow domain structure and inserting site locations and observed extreme wind climate from files. The extreme winds at the sites can then be estimated by calculating a generalised extreme wind climate and using the Applied EWC report script in the Tools menu. The paper provides step-by-step instructions on how to carry out these calculations, and notes that this process can be used without detailed knowledge of the software or models used in WAsP Engineering.

First, you need to make a few input files to WAsP Engineering. In the Climate Analyst, you need to calculate and save the observed extreme wind climate:

1. Right-click Results and choose Create an Oewc
2. Right-click the Oewc and Export to file... to an *.oewc file

In WAsP, you need to export the different site locations and the generalised wind climate to files:

1. Right-click the met. station and Extract site location to a *.wsg file
2. Right-click the wind farm and Extract site locations to a *.wsg file
3. Right-click the generalised wind climate and Export to file... choose type *.lib

In WAsP Engineering, you need to set up a project for the wind farm:

1. From the File menu, choose Create new project...
2. Select Use Vector Map and choose the WAsP vector map for the project setup
3. Provide the latitude and select an area for the project
4. Define the flow domain structure according to the recommendations given on the WAsP home page. (go to WEng > Working with maps in WEng).
5. Right-click the Sites member and choose Insert site locations from file
6. Insert the met. station and the wind farm turbine sites in this way. The calculation height(s) of the sites should now be shown in the Heights pane.
7. From the Insert menu, choose Observed extreme wind climate from file... Select the *.oewc file that was exported from the Climate Analyst. And provide the met. mast coordinates.

Now, the basic WAsP Engineering project has been set up and you can do some calculations. For example, to estimate the extreme winds at the sites, do the following:

1. Right-click the parent object of the met. station (Winds) and choose Calculate a generalised extreme wind climate. NB: This may be a lengthy calculation0F .

2. Left-click your wind farm, hub height and generalised extreme wind climate in the hierarchy in order to select objects for further calculation.
3. In the Tools menu, choose Scripts and then Applied EWC report: 50 y winds for all sites and heights.

Check the results in the MS Word file that opens; this will give you information about the 50-y extreme winds at the sites.

2.4.9.2. IEC site assessment

The process of conducting a full IEC 61400-1 site assessment using a combination of wasp and wasp Engineering, followed by post-processing of results in the Wind farm Assessment Tool (WAT). The WAT tool provides information on various factors such as wind rose, Weibull A- and k-parameters, wind direction deflection, wind shear exponent, turbulence intensity, and standard deviation of wind speed and flow angle. The effective turbulence intensity can be estimated using the WAT tool, and it can also be used for wind farm technical loss and uncertainty estimations. The process involves importing data from the Excel Workbook and the wind turbine generator file, selecting the turbine class and turbulence category, adding terrain data, selecting an appropriate Wöhler exponent for the weakest part of the turbine, and checking whether all turbine sites obey the IEC 61400-1 site assessment rules.

2.5. Evaluation and project management of wind energy

According to "A Manual for the Economic Evaluation of Energy Efficiency and Renewable Energy Technologies" [37], an approach is indicated based on several factors. It includes investor perspectives, rules, risks, finances, and cash flows that will follow operations. Table 2-6 is a quick reference for identifying investment characteristics and different decision criteria. refers to an acceptable measure. "R" indicates a recommended measure. However, this does not mean that other economic measures are inappropriate. On the other hand, "N" means that the measure is generally not recommended. and may yield inaccurate results and conclusions. Finally, "C" refers to a measure commonly used in a characteristic assessment. because each investment and investor are different. Entries in the matrix should be viewed as a rule with several exceptions. For example, according to the Matrix Investment Decisions (TLCC) and Income Requirements (RR) sections, they will not be labeled "recommended" for any decision, but both are valid if the alternative energy services are the same. Or the energy services must be safe, and the cost is the only issue. These measures are generally not recommended, simply because they do not consider the benefits or rewards.

Table 2-9 *Overview of Economic Measures Applying to Specific Investment Features and Decisions*[a]

Investment Features	NPV	TLCC	RR	LCOE	IRR	MIRR	SPB	DPB	B/C	SIR
Investment after return					N					
Regulated investment			R							
Financing							N	N		N
Risk							C,R	R		
Social costs	C,R								C,R	
Taxes							N	N		
Combinations of investments										

Investment Decisions	NPV	TLCC[b]	RR[b]	LCOE	IRR[b]	MIRR	SPB	DPB	B/C	SIR
Accept/reject		N	N		C					
Select from mutually exclusive alternatives[b]	R	C		N	N	N	N	N	N	N
Ranking (Limited budget)				R	C,N	R	N	N	R	R

R - Recommended

N - Not recommended

C - Commonly Used

A blank cell indicates that the measure is acceptable.

a. This table is intended t o serve only as a rough guideline by which an analyst can identify those measures that warrant further investigation. Exceptions to each of the entries will occur.

b. Text discusses some of the exceptions.

Economic Measures

NPV - Net present value MlRR - Modified internal rate of return

Investment Features	NPV	TLCC	RR	LCOE	IRR	MIRR	SPB	DPB	B/C	SIR

TLCC - Total life-cycle cost
LCOE - Levelized cost of energy
RR - Revenue requirements
IRR - Internal rate of return
SPB - Simple payback period
DPB - Discounted payback period
B/C - Benefit-to-cost ratio
SIR - Savings-to-investment ratio

Explanations for the Economic Assessment Measures Matrix [37]

investment properties

- **Investment after return:** It is necessary to take further investment into account. After the investor receives the cash flow from the project (the negative net cash flow of the project in the year in which the compensation is paid),
  Item description: An IRR is not recommended due to negative project net cash flows. after paying returns to investors. This can result in multiple positive IRR values because downstream investments (investments made by retail investors) are improperly discounted. For example, where IRR is not an investor's discount rate, MIRR is acceptable because both problems with IRR can be avoided.
- **Regulated Investments:** Returns on the cost of an investment if it is regulated by a regulatory authority
  Item description: Recommended, prepared, and presented with the necessary income. because it is usually the basis for protecting such investment interests from regulators.
- **Financing:** This refers to the assessment of project-specific loan investments. (as opposed to corporate financing or financing only) calculated at a discount rate that reflects the cost of both equity and liabilities.
  Item description: The payback measure (SPB) may be used for a quick understanding of projects that are not interested in financing. However, clear financial considerations make the analysis extremely complicated. Therefore, the payback measure will not be available when funding is clearly considered. The savings-to-investment ratio (SIR) is not recommended due to the issue of whether an investment is defined as just a portion of the investment or the total investment.

- **Risk:** All investments are subject to the risk of not delivering the promised return. For investments with high uncertainty, the risks should be clearly considered.
  Item description: The payback measure (SPB) is recommended as it is a quick assessment of the length of time during which an investor's capital is at risk. A more formal risk assessment (e.g., decision analysis) is recommended.
- **Social costs:** The total cost of the alternative includes direct costs such as capital costs and O&M costs as well as external costs such as environmental costs. That is, all costs incurred by society are considered social costs.
  Item description: Net present value (NPV) and benefit disposal ratio (B/C) are acceptable and often used to assess investments from a social perspective. Therefore, it is a recommended measure.
- **Taxes:** Taxes have the greatest impact on investment value. and should be considered in every aspect. But the most fundamental analysis of taxes to consider includes state and federal income taxes. property taxes, etc.
  Item description: Including tax in the payback calculation complicates the analysis. Therefore, it is not recommended to use the payback measure (SPB).
- **Combination of Investments:** Sometimes, an investment in one energy technology has an impact on the cost, efficiency, or value of another energy investment. For example, adding additional insulation to a furnace wall will make it more efficient. In these cases, the investment should be assessed as an overall system, i.e., a one-time investment, with costs, efficiency, and value reflecting the characteristics of the combined system.
  Item description: All measures are acceptable and under consideration. as defined for investment properties and decision types

2.6. Carbon dioxide emissions from electricity generation

Reducing carbon emissions through renewable energy is widely recommended as a low-carbon technology. and making use of renewable energy resources [38] to achieve "carbon neutrality" [39], with variations from system to system. In photovoltaic systems, CO_2 emissions while generating electricity are very low. However, while emissions from online solar cells are one-fourth of those from coal and four times those of wind power, emissions from direct-operating wind and hydropower are comparable. When considering indirect emissions, hydropower can have as many as six times the CO_2 emissions of wind power. Depending on the type of power plant, biomass-based power generation is often referred to as carbon neutral. This is because the carbon released in the combustion process is generally absorbed during plant growth. However, total emissions are similar to those of wind power [40], as summarized in Figure 2-3.

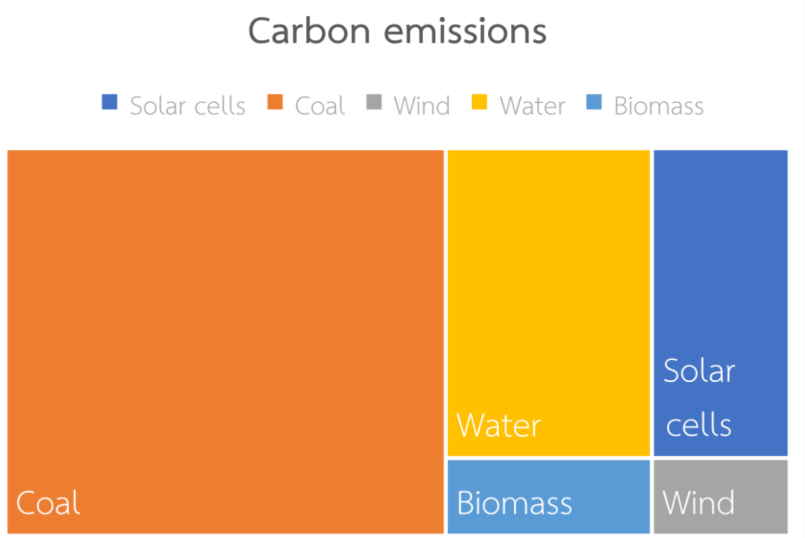


Figure 2-15 *Carbon emissions*

(Source: Carbon dioxide emissions reduction by renewable energy employment in Romania | IEEE Conference Publication | IEEE Xplore, 2022)

Nuclear power generation systems have the highest energy density of any low-carbon energy source in Table 2-7, with 4,000 W/m^2 compared to renewables such as solar cells (4–10 W/m^2) and wind (0.5–1.5). W/m^2) or biomass (0.5-0.6 W/m^2). [41] The trend toward such a system was controversial after the Fukushima nuclear power plant disaster. Many countries have decided to gradually reduce nuclear power and develop renewable energy systems. to reduce problems related to the environment and health.

Table 2-10 *Carbon Dioxide Emissions from Power Supply Technology* [40], [42]

Primary Energy Source	Total CO_2 Emissions (t/GWh)
Coal	1,200
Hydrocarbons	1,000
Nuclear	30
Hydro	400
Wind	70
Photovoltaic	250

Primary Energy Source	Total CO_2 Emissions (t/GWh)
Biomass	110

(Source: ieeexplore.ieee.org, 2022)

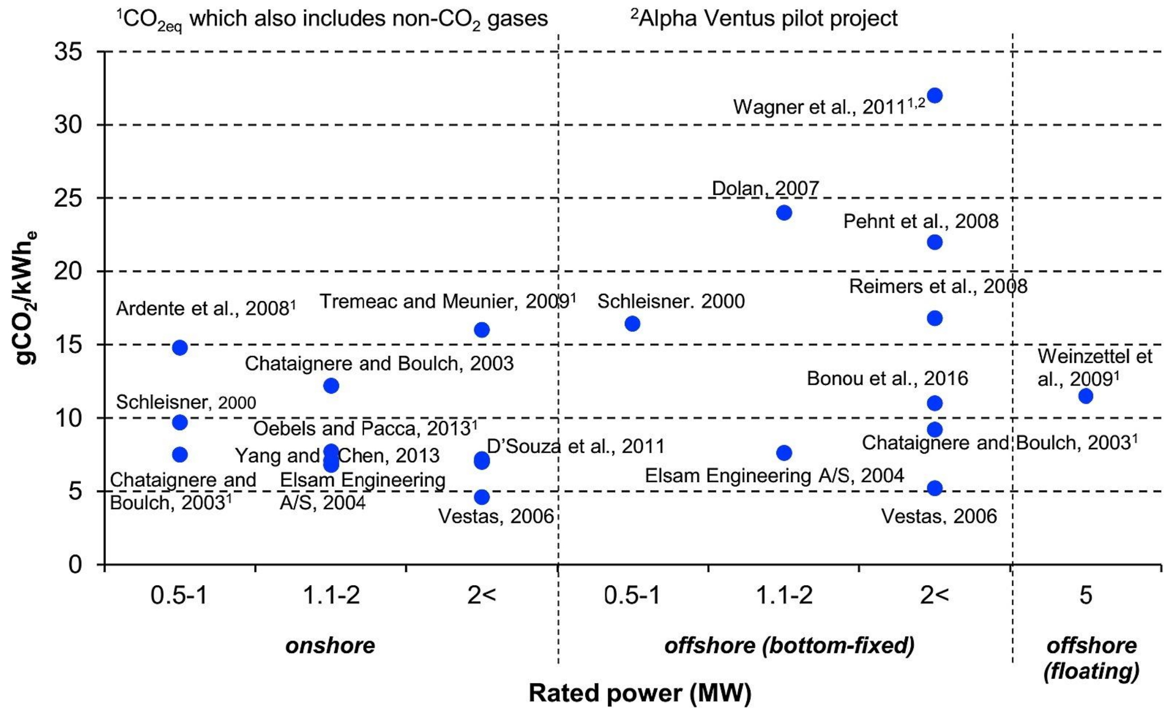


Figure 2-16 *Life cycle carbon footprint of onshore and offshore wind energy as a function of increasing wind turbine nameplate capacity.*

(Source: Life cycle energy and carbon footprint of offshore wind energy. Comparison with onshore counterpart - ScienceDirect).

With very low CO_2 emissions from wind power (Figure 25), it is the top renewable energy source (Table 2-7) with development prospects. and high utilization, with low CO_2 emissions concentrating more on onshore wind than offshore wind, which is of interest for study. Finding additional study guidelines is an issue that will help make the area analysis more comprehensive. The previous study (Table 2-8) pointed out the research issues.

Table 2-11 Summary of existing literature

Author(s)	Country	Size	Economics of wind energy	Environmental variable determinants	Result
[7]	In this study, in order to cover the entire country of Thailand	-	-	Renewable Energy Policy of Thailand	The average annual wind speed of 120 m AGL is in the range of 1.60-5.83 m/s with the highest average annual power density of about 200 W/m^2.
[9]	Baltimore Metropolitan Area, Maryland, USA	Over 150 conventional small wind turbines generate 1990 kWh of electricity per year.	It has a payback period of 13 years.	-	Statistical analysis Weibull's probability density function. The average annual wind speed for all sites is approximately 3 m/s.
[10]	Panhandle Texas, is thenorthern most region of the state of Texas consisting of 16 counties.	A 50-kW wind turbine system and a 42 kW PV system	The payback period is expected to be approximately 13 years for wind and 19 years for solar.	Wind energy, where the most important factor was found to be wind resources of a region.	A 50-kW wind turbine system and a 42 kW PV system calculate PV WATTS. Annual power generation will be 228,531 kWh and 81,581 kWh, respectively.
[11]	Pattani, Yala, and Narathiwat provinces, along with four districts (Chana, Nathawi, Sabayoi,	corresponding to a technical power potential in the order of 300 MW.	-	avoiding greenhouse gas emissions of 1.2 million tones CO_2eq/year	High-resolution mapping of wind resources. At an altitude of 80 m, 100 m, 120 m, and 140 m, it was found that the wind potential area at a wind speed of 120 m aglare above 8.0 m/s

Author(s)	Country	Size	Economics of wind energy	Environmental variable determinants	Result
	and Thepa) of Songkhla province in Thailand				could generate 690 GWh/year of electricity.
[43]	Saudi Arabia	-	The average levelized cost of energy of the proposed buildout is 39 USD MWh^{-1}	-	Saudi Arabia is well positioned for wind power development in the Middle East, with 26% of the electricity demand that can be achieved by wind power. The area near Aqaba Bay is the most rewarding. The turbine is moderately characterized (350 W m2) at a relatively low hub height (75 m).
[42]	Vienna, Austria.	-	-	LCA GHG emissions from wind turbines are very specific. Observable variations range from 8-30 $gCO_2eq/kWhe$ for onshore and 9-19 $gCO_2eq/kWhe$ for offshore turbines.	Review and compare the results of the life cycle analysis of greenhouse gas emissions (GHG). Hydropower, nuclear power, and wind technologies can produce electricity with the least impact on global warming throughout the life cycle.
[44]	Beijing, China	for onshore and offshore wind turbines of 2 MW using	-	GHG emission intensity is 0.082 kg CO_2-eq/MJ for onshore wind turbine, and is 0.130 kg CO_2-eq/MJ for	Use the Life Cycle Assessment (LCA) to estimate the lifetime greenhouse gas (GHG) emissions of onshore and offshore wind turbines with a capacity of 2 MW.

Author(s)	Country	Size	Economics of wind energy	Environmental variable determinants	Result
				offshore wind turbine, respectively.	
[45]	Iran	-	The OWA model identifies the optimal site location at various decision risk levels. The economic efficiency of the wind turbine and the potential purchase price of the turbine are also assessed in terms of net present value (NPV).	-	Ardabil and Southern Khorasan provinces are suitable for installing wind turbines. Wind power purchase prices for large wind farms range from 0.047 to 0.182 US dollars and from 0.074 to 0.384 US dollars for small wind power plants.
[46]	Egypt	Economic Analysis of a 200 MW Coastal Wind Farm	The findings prove that the proposed project could produce approximately 988 GWh per year of electrical energy with an economic price of 1.7 US cents per kWh.	preserving the environment of the Mediterranean region and trying to achieve this goal in industrialized countries.	A meteorological station with a 10 meter mast was built near the Mediterranean coast of Egypt. After taking into account air density correction, wind power densities are assessed at 100 m per month and seasonally. Annually, the station is rated at a high potential of 441 kW/m2.
[47]	Abadan site in Iran and Swatar site in Malta.	10 MW wind farm and 25 MW turbine farm	The LCOE is expected to be 4.01 c€/kWh for a wind farm of 10 MW and 5.76 c€/kWh for a wind farm of 25 MW.	-	The decision variables under consideration concern the number of wind turbines to be installed, their individual distances, and the distance

Author(s)	Country	Size	Economics of wind energy	Environmental variable determinants	Result
					to the main grid. The method also includes the wind speed profile and the site boundary environment. Leveled energy cost (LCOE) and net present value (NPV) were assessed as key outcomes and decision metrics to compare scenarios. Within two relevant locations in the Middle East.

Summary of Research Gaps

Previous reviews (as shown in Table 2-8) have identified gaps in the management of wind farm projects at heights of 60–90 meters above the ground using the WAsP tool and the use of economic tools for a detailed joint analysis. Many previous studies have only used some of these tools, leading to unclear results and a lack of answers to questions about the size of the area at the city level and the positive environmental impacts of the project. Given the rapid growth and changes in the wind energy industry, there is a need for ongoing analysis and further research to address these gaps.

CHAPTER 3.
RESEARCH MATERIALS AND METHODS

3.1. Information about the research areas

Located on the eastern coast of the Gulf of Thailand, 150 kilometers southeast of Bangkok, Thailand, Pattaya is growing rapidly with its location and diverse attractions [48]. Popular destinations in Southeast Asia:

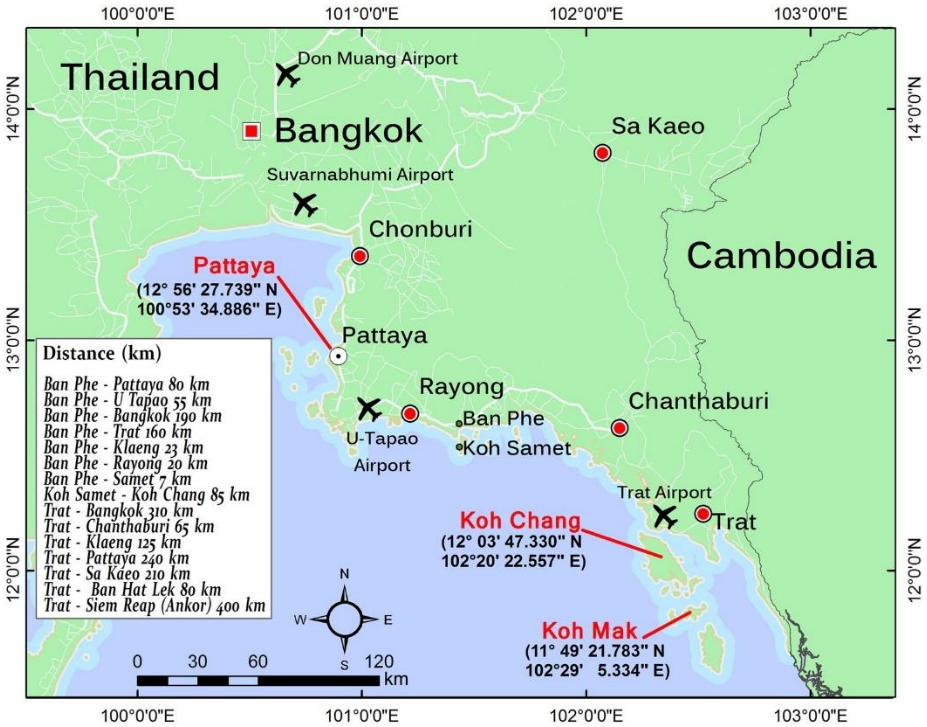


Figure 3-1 *Regional map with study area*

(Source: kohchang.se, 2022)

Chonburi Province [49] is characterized by a combination of five types of terrain, including undulating plains and hills. The coastal plain on the eastern side of the province features rocky cliffs and mangrove forests, contributing to its unique landscape. The province has a 160-kilometer coastline, which is home to many beaches and bays. The weather in Chonburi Province varies throughout the year, divided into three seasons: winter (mid-October to mid-February), summer (mid-February to mid-May), and the rainy season (mid-May to mid-October). The province benefits from sea breezes that help relieve the heat, and strong winds are common in the afternoon and evening.

In western Chonburi, rainfall amounts differ between the coastal areas and the inland regions. Coastal areas in Muang, Sichang, and Sattahip districts experience abundant rainfall, with a total annual rainfall of over 1,200 mm. Bang Lamung, on the other hand, receives less than 1,200 mm of rain annually. Overall, Chonburi receives a total of 1,283.8 mm of rainfall per year. The wettest period in the province occurs in September, with an average rainfall of 268.7 mm and 19 rainy days. The highest rainfall in 24 hours was recorded at Sattahip on November 30, 1970, with 319.6 mm.

Chonburi has been impacted by four tropical cyclones, most of which were strong as depressions and occurred during October-December, although they can also occur during September-January. The depressions are most common from May-October. The climate is influenced by both the northeast and southwest monsoons from May to October [50].

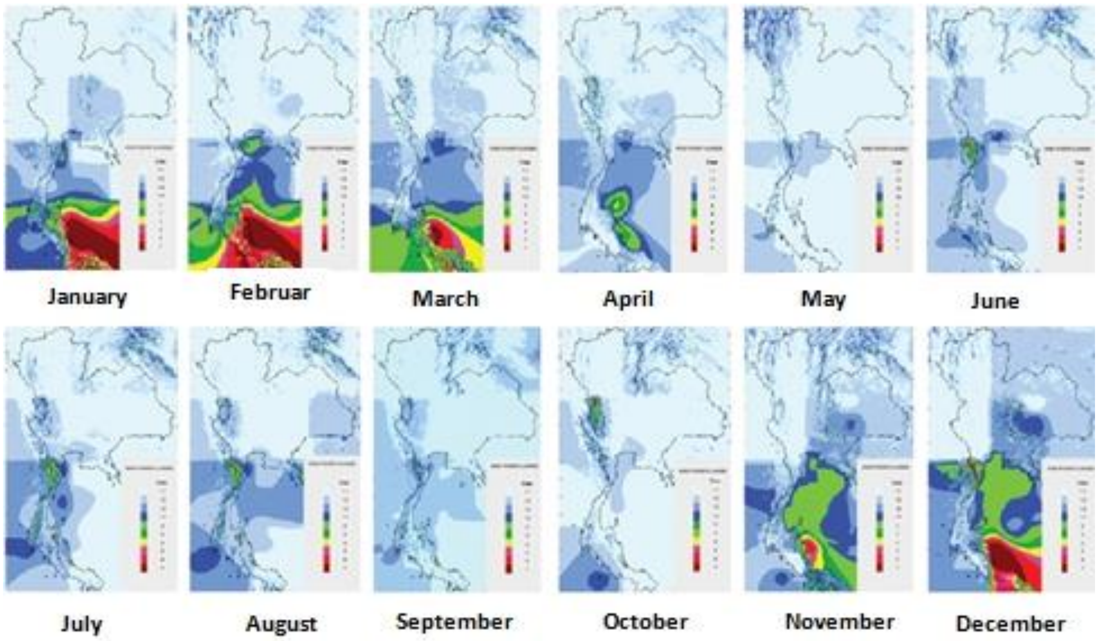
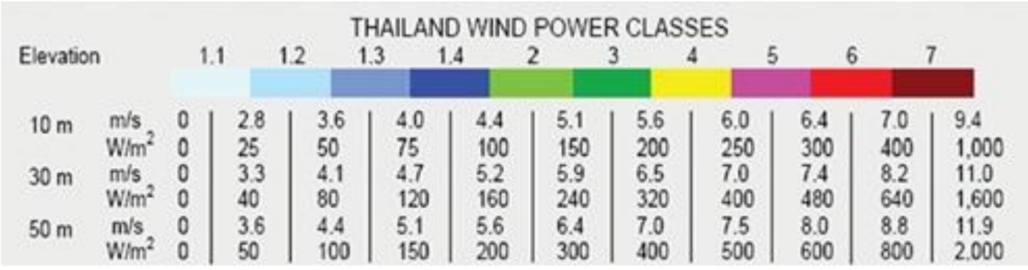


Figure 3-2 *Wind energy potential of each area in Thailand*

(Source: Wind power and its potential in Thailand | Department of Alternative Energy Development and Efficiency (dede.go.th), 2023)


THAILAND WIND POWER CLASSES

Elevation		1.1		1.2		1.3		1.4		2		3		4		5		6		7	
10 m	m/s	0	2.8		3.6		4.0		4.4		5.1		5.6		6.0		6.4		7.0		9.4
	W/m²	0	25		50		75		100		150		200		250		300		400		1,000
30 m	m/s	0	3.3		4.1		4.7		5.2		5.9		6.5		7.0		7.4		8.2		11.0
	W/m²	0	40		80		120		160		240		320		400		480		640		1,600
50 m	m/s	0	3.6		4.4		5.1		5.6		6.4		7.0		7.5		8.0		8.8		11.9
	W/m²	0	50		100		150		200		300		400		500		600		800		2,000

Figure 3-3 *Wind energy potential information of each area in Thailand*
(Source: Wind power and its potential in Thailand | Department of Alternative Energy Development and Efficiency (dede.go.th), 2023)

To showcase the wind energy potential of different areas in Thailand, Figures 3-2 and 3-3 depict the Crimson Area which represents the region with the highest wind energy potential for each month [51], including the wind potential in Chonburi Province [52]. The average wind speed at a height of 10 meters above ground level in Chonburi Province is approximately 4.8 meters per second (m/s) during the monsoon season (May to October) and around 3.3 m/s during the dry season (November to April). Moreover, the highest wind speed is observed in the afternoon and evening, and the potential for developing wind energy is at a medium to a high level.

Table 3-1 *Description of the location of the weather station in the area of Chonburi, Thailand.*

Station name	Latitude (°)	Longitude (°)	Altitude (m a.s.l.)	Measurement period	Recovery
CHON BURI	13.21.20.0	100.58.55.9	8	2019-2021	65.0776%
KO SICHANG	13.09.46.0	100.48.10.1	33	2019-2021	62.6971%
PHATTHAYA	12.55.23.0	100.51.56.2	53	2019-2021	62.0121%

Note: a.s.l.: above sea level.

The study used raw wind data from three meteorological stations obtained from an online database. (https://www.tmd.go.th/en/) of TMD in a separate excel sheet for a period of 3 years and using filters to select only columns and rows of wind speed and wind direction data. by compiling each station's data into a single text file (.txt).

3.2. Materials and procedures

Methods The procedures for this research were performed in the following order.

- Wind speed and direction data obtained from the Meteorological Department for a three-year period (2019–2021) will be processed and analyzed to obtain monthly and yearly data. Wind data were obtained from three meteorological stations in Chonburi province.
- Stations with missing data are not included in the study.
- Each station's wind rose and histogram. Obtained from the Thai Meteorological Department.
- The Wind Atlas Analysis and Application Program (WAsP software) was used to profile the wind and calculate the average speed (m/s) and power density P (W/m2) of the station. The WAsP measures two important Weibull parameters: the k-shape (dimensionless wind data distribution) of the Weibull Distribution and the c-scale parameters (mean wind speed) of the Weibull Distribution.
- Determination of the most suitable wind turbine type for the selected study site, Pattaya, Thailand, to study the potential of wind energy.
- Calculation of expected annual net energy production (AEP) and leveled energy cost (LCOE) for both sites.
- Finally, the site data of the study area, Pattaya, Thailand, were used for economic analysis. to show the worthiness of the project's establishment

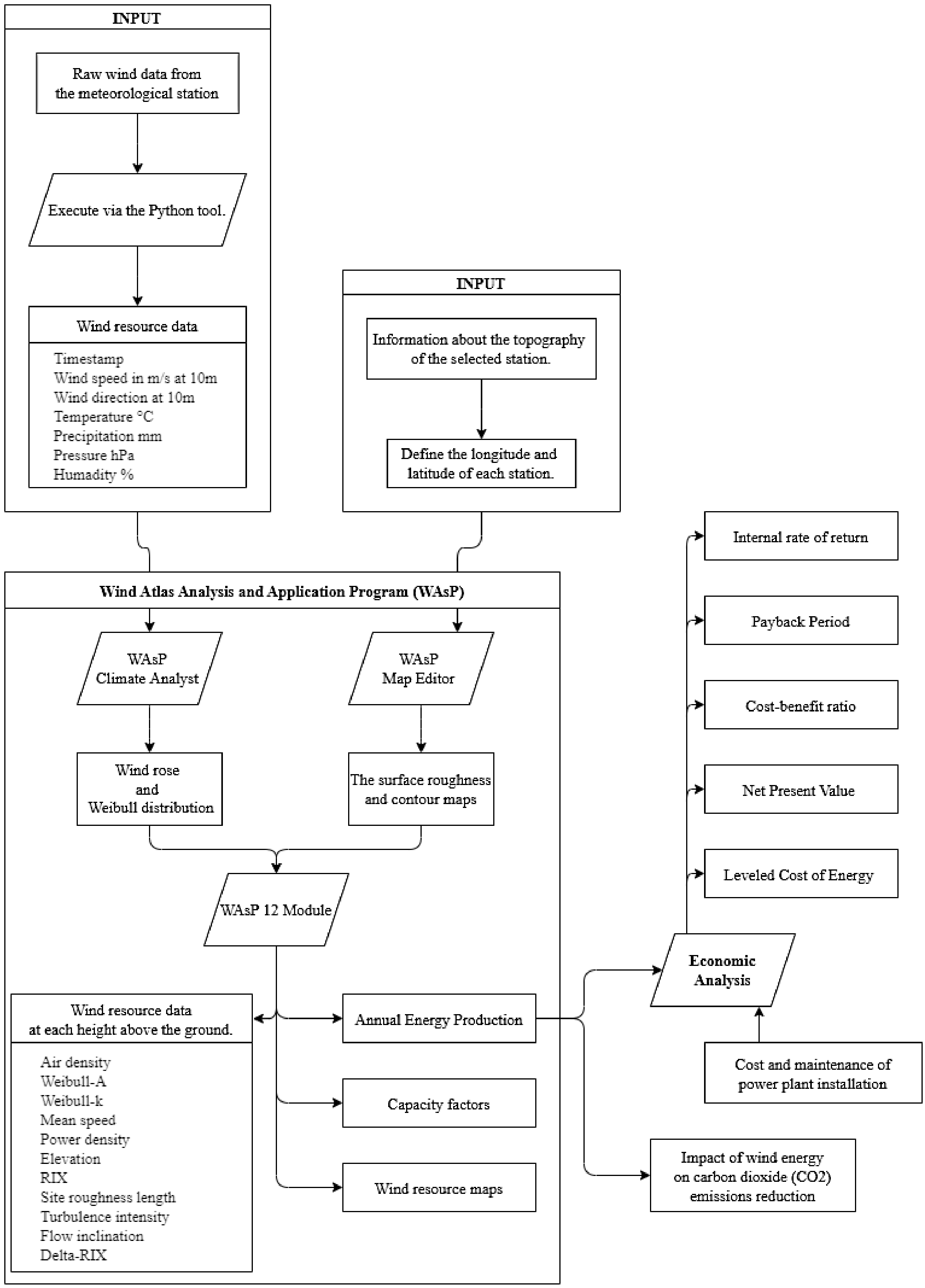


Figure 3-4 Proposed Project Flow Chart.

Description of the Procedure in Figure 3-4: Proposed Project Flow Chart

The proposed project flow chart in Figure 3-4 outlines the procedure in order of input data, consisting of four parts:

1. **Raw wind data from the meteorological station:**
    - Raw wind data was obtained from the Meteorological Department for a period of three years (2019-2021) from three meteorological stations in Chonburi province.
    - The data was imported into Python to manipulate the data. The data of each day were concatenated for the past three years, and the gaps were filtered out. The columns were filtered for Timestamp, Wind speed in m/s at 10 m, Wind direction at 10 m, Temperature in °C, Precipitation in mm, Pressure in hPa, and Humidity in %.
    - Next, the information was saved in .txt format and imported to WAsP Climate Analyst for Wind rose and Weibull distribution graphing.
2. **Information about the topography of the selected station:**
    - The coordinates of TMD's weather stations were converted into the format of site location coordinates given in UTM/USNG (m) for Chon Buri, Thailand, which is in Zone 47.
    - The coordinates were then imported into the WAsP Map Editor to specify the coordinates for the data received from the station and create the surface roughness and contour maps file.
3. **WAsP 12 Module project evaluation:**
    - After performing 1) and 2), the Wind rose and Weibull distribution file and The surface roughness and contour maps file were taken into the project evaluation by the WAsP 12 Module, which resulted in four parts of the data together, including Wind resource data at each height above the ground, Annual Energy Production, Capacity factors, and Wind resource maps.
    - Wind resource data at each height above the ground included air density, Weibull-A, Weibull-k, mean speed, power density, elevation, RIX, site roughness length, turbulence intensity, flow inclination, and Delta-RIX.
4. **Cost and maintenance of power plant installation:**
    - The data was imported to evaluate economic projects by importing Discount rate, Asset's lifetime, Total Installed cost ranges, O&M pricing, Renewable capacity breakdown by type and COD year, and The current exchange rate of 31.4395 THB/USD.

- The levelized energy cost (LCOE), net present value (NPV), cost-benefit ratio or benefit-cost ratio (BCR or B/C ratio), payback period (PBP), Internal Rate of Return (IRR), Financial Internal Rate of Return (FIRR), and Economics Internal Rate of Return (EIRR) were analyzed using the base calculation from the installed capacity of all three wind turbines, which are Bonus 1.3 MW, SWT-1.3-62, and SWT-2.3-82 VS, and the Annual Energy Production (AEP) obtained from the WAsP 12 Module.

5. **Impact of wind energy on carbon dioxide (CO_2) emissions reduction:**
   - The input data included an average CO_2 emissions per unit of 640 g CO_2/kWh, which was calculated together with the base value of Annual Energy Production (AEP) obtained from the WAsP 12 Module in the calculation.

3.3. Steps

Steps for study for technical assessment The Economics of Wind Power in Urban Environments: A Case Study in Pattaya, Thailand, consists of 5 main steps (Figure 3-2). Detailed wind speed, wind direction, and temperature data were collected and screened at a height of 10 meters. Two important Weibull parameters were determined: the k-shape parameter (dimensionless wind data distribution) and the c-scale parameter (mean wind speed) of the Weibull distribution on the wasp. The third step in the wasp wind rose and histogram construction was completed. The output format is data displayed in graphical format. And a map showing the wind characteristics of the data study area. The fourth step is to analyze the location of wind farms in the study area. By specifying the number of wind turbines' exact locations and the values for the study, and finally, the data were statistically calculated. And economics of the study area.

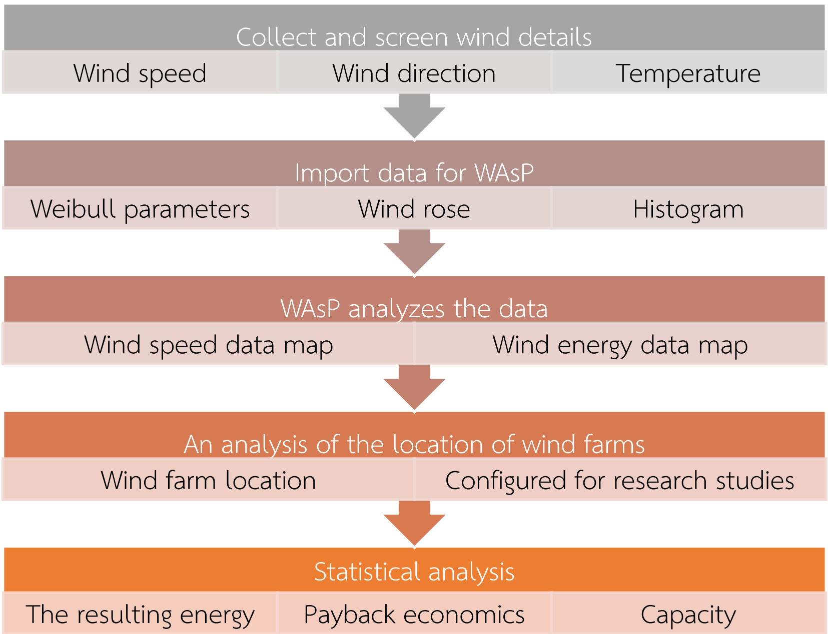


Figure 3-5 *Topographic chart of the research study process*

3.4. Detailed explanation of data selection

Valuation of wind energy production capacity: It has been shown that multi-year datasets significantly improve the strength of results compared to single-year estimates [53]. So, for financiers, the risk of wind power projects for which the AEP is calculated based on short-term measurements is therefore very high. Good-quality longitudinal wind datasets are needed. This, coupled with methods such as measure–correlate–predict (MCP), prevents the lack of quality long-term wind data and low correlation with simultaneously measured data. Most of them need a project to measure wind speed for 3-5 years [54].

3.4.1. Analysis of wind data

Observation input data collects data from weather stations. The case study is a weather station area. Meteorology: Meteorological Department in Chon Buri Province, Thailand, 3 stations: Chonburi Station, Ko Si Chang Station, and Pattaya Station [13]; every 10 minutes, using the combined wind speed, wind direction, and temperature at a height of 10 meters from a 1-year period from day 1. January 2019 to December 31, 2021

3.4.2. Information and verification

Validation to assess the suitability and forecast wind speed frequency of the number of minutes of wind speed data every 10 minutes from 2019 to 2021 is 65.0776%, 62.6971%, and 62.0121%, respectively. missing due to a sensor problem.

Table 3-2 *Mean wind speeds(yearly, by month)*

Mean wind speeds(yearly, by month)														
Station	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Chonburi	2019	0.88	1.73	1.7	1.67	1.51	1.18	0.81	1.67	1.37	---	0.88	0.77	1.29
	2020	0.95	1.51	1.66	1.75	1.77	0.62	0.25	0.35	0.24	0.53	0.07	0.75	0.87
	2021	0.63	0.87	---	---	---	---	---	0.32	0.23	0.84	1.68	1.87	0.92
	Average	0.82	1.37	1.68	1.71	1.64	0.90	0.53	0.78	0.61	0.69	0.88	1.13	1.03
Ko Sichang	2019	0.89	1.16	1.37	1.25	---	---	---	1.62	0.88	---	1.02	1.13	1.16
	2020	0.83	1.09	1.28	1.12	1.15	1.02	0.82	0.9	0.59	0.58	1.09	1.19	0.97
	2021	1.01	0.83	---	---	---	---	---	0.8	0.53	0.37	0	0.01	0.51
	Average	0.91	1.03	1.33	1.19	1.15	1.02	0.82	1.11	0.67	0.48	0.70	0.78	0.88
Phatthaya	2019	0.92	1.13	1.32	1.25	0.91	1.14	1.27	1.56	1.13	---	1.65	1.67	1.27
	2020	1.11	1.42	1.66	1.32	1.32	---	1.02	1.26	1	1.01	2.02	1.81	1.36
	2021	1.48	1.09	---	---	---	---	---	---	---	---	---	---	1.28
	Average	1.17	1.21	1.49	1.29	1.12	1.14	1.15	1.41	1.07	1.01	1.84	1.74	1.30

3.4.3. Preparation of wind data and meteorological towers

As wind speed rises, a set of stations' average gust ratios for average 1- and 10-minute gusts show a statistically significant decline. the number of guests per second. The general pattern of variation in wind speed cannot be accurately predicted [55]. Information from measuring sites about wind can be used to compare neighborhoods [56]. The study's data set included 10-minute averages for temperature, rainfall, wind speed, and direction. relative humidity and atmospheric pressure.

Table 3-3 *The Thai Meteorological Department's list of instrument properties* [57], [58]

Equipment	Sensor Type	Instrument Range	Accuracy	Height (AGL)
Anemometer	Ultrasonic sensor	0–75 m/s	±2%	10 m
Wind vane	Ultrasonic sensor	0–360°	±2%	
Thermometer	Platinum resistance element	−40 °C to 50 °C	±0.3 °C	
Barometer	Digital	800–1100 hPa	±0.2	
Relative humidity	Thin film	0–100% RH	±2% RH	
Rain gauge	Tumbling cup	0–100 mm/h	2%	

(Source: mdpi.com, 2022)

3.4.4. Evaluation of the potential of local wind resources through the Wind Atlas Analysis and Application Program (WAsP).

In Europe, the WAsP linear numerical model has taken over as the accepted practice for wind farms. [59]. using actual data on the production of wind energy. which are gathered through monitoring and data collection technologies. Data on the wind is gathered over time. and as high as the study determined [60]. While also initially "removing" the topographic influence, the forecast was made. Results (topographic images, roughness, and obstacles) were derived from topographic maps of the surrounding area using linear flow models to analyze known wind and weather conditions [61]. For three different turbine sizes, the values of the Weibull distribution parameters—wind gust factor, wind power quantity, and potential power generation—were computed [62]. All sites have unresolved and user-defined WAsPs for wind speeds at hub heights. Net yearly output minimum deviations (-1.2%) were the result of uncorrected projections [59].

3.5. Examining Thailand's wind energy potential in terms of investment decision-making criteria

Building a new power system from renewable energy sources by choice is inevitable. Due to its non-polluting and renewable nature, it has become a major issue for new energy development [63]. There are challenges in many areas: (i) initial costs; (ii) higher operating and investment costs; and (iii) carbon value. The management in each country does not have sufficient and uncertain incentives. This is partly due to political uncertainty. Existing innovation policy tools and carbon policies [64], as a result, require project implementation to assess the potential value. with the criteria used to evaluate the project. Measuring the economic value of different investments

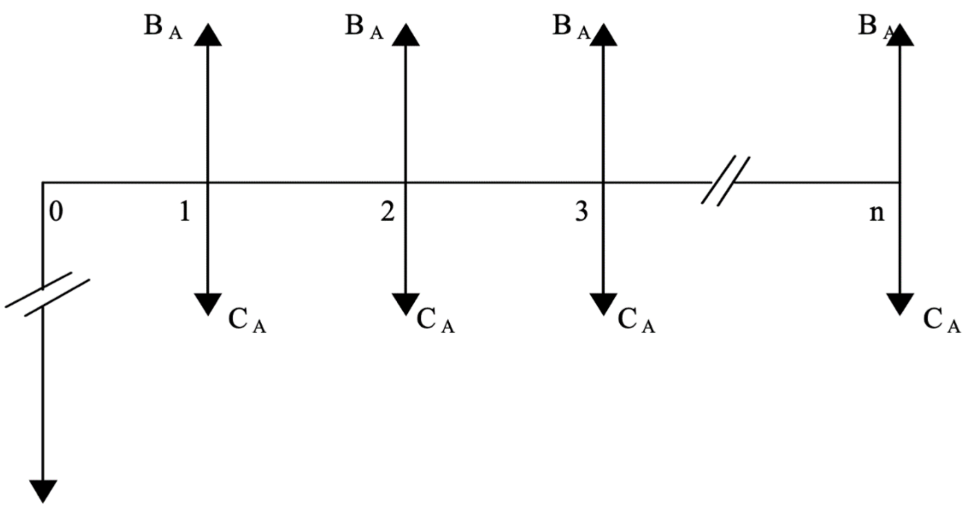


Figure 3-6 *Cash flow diagram of a wind energy project*
(Source: Wind_power_energy.pdf (dolcera.com), page 228)

As can be observed, the cash flow diagram of the wind power project is shown in Figure 3-3. In addition to the initial investment, there are also annual cash inflows and outflows related to the project's life. Therefore, considering all the projects, there are additional economic issues to note [19]:

1. What is the present value of the whole project?

2. Is the project's benefit proportional to the costs involved?
3. How many years does it take to get the investment back from the project?
4. What is the real return on the project? Or what is the highest interest rate that must be provided to fund a project?

The indices used to address these problems include (1) adjusted energy cost (LCOE); (2) net present value (NPV); (3) cost-benefit ratio (BCR or B/C ratio); (4) payback time (PBP) in phases; (5) internal rate of return (IRR), (5.1) Financial Internal Rate of Return (FIRR), and (5.2) Economics Internal Rate of Return (EIRR).

3.5.1. Leveled Energy Cost (LCOE)

The "leveled cost of energy" (LCOE) is proposed by the International Renewable Energy Agency (IRENA) [65] and is used in government policies worldwide towards supporting new renewable energy technologies for more accurate estimates of energy costs. [66] is intended to be an economic assessment of the average total cost of building and operating a power-generating system over the entire lifetime of the system's total energy generated over its lifetime [37], converted into cost units. According to Equation (11-12), the equivalent production is \$/MWh [67].

$$LCOE = \frac{sum\ of\ costs\ over\ lifetime}{sum\ of\ eletrical\ energy\ produced\ over\ lifetime} \quad (11)$$

Or

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t M_t F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \quad (12)$$

Therefore:

I_t = investment expenditure in year t
M_t = operating and maintenance costs in year t
F_t = Fuel expenses in year t
E_t = electricity produced in year t
r = discount rate
n = anticipated system or power plant lifespan

The cost of capital, operations, and maintenance is added to the production cost ratio of wind power plants as stated in Equation (11-12) in the LCOE calculation. efficiency (O&M) and fuel costs. Most importantly, it is devoid of money issues. issues with potential future deterioration or savings on replacement cost This must be taken into account for more complex analyses [68]

3.5.2. Net Present Value or NPV

Net present value (NPV) is the net value of all benefits. The cost (cash inflow) and cost (cash outflow) of a project [19] are widely used in determining whether a plan is useful within the analysis period. It is often used to calculate the difference between the present value of benefits (PVB) and the present value of costs (PVC) [69]. From the information in Figure 3-6, the net present value can be expressed as the equation (13-14).

$$NPV = NPV(B_A)_{1-n} - \{C_I + NPV(C_A)_{1-n}\} \qquad (13)$$

Instead of $NPV(B_A)_{1-n}$ and $NPV(C_A)_{1-n}$ we get

$$NPV = B_A\left[\frac{(1+I)^n-1}{I(1+I)^n}\right] - \left\{C_I\left[1 + m\left(\frac{(1+I)^n-1}{I(1+I)^n}\right)\right]\right\} \qquad (14)$$

Therefore:

B_A	= Annual return on sales of electricity
C_A	= Annual operating and maintenance costs
C_I	= Initial investment cost
I	= Discount interest rate (discount rate)
n	= Duration or economic life of the project
m	= Percentage of annual operating and maintenance costs

Another method for determining the net present value (NPV) can be calculated using the equation (15-16).

$$NPV = \sum_{t=0}^{t}\frac{Year\ n\ Total\ cash\ Flow}{(1+Discount\ Rate)^n} - C_0 \qquad (15)$$

Or

$$NPV = \sum_{t=0}^{t} \frac{C_t}{(1+i)^t} - C_0 \qquad (16)$$

Therefore:

C_t = net cash inflow (net cash flow) during period t

C_0 = total investment cost

i = discount interest rate (discount rate)

t = duration or economic life of the project

The usage discount rate will be the company-specific rate. as it relates to the way the company gets paid. It is the rate of return an investor expects or the cost of borrowing money. If shareholders expect a 12% return, that's the discount rate the company uses to calculate the NPV. If the company pays 4% interest on its debt, it may use that figure as the discount rate. The CFO's office usually sets the rate [70].

However, the NPV equation provides a guideline for analyzing economically viable project investment outcomes [69]:

- NPV > 0 (positive) This project is feasible.
- NPV < 0 (Negative) This project is not feasible.
- NPV = 0 Project Benefit equals Cost

If the NPV value is greater than 0, the project is economically acceptable as it generates profits for investors. while comparing investment options that are not discriminating against each other. Projects with a higher NPV should be chosen [19].

3.5.3. Cost ratio or BCR or B/C ratio

The cost-benefit ratio (BCR) is the ratio of the cumulative present value of all benefits to the cumulative present value of all costs. This includes the initial investment. Even though the investment has passed or is only in the first year of operation, part of reducing errors is comparing two projects with different initial investment levels. Judging merit solely based on NPV can be misleading. Projects with high capital may be more likely to show a positive

NPV than projects requiring lower capital. In such a situation, the cost-benefit ratio (BCR) is a better tool for making economic judgments [19], according to Equation (17-18).

$$BCR = \frac{NPV(B_A)_{1-n}}{C_I + NPV(C_A)_{1-n}} \quad (17)$$

From the relation in equation (17) we get

$$BCR = \frac{B_A\left[\frac{(1+I)^n - 1}{I(1+I)^n}\right]}{C_I\left[1 + m\left(\frac{(1+I)^n - 1}{I(1+I)^n}\right)\right]} \quad (18)$$

Therefore:

B_A = Annual return on sales of electricity
C_A = Annual operating and maintenance costs
C_I = Total investment cost
I = Discount interest rate (discount rate)
n = Duration or economic life of the project
m = Percentage of annual operating and maintenance costs

However, the BCR equation provides a guideline for analyzing economic investment results. That a project is acceptable if the BCR is greater than 1 [19], [69] is:

- Net BCR > 1 indicates that the project is feasible.
- Net BCR < 1 indicates that the project is not feasible or unfavorable.
- Net BCR = 1 indicates that the benefit of the project is proportional to the cost incurred.

Another way to find the BCR or B/C ratio is by using the ratio. Present Value of Return (PVB) to Present Value Cost (PVC) over the project's life, according to Equation (19-20).

$$BCR = \frac{Present\ value\ of\ benefit: PVB}{Present\ value\ of\ cost: PVC} \quad (19)$$

Or

$$BCR = \frac{\sum_{t=0}^{t} \frac{B_t}{(1+r)^t}}{\sum_{t=0}^{t} \frac{C_t}{(1+r)^t}} \qquad (20)$$

Therefore:

B_t = benefit at time t

C_t = cost measure at time t

r = discount interest rate (discount rate)

t = duration or economic life of the project

Project feasibility is determined by assessing the total benefits against the costs incurred in the first year of development using the plan year's discount rate. and the present value of the return (PVB). The present value cost (PVC) can be formulated by

1. **Present value of benefit or PVB** is the sum of the discounted benefit flows [71] whenever the benefits and costs used in the benefit-cost analysis occur in the future. It is important to reduce these future values to determine the present value [72] according to Equation (21).

$$PVB = \sum_{t=0}^{t} \frac{B_t}{(1+r)^t} \qquad (21)$$

Therefore:

B_t = benefit at time t

r = discount interest rate (discount rate)

t = duration or economic life of the project

2. **Present value of cost or PVC** It is the calculation of expenses incurred during the project period. This may vary depending on the type and design chosen. The present value of cost (PVC) is calculated according to Equation (17). The following section describes the cost estimates and the values taken for the entire study. such as the price

structure accessory fee operating and maintenance expenses, etc. [73]

$$PVC = \sum_{t=0}^{t} \frac{C_t}{(1+r)^t} \qquad (22)$$

Therefore:

C_t = cost measure at time t

r = discount interest rate (discount rate)

t = duration or economic life of the project

3.5.4. Payback Period or PBP

The payback period (PBP) is the time it takes to return the investment capital. It is important for investors to know the time elapsed between worth and investment value [73]. In this study, significance was identified as indicated in (23-28). It is an analysis of the year in which the net present value of all costs is equal to the net present value of all benefits. Therefore, PBP specifies the minimum period required to invest in the project until the payback time at PBP.

$$NPV(B_A)_{1-n} = C_I + NPV(C_A)_{1-n} \qquad (23)$$

That is:

$$B_A\left[\frac{(1+I)^n-1}{I(1+I)^n}\right] = C_I\left[1 + m\left(\frac{(1+I)^n-1}{I(1+I)^n}\right)\right] \qquad (24)$$

The payback period is calculated by solving the above equation. For n, the above equation can be rewritten as

$$\frac{C_I}{B_A-mC_I} = \left[\frac{(1+I)^n-1}{I(1+I)^n}\right] \qquad (25)$$

Which can be rearranged and reduced to

$$(1+I)^n = \left(1 - \frac{C_I}{B_A-mC_I}\right)^{-1} \qquad (26)$$

Find the logarithm of both sides.

$$n\ \ln(1+I) = -\ln\left(1-\frac{C_I}{B_A - mC_I}\right) \quad (27)$$

So,

$$n = -\frac{\ln\left(1-\frac{C_I}{B_A - mC_I}\right)}{\ln(1+I)} \quad (28)$$

Therefore:

B_A = Annual return on sales of electricity
C_A = Annual operating and maintenance costs
C_I = total investment cost
I = discount interest rate (discount rate)
n = duration
m = percentage of annual operating and maintenance costs

The cumulative net present value of costs and benefits for a typical wind energy project is shown in Figure 3-7. The cost and benefit curves converge at a point corresponding to the project's payback period as operations pass through. a period of time, and if there is a comparative project, a project with a lower payback period is recommended [19]

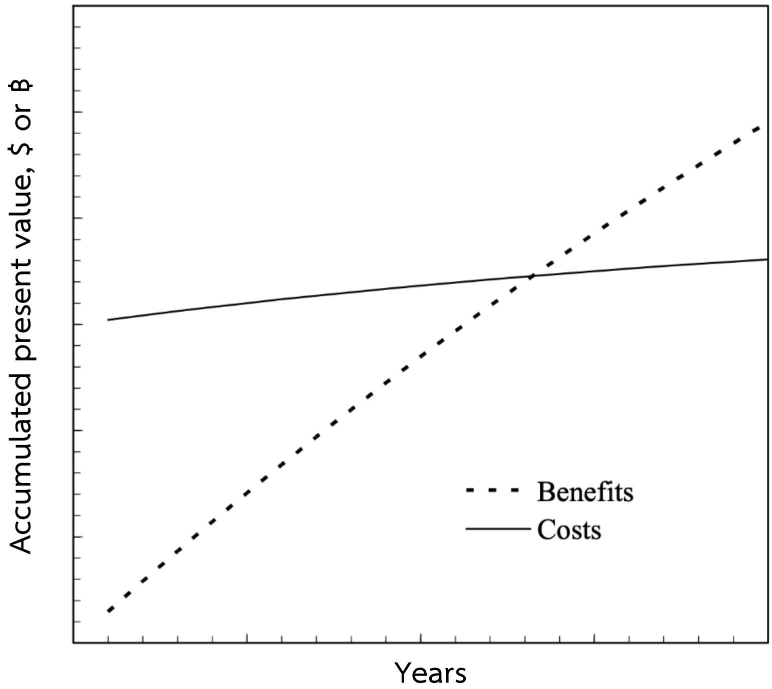


Figure 3-7 *Accumulated present value of costs and benefits*

(Source: Wind_power_energy.pdf (dolcera.com), page 230).

Project investment is economically unacceptable when the PBP is of high value (long payback period) and the PBP does not include the time value of money. There is also no need to make assumptions about discounts or interest rates; otherwise, a shorter PBP indicates a better investment. It is known that the threshold of PBP value for availability is higher than the profitability of a project [74].

Another method for determining PBP can be the ratio of the total cost of project establishment to annual operating cash flow income, which is calculated following Equation (29).

$$PBP = \frac{Initial\ investment\ (USD\ or\ THB)}{Annual\ saving\ (USD\ or\ THB)/years} = \text{years} \quad (29)$$

Therefore:

$Initial\ investment$ = Total capital value in setting up the project.

$Annual\ saving$ = Annual operating cash flow income

Numerically, PBP is the ratio of increased acquisition costs (e.g., from a less efficient design to a more efficient design) to the decrease in annual operating costs. This type of calculation is known as the "simple" payback period because it does not consider changes in operating expenses over time or money value over time [75].

3.5.5. Internal Rate of Return or IRR

One of the key criteria for determining the economic merit of a project is the internal rate of return (IRR), which is the discount rate at which the cumulative present value of all costs is equal to the benefit (30) [19].

$$NPV(B_A)_{1-n} = C_I + NPV(C_A)_{1-n} \tag{30}$$

The IRR is the discount rate where the net present value (NPV) of the project is zero. The IRR is the highest interest rate. (actually) that the investment can be received Since the net present value of the discounted project at IRR is zero, PBP at IRR is the project's lifespan, and IRR is the discount rate.

$$B_A\left[\frac{(1+IRR)^n-1}{IRR(1+IRR)^n}\right] = C_I\left[1 + m\left(\frac{(1+IRR)^n-1}{IRR(1+IRR)^n}\right)\right] \tag{31}$$

Therefore:

B_A = Annual return on sales of electricity

C_A = Annual operating and maintenance costs

C_I = total investment cost

IRR = discount interest rate (discount rate)

n = duration

m = percentage of annual operating and maintenance costs

From the expression (30) above, the IRR can be solved by trial and error, or more precisely, using numerical techniques such as the Newton-Rafson method [76]

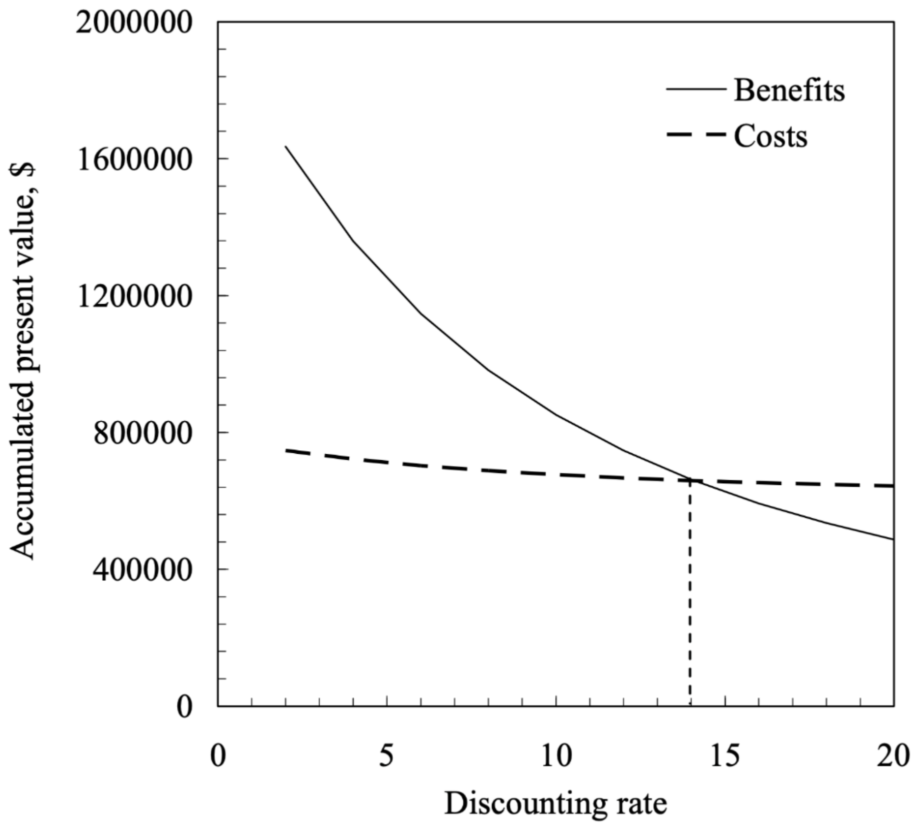


Figure 3-8 *Instance accumulated present value of costs and benefits discounted at different rates*

(Source: [Wind_power_energy.pdf (dolcera.com)](), page 231).

The cumulative net present value of the costs and benefits of a typical project [19] is shown in Figure 3-5. The intersection of the cost-benefit curve corresponds to the project's IRR. The project will accept no more than a 14 percent effective interest rate.

Another method of figuring out IRR is by making NPV = 0. In other words, IRR is the discount rate at which the present value of all benefits (PVB) is equal to the present value of all costs (PVC) [72], which is equal to the sum of the present values of the cash flows is zero. If the project's NPV is zero at the selected discount rate, that rate is IRR. IRR is algebraic parity. Not much and not less. Mathematically [73], it is expressed as: (32-33).

$$PV(Benefits) - PV(Costs) = 0 \tag{32}$$

Or

$$\sum_{t=0}^{n} \frac{C_t}{(1+i)^t} = 0 \qquad (33)$$

Therefore:

C_t = Cash flow in period t

i = discount interest rate (discount rate)

t = duration or economic life of the project

In general, the IRR should be greater than the discount rate for the project to be accepted. which has several limitations, can be explored by looking at an example of cash flow and ensuring that when the limitations are known, they will be used carefully and efficiently. Concerning investment [73]:

- Tell investors about the size or duration of the project.
- It does not differentiate between operating cash flows or income from sales.
- It does not differentiate between early and late cash flows.
- Considered cash flow can be reinvested at IRR.
- Every year, cash flow is considered equally risky.
- It says nothing about leverage risk, and
- It doesn't say anything about leasing assets, operations, or liquidity risks.

The Internal Rate of Return (IRR) [77] is a financial metric used to assess the profitability of a potential investment by calculating the discount rate at which the net present value of the investment equals zero. The Economic Internal Rate of Return (EIRR) is a modified version of IRR that takes into account the opportunity cost of capital, which is the return that could have been earned by investing the same funds in an alternative project with a similar risk profile. EIRR [78] adjusts the discount rate used in IRR to reflect the opportunity cost of capital, providing a more accurate estimate of the economic profitability of the investment.

Financial Internal Rate of Return (FIRR) [79], on the other hand, takes into account the financing structure of the project, assuming that the project is financed with a combination of debt and equity. FIRR calculates the rate of return that the project generates for the investors and creditors, providing a more accurate estimate of the financial profitability of the investment. EIRR and FIRR are modified versions of IRR that provide a more comprehensive assessment of the potential profitability of an investment, taking into account factors such as reinvestment of cash flows and financing structure.

Both EIRR and FIRR are more complex to calculate than IRR, as they require more detailed information about the investment and its financing structure. However, they provide a more comprehensive assessment of the potential profitability of the investment, taking into account both economic and financial factors. It is worth noting that the accuracy of these metrics depends on the accuracy of the input data and assumptions made, and they should be used in conjunction with other financial metrics to make informed investment decisions.

3.5.5.1. Financial Internal Rate of Return (FIRR)

The Financial Internal Rate of Return (FIRR) [79] is an important financial metric used to evaluate the return on investment of an income generation project. It is commonly used to make investment decisions and assess the profitability of projects. The general approach to calculating FIRR has been widely discussed and seems to be well-established, where cash flow analysis uniformly induces FIRR. However, a closer look at FIRR from a different investor's point of view can result in different implications. This paper aims to address this issue by providing a detailed examination of FIRR from different perspectives.

The FIRR is obtained by equating the present value of investment costs as cash outflows to the present value of net incomes as cash inflows. The equation for FIRR is as follows:

$$I_0 + \frac{I_1}{(1-r)^1} + \frac{I_2}{(1-r)^2} + \cdots + \frac{I_m}{(1-r)^m} = \frac{B_1}{(1-r)^1} + \frac{B_2}{(1-r)^2} + \cdots + \frac{B_m}{(1-r)^m} \quad (34)$$

namely,

$$\sum_{n=0}^{m} \frac{I_n}{(1+r)^n} = \sum_{n=1}^{m} \frac{B_n}{(1+r)^n} \quad (35)$$

where:

I_0 = the initial investment cost in the first year

I_1 to I_m = denote additional investment costs for maintenance and rehabilitation during the project's entire life period from year 1 to year m. On the other hand,

B_1 to B_m = are the annual net incomes for the entire project life period, from year 1 to year m.

By solving the equation, we can obtain the value of r, which represents the FIRR.

Or

$$NPV = \sum_{t=0}^{n} \frac{CF_t}{(1+r)^t} = I_0 \qquad (36)$$

where:

NPV = the net present value

CF_t = net cash flow in period t

r = discount rate (FIRR)

t = time period, and

I_0 = the initial investment cost in the first year

However, the implication of FIRR can vary depending on the investor's perspective. Therefore, this paper examines FIRR from various angles to provide a comprehensive understanding of the metric. It aims to contribute to the existing literature on FIRR by providing an in-depth analysis of the metric and its various implications. The findings of this paper can be valuable for investors and project managers in evaluating the financial feasibility of income generation projects.

Interpretation of FIRR:

FIRR is a modified version of IRR that takes into account both the revenue generated by the project and the operating and maintenance costs. This provides a more accurate representation of the project's profitability than

IRR. Additionally, FIRR assumes that all cash flows generated by the project are reinvested at the same rate as FIRR.

Caution for FIRR:

Despite the advantages of FIRR, one limitation is that it may not fully capture the socio-economic impact of a project, which could be important for certain types of investments. Additionally, FIRR assumes that all cash flows generated by the project can be reinvested at the same rate, which may not always be the case. Therefore, it is important to consider these limitations when using FIRR as a measure of investment profitability.

3.5.5.2. Economics Internal Rate of Return (EIRR)

The Economics Internal Rate of Return (EIRR) [80] is an indicator used to measure the economic return on investment of a project. It represents the percentage rate at which the present value of net benefits equals the present value of investment costs. The EIRR does not include taxes, fees, and other transfer payments in the project cost. The relationship between the EIRR and the present value of net benefits can be expressed as follows:

$$NPV = 0 = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+r)^t} \quad (37)$$

where:

NPV = the net present value

B_t = the net benefits in period t

C_t = the costs in period t, and

r = the EIRR.

The EIRR is the discount rate that makes the present value of net benefits equal to zero. If the EIRR is greater than the cost of capital, the project is considered economically viable. In other words, if the EIRR is higher than the opportunity cost of capital or the interest rate on a similar investment, the project is worth investing in.

The EIRR is useful in comparing the economic returns of different projects and choosing the most profitable one. It can also be used to evaluate the economic viability of a project in different economic and financial conditions. However, the EIRR should not be the only criterion for investment decision-making, as other factors such as social, environmental, and political factors should also be taken into consideration.

In conclusion, the EIRR is a useful indicator for evaluating the economic viability of a project. It is based on the present value of net benefits and the investment costs, and it represents the percentage rate at which the present value of net benefits equals the present value of investment costs. The EIRR is a key factor in investment decision-making, but it should be used in conjunction with other factors to make a well-informed decision.

Interpretation of EIRR:

The EIRR is a more comprehensive measure than IRR or FIRR, as it takes into account not only financial factors but also the broader socio-economic impact of a project, including external factors such as environmental and social costs and benefits. This can provide a more holistic view of the project's value beyond just financial profitability.

Caution for EIRR:

One limitation of the EIRR is that it can be challenging to accurately quantify the socio-economic impact of a project, and the analysis may involve subjective judgments. Additionally, the EIRR calculation may require more detailed information and analysis compared to IRR or FIRR, which can increase computational complexity. Finally, the EIRR may not be suitable for all types of investments, but it may be useful for projects with significant economic, social, or environmental impacts.

Comparative Analysis [81], [82] While IRR, FIRR, and EIRR all measure the rate of return of an investment project, they differ in their scope and assumptions. IRR focuses solely on the financial performance of the project and assumes that all cash flows are reinvested at the same rate as the IRR. FIRR extends the IRR by considering the operating and maintenance costs, as well as the revenue generated by the project, but still assumes that all cash flows are reinvested at the same rate as the FIRR. EIRR goes beyond financial performance and considers the broader economic and societal impacts of the project, but it requires a more comprehensive analysis of costs and benefits, including externalities.

In conclusion, IRR, FIRR, and EIRR [83], [84] are all useful measures for evaluating investment projects, but their appropriate application depends on the nature and objectives of the project. IRR is suitable for evaluating projects with conventional cash flows and short life spans. FIRR is appropriate for evaluating income-generating projects with long-term cash flows, while EIRR is suitable for evaluating projects with significant economic, social, or environmental impact. Analysts and investors should carefully consider the scope and assumptions of each measure before using them to make investment decisions.

Table 3-4 Conclusion on the use of economic indexes to use in the assessment of wind energy projects

Index	Interpretation	Precautions
(1) Leveled Energy Cost (LCOE)	Interpretation uses the lowest value as an option for the project being compared. because it represents a lower cost This can compare options when different operations, investments, and working periods are available.	The LCOE should not be calculated for individual power-hungry systems. The savings caused by the energy-saving system will cause a difference in cost that is not realistic. It should be taken into account that the LCOE is a modern technological system that is equal among the comparators.
(2) Net present value (NPV)	If the NPV value is greater than 0, the project is economically acceptable as it generates profits for investors. ● NPV > 0 (positive) This project is feasible. ● NPV < 0 (negative) This project is not feasible. ● NPV = 0 Benefit equals cost.	While comparing investment options that do not discriminate against each other. Projects with a higher NPV should be chosen.
(3) Cost-benefit ratio (BCR or B/C ratio)	A project is acceptable if more than 1 BCR is: ● Net BCR > 1 indicates that this project is feasible. ● Net BCR < 1 indicates that the project is not feasible or unfavorable. ● Net BCR = 1 indicates that the benefit of the project is proportional to the cost incurred.	Annual returns may be affected by political uncertainty. energy policy at that time.

Index	Interpretation	Precautions
(4) Payback period (PBP)	Interpretation uses the lowest value as an option for the project being compared. because it will show a faster return on investment.	If PBP is recommended, use projects with lower payback periods. The time value of money should be taken into account. to change in the future.
(5) internal rate of return (IRR)	● IRR represents the highest interest rate. The investment can be received because the net present value of the discounted project at the IRR is zero. ● PBP where IRR is the life of the project and IRR is the discount rate.	It is not recommended to use IRR after paying returns to investors. because the net cash flow of the project will be negative. This may result in multiple positive IRR values.
(5.1.) Financial Internal Rate of Return (FIRR)	FIRR is an extended version of IRR that considers the operating and maintenance costs as well as the revenue generated by the project, providing a more accurate representation of the project's profitability than IRR. FIRR also assumes that all cash flows generated by the project will be reinvested at the same rate as FIRR.	● FIRR may not fully capture the economic and social impact of the project, which can be crucial for certain types of investments. ● Additionally, FIRR assumes that all cash flows will be reinvested at the same rate, which may not be true in practice.
(5.2.) Economic Internal Rate of Return (EIRR)	EIRR is a comprehensive measure that considers the broad socio-economic impact of a project, as well as external factors such as environmental and social costs and benefits. This can provide a more holistic view of the project's value in addition to financial profitability.	● It can be challenging to accurately quantify the economic and social impact of a project. ● Furthermore, EIRR may be computationally complex compared to IRR and FIRR and may require additional data and analysis.

Index	Interpretation	Precautions
		• Finally, EIRR may not be suitable for all types of investments and may be more applicable for projects with significant economic, social, or environmental impacts.

3.6. Impact of wind energy on carbon dioxide (CO_2) emissions reduction

Reducing carbon dioxide emissions is one of the best practices for achieving constrained-use objectives. on the environment, emphasizing mitigating the global warming reduction process through energy policy [85]. Approximately 40% of global CO_2 emissions are emitted from electricity generation through burning fossil fuels to generate the heat used to power steam turbines. water [86]. There is therefore a global effort to mitigate climate change and its impacts. through multidisciplinary research that raises global debate. with the emergence of new evidence to raise awareness. for national policies and planning on climate change in each country [87] and has equivalent carbon emission details. The process to be assessed and analyzed has an average CO_2 emission per unit of 640 g CO_2/kWh [88]–[91], calculated according to equations 38–39.

$$Emission\ or\ CO_{2,emission} = ActivityData \times EmissionFactor \quad (38)$$

Therefore:

$ActivityData$ = amount of energy i.e. electricity produced in (kWh)

$EmissionFactor$ = Average for a given time period of emissions per unit (g CO_2e/kWh).

or another way is

$$CO_{2,emission} = A \times C \times h \times F \quad (39)$$

Therefore:

A = Installed capacity of wind energy (GW)

C = capacity factor (%)

h = number of hours in a year (h)

F = Emission Factor (g CO_2/kWh)

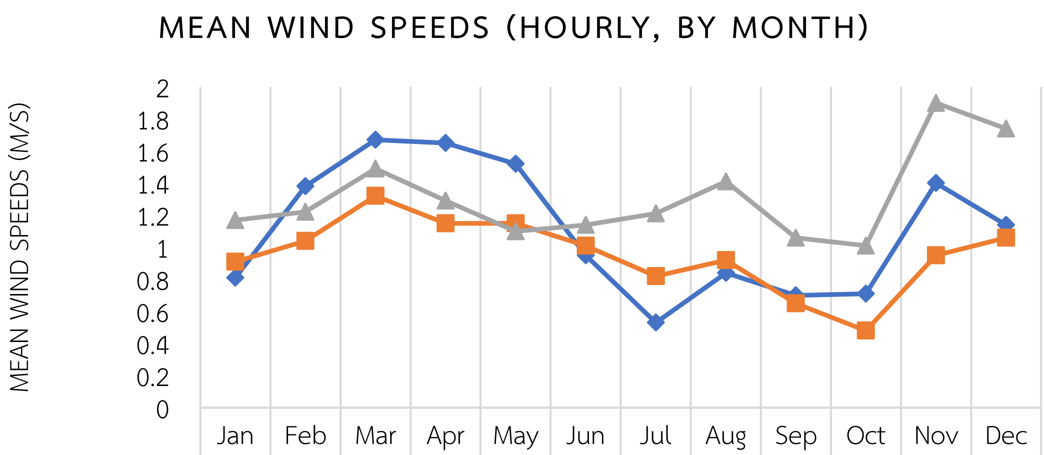
3.7. Operating period

Table 3-5 Operating period

Activities/Steps	Academic year 2021 – 2022 month																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1. Review and research on wind assessments.	←	—	—	—	—	—	—	—	—	—	—	→												
2. Preparation and presentation of thesis work											←	—	—	—	→									
3. data collection												←	—	—	—	→								
4. Learning the WAsP program										←	—	—	—	—	—	→								
5. Analyze the data													←	—	—	—	—	→						
6. Writing a progress report											←	—	—	—	—	—	—	—	—	—	—	—	→	
6.1 First Progress Report													←	—	—	→								
6.2 2nd Progress Report																		←	—	→				
6.3 Final Progress Report																						←	—	→
7. Writing a full thesis															←	—	—	—	—	—	—	—	—	→

CHAPTER 4.
RESULTS AND DISCUSSION

Establishing a wind farm for power generation is an important factor in the potential of wind resources to affect power generation in the system. It can be estimated from the wind speed parameters. and historical data in the evaluated area shows differences that change depending on the time of day, day, season, and time of day [22]. For the selection of wind turbines, the index, namely wind turbine technology and efficiency, is considered. on wind resources in the area [92]. the Chonburi station area Ko Sichang station area Pattaya station area the highest and lowest wind speeds were at a height of 10 m above the ground, respectively (Table 4-1), and Figure 4-1 shows the monthly average wind speed (m/s) at 10 m (AGL) during the period. For 3 years (2019–2021), the average wind speed will decrease from May to October. While it will be higher from November to April as the northeast monsoon blowing from the South China Sea brings strong winds to the Gulf of Thailand and coastal areas of the southeastern region of Thailand [93], the data makes it possible to predict the timing of the shutdown of the system for maintenance. It is also used for forecasting the case where the wind power is lower than the production break-even point.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Chonburi	0.81	1.38	1.67	1.65	1.52	0.95	0.53	0.84	0.7	0.71	1.4	1.14
Ko Sichang	0.91	1.04	1.32	1.15	1.15	1.01	0.82	0.92	0.65	0.48	0.95	1.06
Pattaya	1.17	1.22	1.49	1.29	1.1	1.14	1.21	1.41	1.06	1.01	1.9	1.74

Figure 4-1 *Average wind speed (m/s) monthly at 10 m (AGL)*

Table 4-1 *Mean speed All Sector [°] highest and lowest on 10, 60, 90, and 120 meters above ground level.*

Measurement station	Altitude above the ground	Minimum wind speed	Maximum wind speed	Average Wind Speed 2019-2021
Chonburi Station	10 m.	0.20 m/s	4.72 m/s	1.88 m/s
	60 m.	1.67 m/s	4.41 m/s	2.68 m/s
	90 m.	2.09 m/s	4.55 m/s	2.93 m/s
	120 m.	2.41 m/s	4.65 m/s	3.15 m/s
Ko Sichang Station	10 m.	0.41 m/s	2.32 m/s	1.48 m/s
	60 m.	1.35 m/s	2.77 m/s	1.90 m/s
	90 m.	1.58 m/s	2.77 m/s	2.03 m/s
	120 m.	1.76 m/s	2.78 m/s	2.14 m/s
Pattaya Station	10 m.	0.79 m/s	2.56 m/s	1.42 m/s
	60 m.	1.58 m/s	2.87 m/s	1.88 m/s
	90 m.	1.77 m/s	2.84 m/s	2.02 m/s
	120 m.	1.94 m/s	2.83 m/s	2.15 m/s

Table 4-2 *Mean speed Max Sector [°] highest and lowest on 10, 60, 90, and 120 meters above ground level.*

measurement station	Altitude above the ground	Sector [°]	Maximum wind speed
Chonburi Station	10 m.	60	6.33 m/s
	60 m.	60	7.09 m/s
	90 m.	60	7.29 m/s
	120 m.	60	7.43 m/s
Ko Sichang Station	10 m.	150	3.45 m/s
	60 m.	150	3.90 m/s
	90 m.	150	3.96 m/s
	120 m.	150	4.00 m/s
Pattaya Station	10 m.	90	3.88 m/s
	60 m.	90	4.18 m/s
	90 m.	90	4.07 m/s
	120 m.	90	4.02 m/s

From the information in Figure 4-1 and Table 4-1 – 4-5, it can be used to identify the sector [°] wind speed and elevation range suitable for each area. The average wind speed at Chonburi Station at the altitudes of 10, 60, 90, and 120 meters above the ground was 1.88, 2.68, 2.93, and 3.15 m/s, respectively, with Sector 60 being the appropriate direction. The altitudes at 10, 60, 90, and 120 meters above the ground are 1.48, 1.90, 2.03, and 2.14 m/s, respectively, with Sector 150 being the appropriate direction. and Pattaya Station, average wind speeds at altitudes of 10, 60, 90, and 120 meters above ground were 1.42, 1.88, 2.02, and 2.15 m/s, respectively, with Sector 150 being the appropriate direction. However, the maximum wind speed at Pattaya Station shows that the maximum possible wind turbine tower is 60 m. On the level that is higher, there is a tendency for a decrease in wind speed.

4.1. Local wind resource information

Pattaya area study area Bang Lamung District Chonburi Province from Thailand to study wind distribution and direction According to the proof of the potential of wind resources in the area by receiving data recorded from the weather station meteorology Meteorological Department in the province of Chonburi, Thailand [13] during a period of 3 years from January 1, 2019, to December 31, 2021, every 10 minutes at a height of 10 meters above the ground. and the Weibull distribution was manipulated through the characteristics of different types of distributions to determine the average wind speed. average power density and other parameters To analyze the wind speed and wind direction at the height of 60 and 90 m above the ground while using the wind energy analysis tool. Operated by WAsP software

4.1.1. Chonburi station

Chonburi station area Located in Chonburi Province, Lat-Lon-Height at Latitude N13° 21′ 20.00160″ Longitude E100° 58′ 55.89840″ Anemometer at 13.36°N 100.98°E. Observed wind conditions for the area are shown in Wind rose and the Weibull histogram of wind speed is shown in Figures 4-2, 4-3.

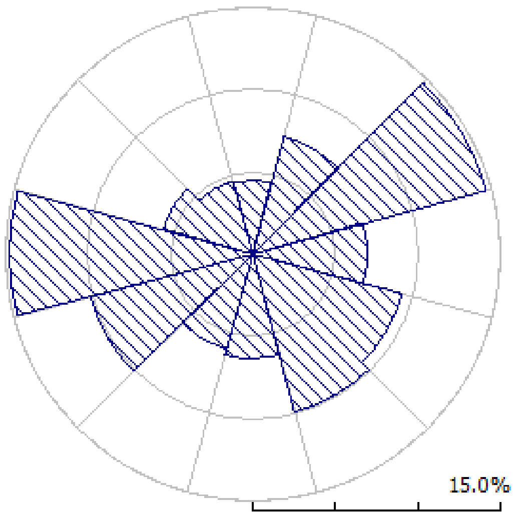


Figure 4-2 *Chonburi Wind rose histogram*

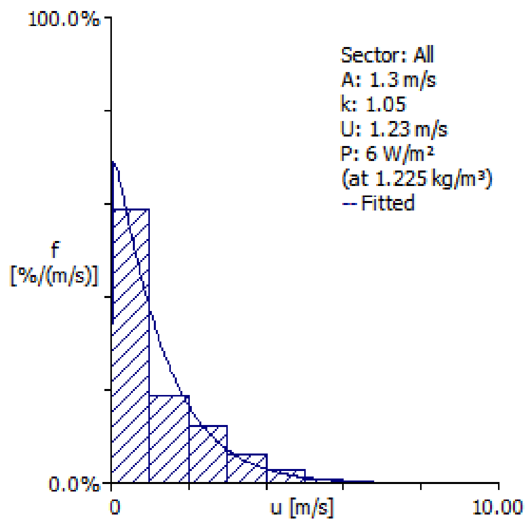


Figure 4-3 *Chonburi Weibull histogram*

The Wind rose and the Weibull histogram shows strong winds blowing from the northeast. and west of Chonburi Station Based on simulations in WAsP and calculations obtained from the Weibull distribution for Chonburi stations. The average velocity is 1.23 m/s with a power density of 6 W/m².

Table 4-3 *Wind resource data in the area of Chonburi station at heights of 10, 60, and 90 meters above ground.*

Sector [°]	Variable	Mean	Min	Max
		Chonburi Resource grid 10 m.		
All	Air density	1.146 kg/m³	1.077 kg/m³	1.154 kg/m³
All	Weibull-A	1.9 m/s	0.2 m/s	4.8 m/s
All	Weibull-k	1.07	0.78	1.17
All	Mean speed	1.88 m/s	0.20 m/s	4.72 m/s
All	Power density	23 W/m²	0 W/m²	291 W/m²
All	Elevation	47.9 m	-37.4 m	774.3 m
All	RIX	2.40%	0.00%	28.50%
All	Site roughness length	0.216 m	0.000 m	1.500 m
All	Turbulence intensity			
All	Flow inclination			
All	Delta-RIX	2.40%	0.00%	28.50%
		Chonburi Resource grid 60 m.		
All	Air density	1.141 kg/m³	1.073 kg/m³	1.149 kg/m³
All	Weibull-A	2.9 m/s	1.8 m/s	4.7 m/s
All	Weibull-k	1.22	0.96	1.37
All	Mean speed	2.68 m/s	1.67 m/s	4.41 m/s
All	Power density	44 W/m²	9 W/m²	184 W/m²
All	Elevation	47.9 m	-37.4 m	774.3 m
All	RIX	2.40%	0.00%	28.50%
All	Site roughness length	0.216 m	0.000 m	1.500 m
All	Turbulence intensity			
All	Flow inclination			
All	Delta-RIX	2.40%	0.00%	28.50%
		Chonburi Resource grid 90 m.		
All	Air density	1.138 kg/m³	1.070 kg/m³	1.146 kg/m³
All	Weibull-A	3.1 m/s	2.2 m/s	4.9 m/s
All	Weibull-k	1.25	1.02	1.4
All	Mean speed	2.93 m/s	2.09 m/s	4.55 m/s
All	Power density	54 W/m²	17 W/m²	188 W/m²
All	Elevation	47.9 m	-37.4 m	774.3 m
All	RIX	2.40%	0.00%	28.50%

Sector [°]	Variable	Mean	Min	Max
All	Site roughness length	0.216 m	0.000 m	1.500 m
All	Turbulence intensity			
All	Flow inclination			
All	Delta-RIX	2.40%	0.00%	28.50%
Chonburi Resource grid 120 m.				
All	Air density	1.135 kg/m³	1.067 kg/m³	1.143 kg/m³
All	Weibull-A	3.4 m/s	2.5 m/s	5.0 m/s
All	Weibull-k	1.25	1.04	1.38
All	Mean speed	3.15 m/s	2.41 m/s	4.65 m/s
All	Power density	67 W/m²	26 W/m²	201 W/m²
All	Elevation	47.9 m	-37.4 m	774.3 m
All	RIX	2.40%	0.00%	28.50%
All	Site roughness length	0.216 m	0.000 m	1.500 m
All	Turbulence intensity			
All	Flow inclination			
All	Delta-RIX	2.40%	0.00%	28.50%

Note: The use of the Tolerance Index (RIX) belongs to the use of WAsP in the help system. An objective measurement of the slope boundary in an area. Additionally, the difference in RIX values between the found values, the station (which uses wind maps) and the wind turbine site can be used to estimate prediction errors. In case of large RIX differences

The values of average speed and power densities are tabulated in Table 4-3. Results indicated that at 10 m above ground, the average velocity is 1.88 m/s with an average power density of 23 W/m², at 60 m above ground. The average velocity is 2.68 m/s with an average power density of 44 W/m², at 90 m above ground. Its average velocity is 2.93 m/s with an average power density of 54 W/m² and at 120 m above ground. The average velocity is 3.15 m/s with an average power density of 67 W/m².

4.1.2. Ko Sichang station

Ko Sichang station area Located in Chonburi Province, Lat-Lon-Height at Latitude N13° 09′ 46.00080″ Longitude E100° 48′ 10.10160″ Anemometer at 13.16°N 100.80°E. Observed wind conditions for the area are shown in Wind rose and the Weibull histogram of wind speed is shown in Figures 4-4, 4-5.

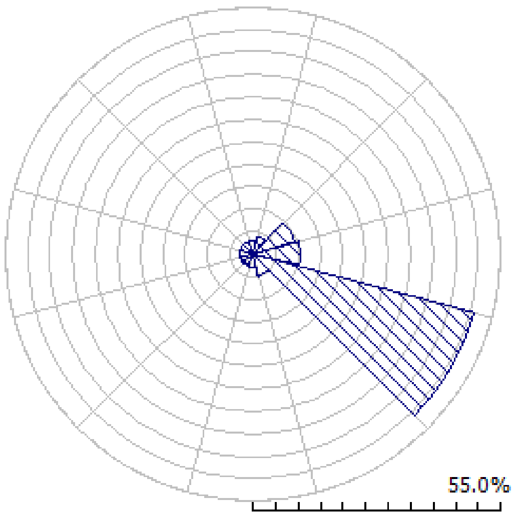


Figure 4-4 *Ko Sichang Wind rose histogram*

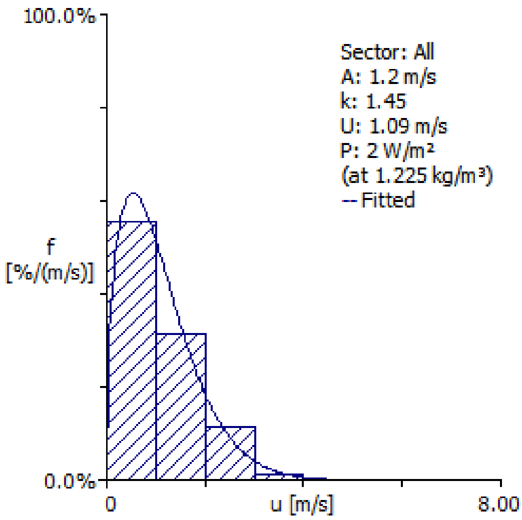


Figure 4-5 *Ko Sichang Weibull histogram*

The wind rose and the Weibull histogram shows strong winds blowing from the southeast of Ko Sichang station. Based on simulations in WAsP and calculations obtained from the Weibull distribution for Ko Sichang station. The average velocity is 1.09 m/s with a power density of 2 W/m².

Table 4-4 *Wind resource data in the area of Ko Sichang station at heights of 10, 60, and 90 meters above ground.*

Sector [°]	Variable	Mean	Min	Max
		Ko Sichang Resource grid 10 m.		
All	Air density	1.152 kg/m³	1.136 kg/m³	1.153 kg/m³
All	Weibull-A	1.6 m/s	0.4 m/s	2.4 m/s
All	Weibull-k	1.37	0.94	1.5
All	Mean speed	1.48 m/s	0.41 m/s	2.32 m/s
All	Power density	6 W/m²	0 W/m²	32 W/m²
All	Elevation	4.1 m	0.0 m	175.5 m
All	RIX	0.40%	0.00%	7.80%
All	Site roughness length	0.066 m	0.000 m	1.500 m
All	Turbulence intensity			
All	Flow inclination			
All	Delta-RIX	-1.20%	-1.60%	6.20%
		Ko Sichang Resource grid 60 m.		
All	Air density	1.148 kg/m³	1.131 kg/m³	1.148 kg/m³
All	Weibull-A	2.1 m/s	1.5 m/s	3.1 m/s
All	Weibull-k	152.00%	139.00%	164.00%
All	Mean speed	1.90 m/s	1.35 m/s	2.77 m/s
All	Power density	11 W/m²	4 W/m²	31 W/m²
All	Elevation	4.1 m	0.0 m	175.5 m
All	RIX	0.40%	0.00%	7.80%
All	Site roughness length	0.066 m	0.000 m	1.500 m
All	Turbulence intensity			
All	Flow inclination			
All	Delta-RIX	-1.20%	-1.60%	6.20%
		Ko Sichang Resource grid 90 m.		
All	Air density	1.145 kg/m³	1.129 kg/m³	1.145 kg/m³
All	Weibull-A	2.3 m/s	1.8 m/s	3.1 m/s
All	Weibull-k	1.54	1.46	1.67
All	Mean speed	2.03 m/s	1.58 m/s	2.77 m/s
All	Power density	13 W/m²	5 W/m²	31 W/m²
All	Elevation	4.1 m	0.0 m	175.5 m
All	RIX	0.40%	0.00%	7.80%

Sector [°]	Variable	Mean	Min	Max
All	Site roughness length	0.066 m	0.000 m	1.500 m
All	Turbulence intensity			
All	Flow inclination			
All	Delta-RIX	-1.20%	-1.60%	6.20%
		Ko Sichang Resource grid 120 m.		
All	Air density	1.142 kg/m³	1.126 kg/m³	1.142 kg/m³
All	Weibull-A	2.4 m/s	2.0 m/s	3.1 m/s
All	Weibull-k	1.54	1.47	1.66
All	Mean speed	2.14 m/s	1.76 m/s	2.78 m/s
All	Power density	15 W/m²	8 W/m²	31 W/m²
All	Elevation	4.1 m	0.0 m	175.5 m
All	RIX	0.40%	0.00%	7.80%
All	Site roughness length	0.066 m	0.000 m	1.500 m
All	Turbulence intensity			
All	Flow inclination			
All	Delta-RIX	-1.20%	-1.60%	6.20%

Note: The use of the Tolerance Index (RIX) belongs to the use of WAsP in the help system. An objective measurement of the slope boundary in an area. Additionally, the difference in RIX values between the found values, the station (which uses wind maps) and the wind turbine site can be used to estimate prediction errors. In case of large RIX differences

The values of average speed and power densities are tabulated in Table 4-4. Results indicated that at 10 m above ground, the average velocity is 1.48 m/s with an average power density of 6 W/m², at 60 m above ground. The average velocity is 1.90 m/s with an average power density of 11 W/m², at 90 m above ground. The average velocity is 2.03 m/s with an average power density of 13 W/m² and at a height of 120 m above the ground. Its average velocity is 2.14 m/s with an average power density of 15 W/m².

4.1.3. Pattaya station

Pattaya station area Located in Chonburi Province, Lat-Lon-Height at Latitude N12° 55′ 23.00160″ Longitude E100° 51′ 56.19960″ Anemometer at 12.92°N 100.87°E. The observed wind conditions for the area are shown in Wind rose and the Weibull histogram of wind speed is shown in Figures 4-6, 4-7.

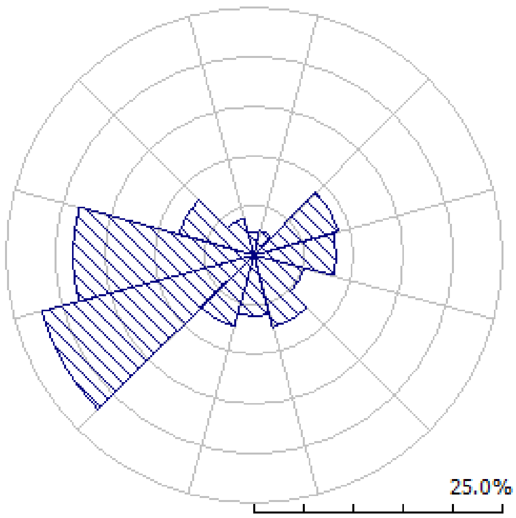


Figure 4-6 *Pattaya Wind rose histogram*

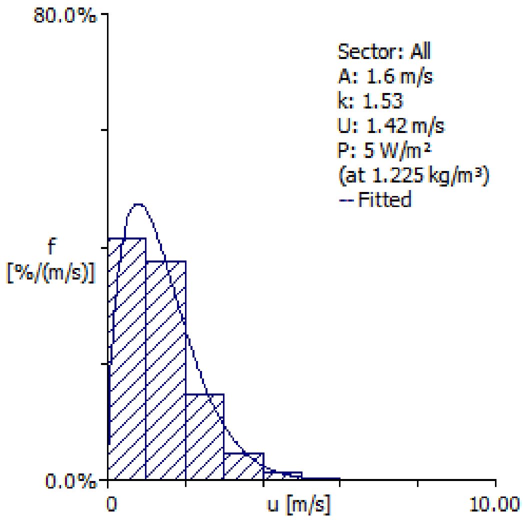


Figure 4-7 *Pattaya Weibull histogram*

Wind rose and Weibull histogram showing strong winds blowing from the west. and southwest of Pattaya Station Based on simulations in WAsP and calculations obtained from the Weibull distribution for Pattaya Station. The average velocity is 1.42 m/s with a power density of 5 W/m².

Table 4-5 Wind resource data in the Pattaya station area at heights of 10, 60, and 90 meters above ground.

Sector [°]	Variable	Mean	Min	Max
		Pattaya Resource grid 10 m.		
All	Air density	1.152 kg/m³	1.137 kg/m³	1.153 kg/m³
All	Weibull-A	1.6 m/s	0.9 m/s	2.8 m/s
All	Weibull-k	1.49	1.19	1.65
All	Mean speed	1.42 m/s	0.79 m/s	2.56 m/s
All	Power density	5 W/m²	1 W/m²	28 W/m²
All	Elevation	12.4 m	0.0 m	174.0 m
All	RIX	0.10%	0.00%	6.50%
All	Site roughness length	0.072 m	0.000 m	1.500 m
All	Turbulence intensity			
All	Flow inclination			
All	Delta-RIX	-0.30%	-0.40%	6.10%
		Pattaya Resource grid 60 m.		
All	Air density	1.147 kg/m³	1.132 kg/m³	1.148 kg/m³
All	Weibull-A	2.1 m/s	1.8 m/s	3.2 m/s
All	Weibull-k	171.00%	154.00%	182.00%
All	Mean speed	1.88 m/s	1.58 m/s	2.87 m/s
All	Power density	9 W/m²	5 W/m²	32 W/m²
All	Elevation	12.4 m	0.0 m	174.0 m
All	RIX	0.10%	0.00%	6.50%
All	Site roughness length	0.072 m	0.000 m	1.500 m
All	Turbulence intensity			
All	Flow inclination			
All	Delta-RIX	-0.30%	-0.40%	6.10%
		Pattaya Resource grid 90 m.		
All	Air density	1.144 kg/m³	1.129 kg/m³	1.146 kg/m³
All	Weibull-A	2.3 m/s	2.0 m/s	3.2 m/s
All	Weibull-k	1.75	1.6	1.85
All	Mean speed	2.02 m/s	1.77 m/s	2.84 m/s
All	Power density	11 W/m²	7 W/m²	30 W/m²
All	Elevation	12.4 m	0.0 m	174.0 m
All	RIX	0.10%	0.00%	6.50%

Sector [°]	Variable	Mean	Min	Max
All	Site roughness length	0.072 m	0.000 m	1.500 m
All	Turbulence intensity			
All	Flow inclination			
All	Delta-RIX	-0.30%	-0.40%	6.10%
		Pattaya Resource grid 120 m.		
All	Air density	1.141 kg/m³	1.126 kg/m³	1.143 kg/m³
All	Weibull-A	2.4 m/s	2.2 m/s	3.2 m/s
All	Weibull-k	1.74	1.61	1.83
All	Mean speed	2.15 m/s	1.94 m/s	2.83 m/s
All	Power density	13 W/m²	9 W/m²	30 W/m²
All	Elevation	12.4 m	0.0 m	174.0 m
All	RIX	0.10%	0.00%	6.50%
All	Site roughness length	0.072 m	0.000 m	1.500 m
All	Turbulence intensity			
All	Flow inclination			
All	Delta-RIX	-0.30%	-0.40%	6.10%

Note: The use of the Tolerance Index (RIX) belongs to the use of WAsP in the help system. An objective measurement of the slope boundary in an area. Additionally, the difference in RIX values between the found values, the station (which uses wind maps) and the wind turbine site can be used to estimate prediction errors. In case of large RIX differences

The values of average speed and power densities are tabulated in Table 4-5. Results indicated that at 10 m above ground, the average velocity is 1.42 m/s with an average power density of 5 W/m², at 60 m above ground. The average velocity is 1.88 m/s with an average power density of 9 W/m², at 90 m above the ground. The mean velocity is 2.02 m/s with an average power density of 11 W/m² and at a height of 120 m above the ground. Its average velocity is 2.15 m/s with an average power density of 13 W/m².

Table 4-6 *Classes of wind power density at 10 m and 50 m^(a)* [94]–[96]

Resource Potential	Wind Power Class	10 m (33 ft)		50 m (164 ft)	
		Wind Power Density (W/m^2)	Wind Speed$^{(b)}$ (W/m^2)	Wind Power Density (W/m^2)	Wind Speed$^{(b)}$ (W/m^2)
Poor	1	≤100	≤4.4 (9.8)	≤200	≤5.6 (12.5)
Marginal	2	≤150	≤5.1 (11.5)	≤300	≤6.4 (14.3)
Fair	3	≤200	≤5.6 (12.5)	≤400	≤7.0 (15.7)
Good	4	≤250	≤6.0 (13.4)	≤500	≤7.5 (16.8)
Excellent	5	≤300	≤6.4 (14.3)	≤600	≤8.0 (17.9)
Outstanding	6	≤400	≤7.0 (15.7)	≤800	≤8.8 (19.7)
Superb	7	≤1,000	≤9.4 (21.1)	≤2,000	≤11.9 (26.6)

a. Vertical extrapolation of wind speed based on the 1/7 power law.

b. Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, speed increases 3%/ 1000 m (5%/5000 ft) elevation.

Wind resource data in the area of Chonburi Station found that the mean value of mean speed was 1.88 m/s and power density was 23 W/m^2. Wind resource data in the area of Ko Sichang Station found that the mean value of mean speed was 1.88 m/s and power density was 23 W/m^2. The mean value of mean speed was 1.48 m/s, and the power density was 6 W/m^2, while wind resource data in the Pattaya Station area at a height of 10 meters above the ground revealed a mean value of the mean speed of 1.42 m/s and a power density of 5 W/m^2, both of which are in wind power class 1 and have low resource potential.

4.2. Assessment of wind area and turbine location

4.2.1. Data and size of wind turbines

Table 4-7 *Wind Turbine Model Information (Appendix C)*

No	Turbines	Rotor diameter (m)	Rated power (estimated) (MW)	Default height (m)	Low speed limit cut (m/s)	High speed limit cut (m/s)
1	Bonus 1 MW	54.20	1.0000	50.00	4.00	25.00

No	Turbines	Rotor diameter (m)	Rated power (estimated) (MW)	Default height (m)	Low speed limit cut (m/s)	High speed limit cut (m/s)
2	Bonus 1.3 MW	62.00	1.3000	60.00	3.00	25.00
3	Bonus 2 MW	76.00	2.0000	60.00	4.00	25.00
4	Bonus 300 kW Mk III	33.40	Undefined	30.00	3.00	25.00
5	Bonus 450 kW MkIII	37.00	Undefined	35.00	4.00	25.00
6	NEG-Micon 750/44 (750 kW)	44.00	0.7600	50.00	4.00	25.00
7	NEG-Micon 750/48 (750 kW)	48.20	0.7600	50.00	4.00	25.00
8	PowerWind 56 59.0 m	56.00	0.9000	59.00	3.00	25.00
9	PowerWind 56 71.0 m	56.00	0.9000	71.00	3.00	25.00
10	PowerWind 90	90.00	2.5000	98.00	3.00	25.00
11	SWT-1.3-62	62.00	1.3000	60.00	3.00	25.00
12	SWT-2.3-82 VS	82.40	2.3000	80.00	3.00	25.00
13	SWT-2.3-93	93.00	2.3000	80.00	3.00	25.00
14	SWT-3.6-107	107.00	3.6000	80.00	3.00	25.00
15	V100-1.8 MW 50 Hz VCS	100.00	1.8000	80.00	3.00	20.00
16	V100-1.8 MW 60 Hz VCS	100.00	1.8250	80.00	3.00	20.00
17	V100-1.8 MW GridStreamer	100.00	1.8000	80.00	3.00	20.00
18	V100-2.0 MW GridStreamer	100.00	2.0000	80.00	3.00	20.00
19	V100-2.6 MW VCS 50 Hz	100.00	2.6000	80.00	3.50	23.00
20	V112-3.0 MW	112.00	3.1000	84.00	3.00	25.00
21	V112-3.0 MW 50 Hz Offshore	112.00	3.0000	84.00	3.00	25.00
22	V80-2.0 MW 50 Hz VCS	80.00	2.0000	67.00	4.00	25.00
23	V80-2.0 MW 60 Hz VCS	80.00	2.0000	67.00	4.00	25.00
24	V90-1.8 MW 50 Hz VCS	90.00	1.8000	80.00	4.00	25.00

No	Turbines	Rotor diameter (m)	Rated power (estimated) (MW)	Default height (m)	Low speed limit cut (m/s)	High speed limit cut (m/s)
25	V90-1.8 MW GridStreamer	90.00	1.8000	80.00	4.00	25.00
26	V90-1.8 MW VCUS	90.00	1.8250	80.00	4.00	25.00
27	V90-2.0 MW 50 Hz VCS	90.00	2.0000	80.00	4.00	25.00
28	V90-2.0 MW GridStreamer	90.00	2.0000	80.00	4.00	25.00
29	V90-3.0 MW VCRS 60 Hz	90.00	3.0000	80.00	4.00	25.00
30	V90-3.0 MW VCS 50 Hz	90.00	3.0000	80.00	4.00	25.00
31	Vestas V52-850 kW	52.00	0.8600	55.00	4.00	25.00
32	Vestas V60-850 kW	60.00	0.8600	60.00	3.00	20.00
33	Vestas V80-2.0 MW GridStreamer™	80.00	2.0000	80.00	4.00	25.00
34	Vestas V82 (1650 kW)	82.00	1.6500	70.00	3.00	20.00

From the information in Tables 4-3 – 4-6 and the spatial information in 4.1, in order to analyze the opportunity and feasibility of the area, wind turbines with high and low-speed limit cuts are used to produce the widest range of power. Wind fluctuations are high, rotor diameter ranges between 60 and 90 meters, and the default height ranges between 60 and 90 meters. It was found that there are 3 types of wind turbines: 1. Bonus 1.3 MW with rated power (estimated) 1.3000 MW, 2. SWT-1.3-62 with rated power (estimated) 1.3000 MW, and 3. SWT-2.3-82 VS with rated power (estimated) 2.3000 MW.

4.2.2. Average annual net energy production by area

4.2.2.1. Chonburi station

Table 4-8 *AEP (GWh) on the Chonburi station area of the Bonus 1.3 MW wind turbine*

Maximum Value	1.386 GWh at (719780, 1470710)
Minimum Value	0.054 GWh at (718280, 1471010)
Mean Value	0.385 GWh

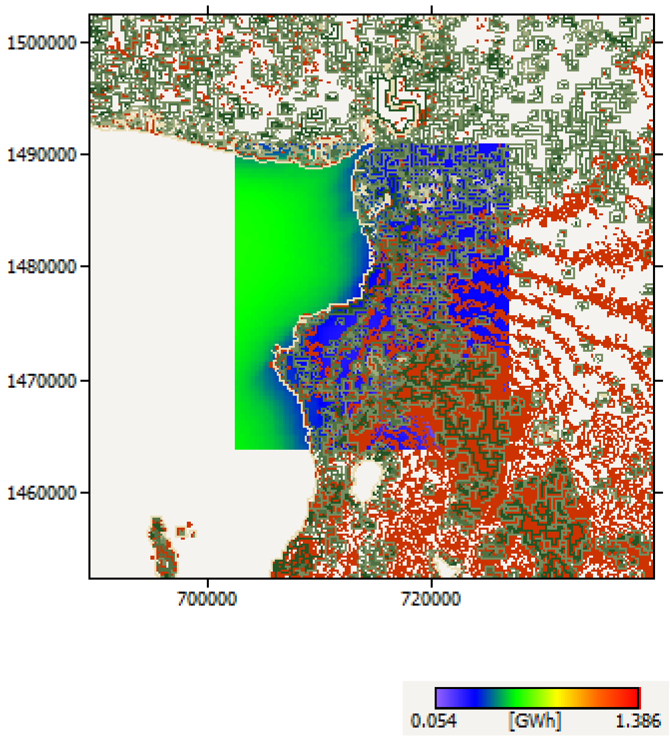


Figure 4-8 *AEP (GWh) Wind turbine Bonus 1.3 MW model of Chonburi Station*

The wind turbine model Bonus 1.3 MW has an estimated rated power of 1.3000 MW, a default height of 60 m, an average annual energy production (AEP) of 0.385 GWh in the Chonburi station area, and a maximum production capacity of 1.386 GWh.

Table 4-9 AEP (GWh) on the Chonburi station area of the SWT-1.3-62 wind turbine.

Maximum Value	1.451 GWh at (719780, 1470710)
Minimum Value	0.062 GWh at (718280, 1471010)
Mean Value	0.418 GWh

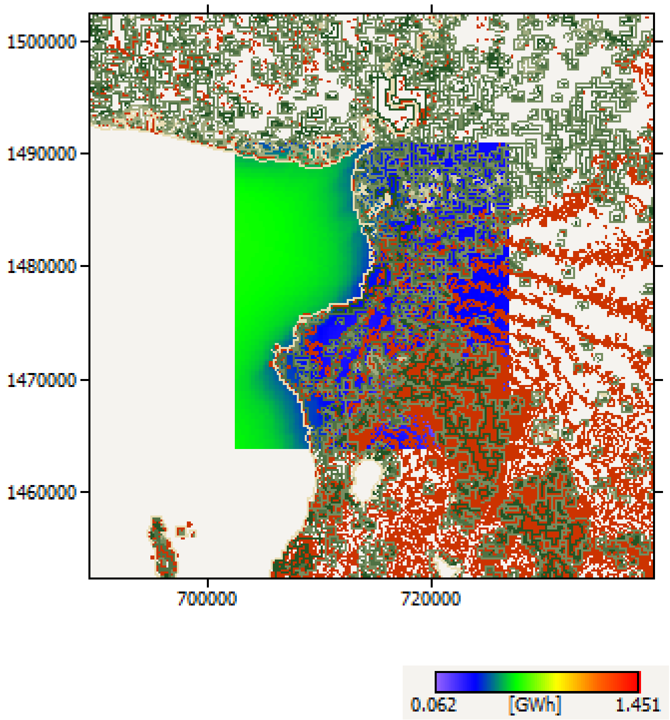


Figure 4-9 *AEP (GWh) Wind turbine SWT-1.3-62 model of Chonburi Station*

The wind turbine model SWT-1.3-62 has an estimated rated power of 1.3000 MW, a default height of 60 m, an average annual energy production (AEP) of 0.418 GWh in the Chonburi station area, and a maximum production capacity of 1.451 GWh.

__Table 4-10__ AEP (GWh) on the Chonburi station area of the SWT-2.3-82 VS wind turbine

Maximum Value	2.544 GWh at (719780, 1470710)
Minimum Value	0.175 GWh at (720680, 1465310)
Mean Value	0.792 GWh

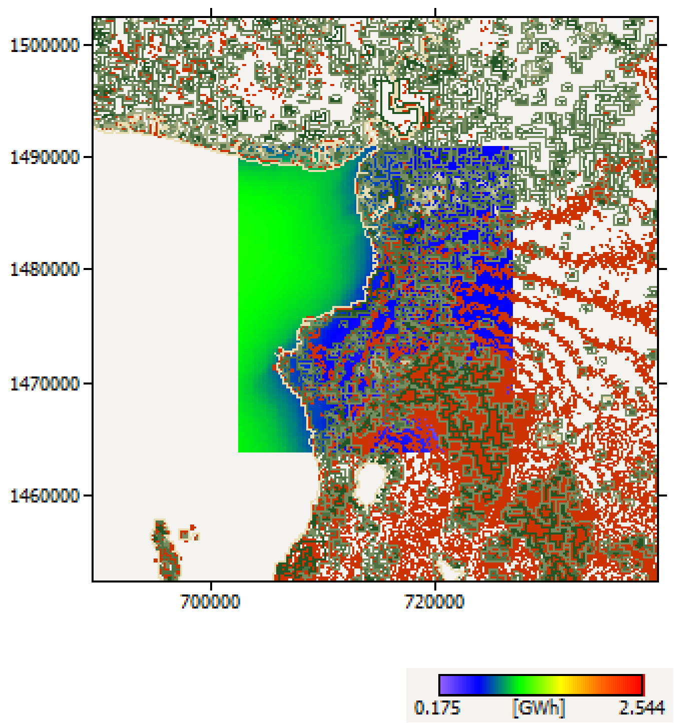


__Figure 4-10__ AEP (GWh) Wind turbine SWT-2.3-82 VS model of Chonburi Station

The wind turbine model SWT-2.3-82 VS has an estimated rated power of 2.3000 MW, a default height of 80 m, an average annual energy production (AEP) of 0.792 GWh in the Chonburi station area, and a maximum production capacity of 2.544 GWh.

4.2.2.2. Ko Sichang station

Table 4-11 *AEP (GWh) on the Ko Sichang station area of the Bonus 1.3 MW wind turbine.*

Maximum Value	2.766 GWh at (695610, 1456730)
Minimum Value	0.341 GWh at (708210, 1452230)
Mean Value	1.144 GWh

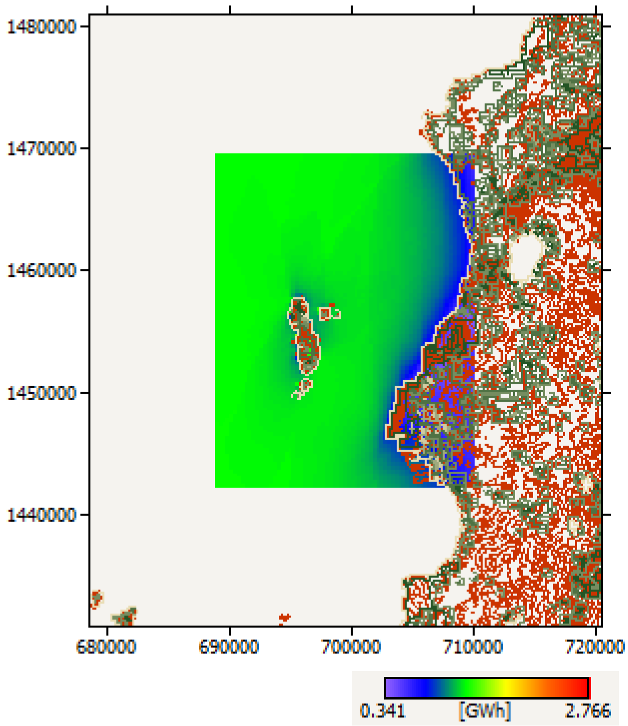


Figure 4-11 *AEP (GWh) Wind turbine SWT-1.3-62 model of Ko Sichang Station*

The wind turbine model Bonus 1.3 MW has an estimated rated power of 1.3000 MW, a default height of 60 m, an average annual energy production (AEP) of 1.144 GWh in the Ko Sichang station area, and a maximum production capacity of 2.766 GWh.

Table 4-12 *AEP (GWh) on the Ko Si Chang station area of the wind turbine model SWT-1.3-62*

Maximum Value	2.931 GWh at (695610, 1456730)
Minimum Value	0.397 GWh at (708210, 1452230)
Mean Value	1.270 GWh

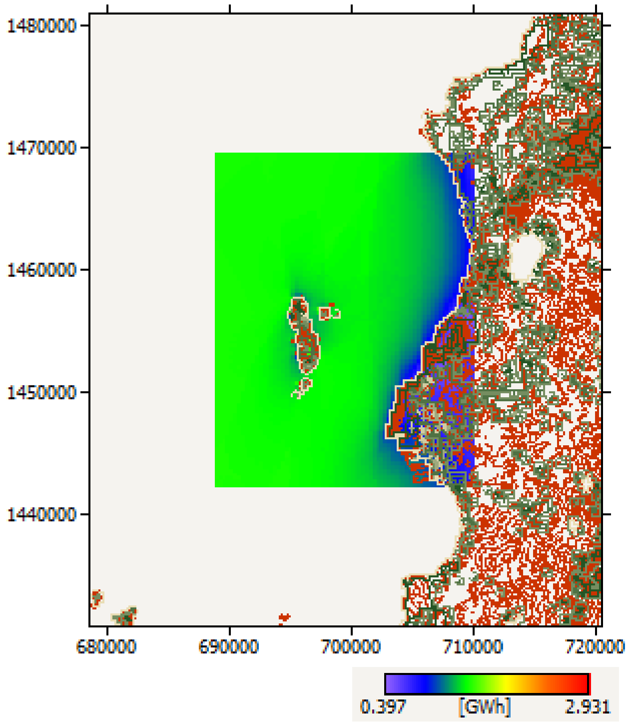


Figure 4-12 *AEP (GWh) Wind turbine SWT-1.3-62 model of Ko Sichang Station*

The wind turbine model SWT-1.3-62 has an estimated rated power of 1.3000 MW, a default height of 60 m, an average annual energy production (AEP) of 1.270 GWh in the Ko Sichang station area, and a maximum production capacity of 2.931 GWh.

Table 4-13 *AEP (GWh) on the Ko Si Chang station area of the SWT-2.3-82 VS wind turbine*

Maximum Value	4.894 GWh at (695610, 1456730)
Minimum Value	0.865 GWh at (708210, 1452230)
Mean Value	2.297 GWh

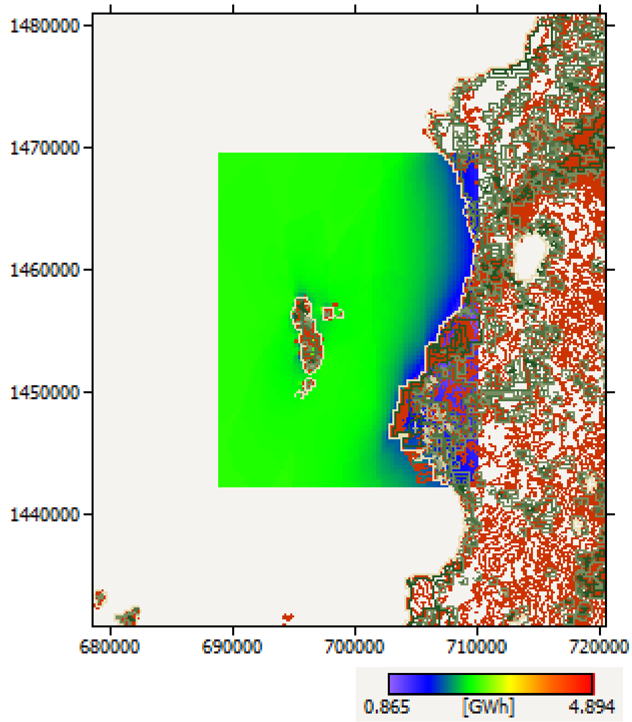


Figure 4-13 *AEP (GWh) Wind turbine SWT-2.3-82 VS model of Ko Sichang Station*

The wind turbine model SWT-2.3-82 VS has an estimated rated power of 2.3000 MW, a default height of 80 m, an average annual energy production (AEP) of 4.894 GWh in the Ko Sichang station area, and a maximum production capacity of 2.297 GWh.

4.2.2.3. Pattaya station

Table 4-14 *AEP (GWh) on the Pattaya station area of the Bonus 1.3 MW wind turbine*

Maximum Value	255.022 MWh at (692810, 1428760)
Minimum Value	13.059 MWh at (710510, 1426060)
Mean Value	39.368 MWh

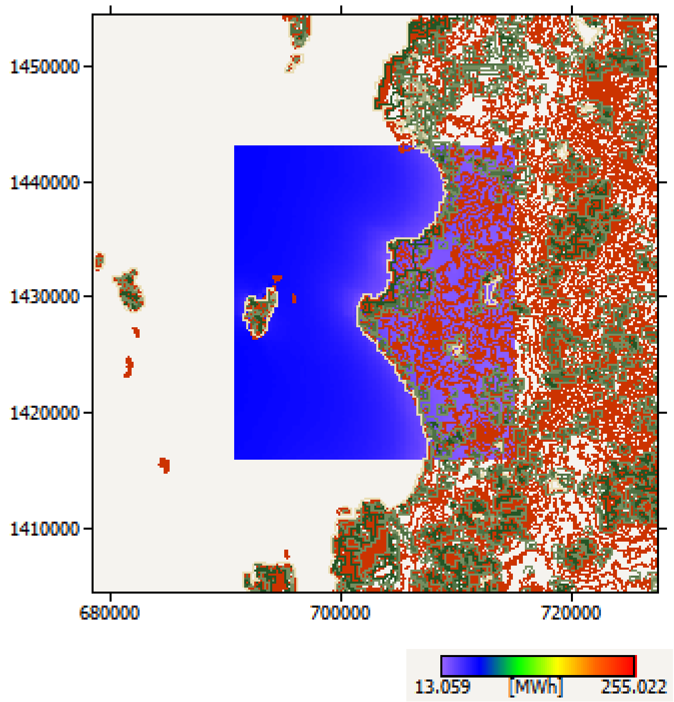


Figure 4-14 *AEP (GWh) Wind turbine Bonus 1.3 MW model of Pattaya Station*

The wind turbine model Bonus 1.3 MW has an estimated rated power of 1.3000 MW, a default height of 60 m, an average annual energy production (AEP) of 39.368 MWh in the Pattaya station area, and a maximum production capacity of 255.022 MWh.

__Table 4-15__ AEP (GWh) on the Pattaya station area of the SWT-1.3-62 wind turbine.

Maximum Value	293.533 MWh at (692810, 1428760)
Minimum Value	15.952 MWh at (710510, 1426060)
Mean Value	47.314 MWh

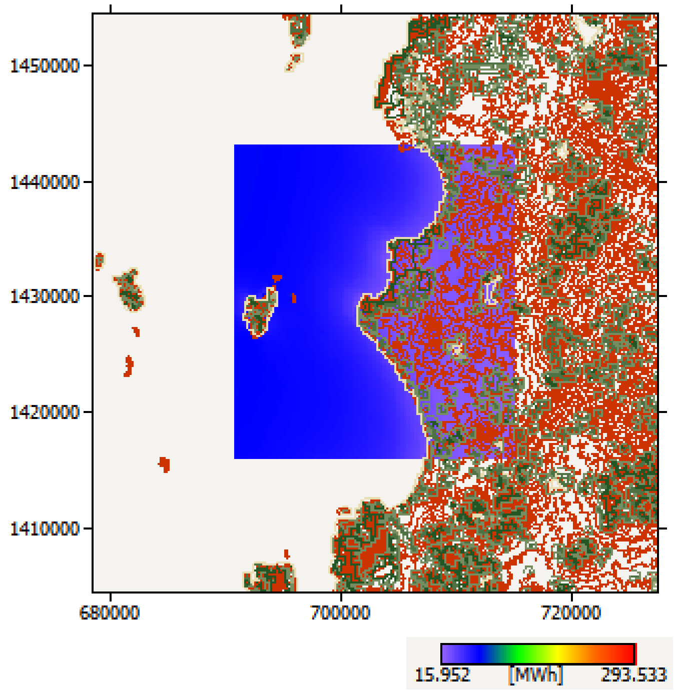


__Figure 4-15__ AEP (GWh) Wind turbine SWT-1.3-62 model of Pattaya Station

The wind turbine model SWT-1.3-62 has an estimated rated power of 1.3000 MW, a default height of 60 m, an average annual energy production (AEP) of 47.314 MWh in the Pattaya station area, and a maximum production capacity of 293.533 MWh.

Table 4-16 AEP (GWh) on the Pattaya station area of the SWT-2.3-82 VS wind turbine

Maximum Value	437.988 MWh at (692810, 1428760)
Minimum Value	33.584 MWh at (710510, 1426060)
Mean Value	85.661 MWh

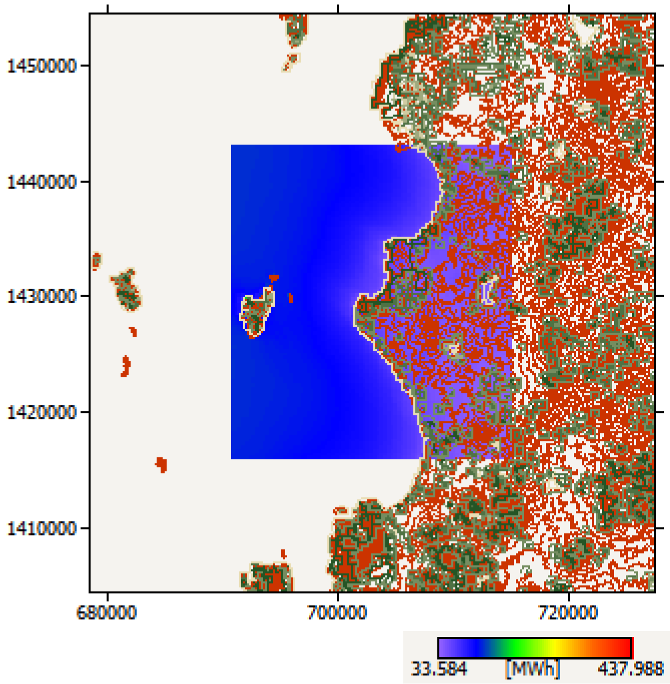


Figure 4-16 *AEP (GWh) Wind turbine SWT-2.3-82 VS model of Pattaya Station*

The wind turbine model SWT-2.3-82 VS has an estimated rated power of 2.3000 MW, a default height of 80 m, an average annual energy production (AEP) of 85.661 MWh in the Pattaya station area, and a maximum production capacity of 437.988 MWh.

4.2.3. Wind farm simulation data for electricity generation by area

4.2.3.1. Chonburi station

The turbine clusters, Ban Bueng and Nong Khang Khok, utilize Bonus 1.3 MW wind turbines, SWT-1.3-62 and SWT-2.3-82 VS respectively. These clusters are located in the Chonburi station area within the Chonburi province, as depicted in Figures 4-17 to 4-22, with the site location coordinates given in UTM/USNG (m) and Zone 47, as detailed in Table 4-17.

Table 4-17 *Chonburi Turbine Cluster Site Location*

Turbine cluster	**Site Location (UTM/USNG (m), Zone 47)**	
	Ban Bueng	**Nong Khang Khok**
Turbine site 001	(722785.6,1469108.0)	(719710.8,1471026.0)
Turbine site 002	(722676.1,1468944.0)	(719833.0, 1470881.0)
Turbine site 003	(722816.9,1468772.0)	(719688.6,1470804.0)
Turbine site 004	(722676.1,1468569.0)	(719833.0, 1470648.0)
Turbine site 005	(722777.8,1468444.0)	(719699.8,1470515.0)
Turbine site 006	(722691.8,1468303.0)	(719810.8,1470415.0)

Wind farm: 'Turbine cluster Ban Bueng Bonus 1.3 MW'

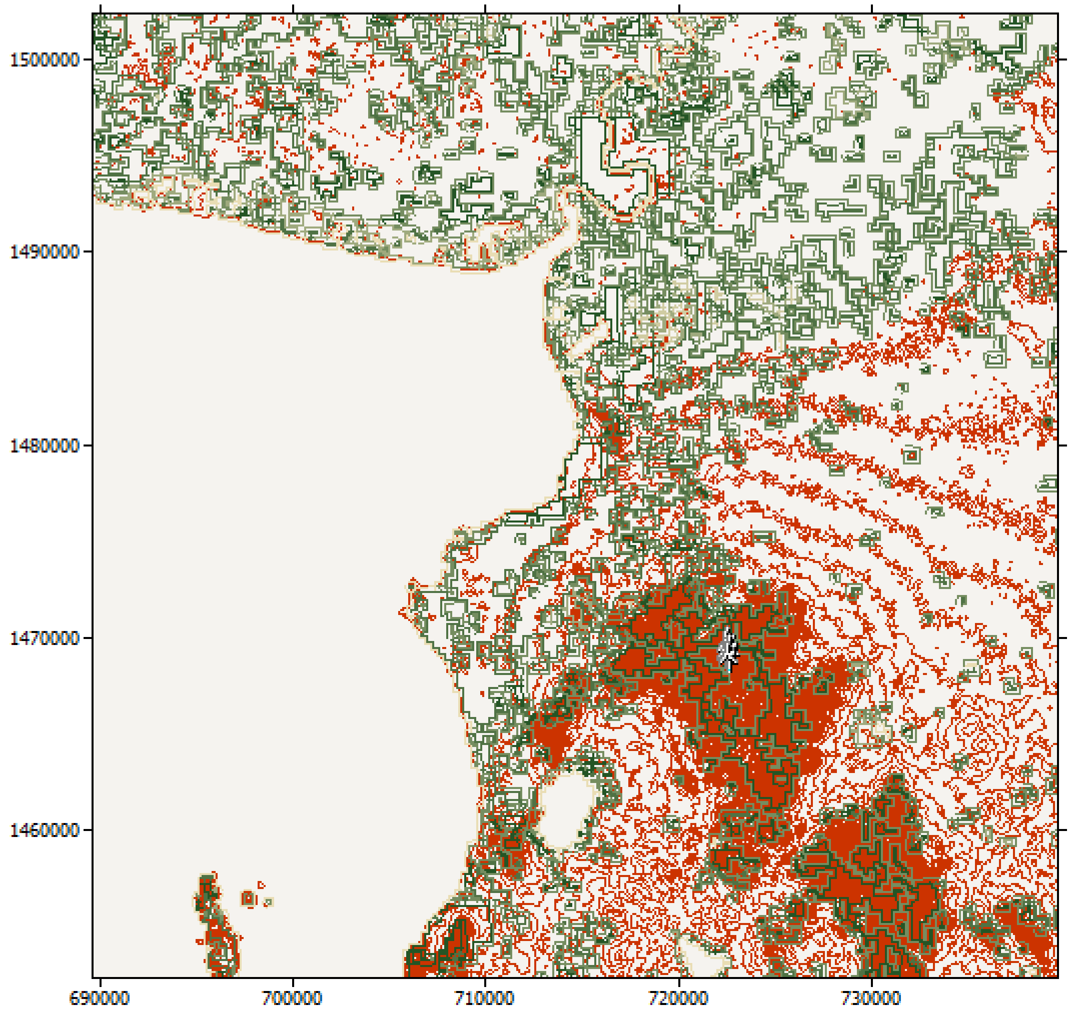


Figure 4-17 *Wind farm: 'Turbine cluster Ban Bueng Bonus 1.3 MW'*

Table 4-18 *Summary results Wind farm: 'Turbine cluster Ban Bueng Bonus 1.3 MW'*

Parameter	Total	Average	Minimum	Maximum
Net AEP [GWh]	6.061	1.010	0.950	1.102
Gross AEP [GWh]	6.303	1.051	0.995	1.149
Wake loss [%]	3.84	-	-	-
Capacity factor [%]	8.9	-	8.3	9.7

Table 4-19 *Site results Wind farm: 'Turbine cluster Ban Bueng Bonus 1.3 MW'*

Site	Elevation [m] a.s.l.	Height [m] a.g.l.	Air density [kg/m&sup3]	Net AEP [GWh]	Wake loss [%]	Capacity factor [%]
Turbine site 001	684.8	60.0	1.081	1.016	1.52	8.9
Turbine site 002	694.1	60.0	1.080	0.950	5.86	8.3
Turbine site 003	737.5	60.0	1.076	0.974	2.11	8.5
Turbine site 004	757.4	60.0	1.074	1.023	6.91	9.0
Turbine site 005	741.2	60.0	1.076	0.996	2.26	8.7
Turbine site 006	776.8	60.0	1.072	1.102	4.12	9.7

Table 4-20 *Site wind climates Wind farm: 'Turbine cluster Ban Bueng Bonus 1.3 MW'*

Site	H [m]	A [m/s]	k	U [m/s]	E [W/m²]	RIX [%]	dRIX [%]
Turbine site 001	60.0	4.2	1.22	3.89	124	24.1	24.1
Turbine site 002	60.0	4.1	1.22	3.86	120	23.3	23.3
Turbine site 003	60.0	4.2	1.26	3.90	116	24.7	24.7
Turbine site 004	60.0	4.3	1.24	4.03	132	26.3	26.3
Turbine site 005	60.0	4.2	1.23	3.89	120	25.3	25.2
Turbine site 006	60.0	4.4	1.24	4.10	139	26.8	26.8

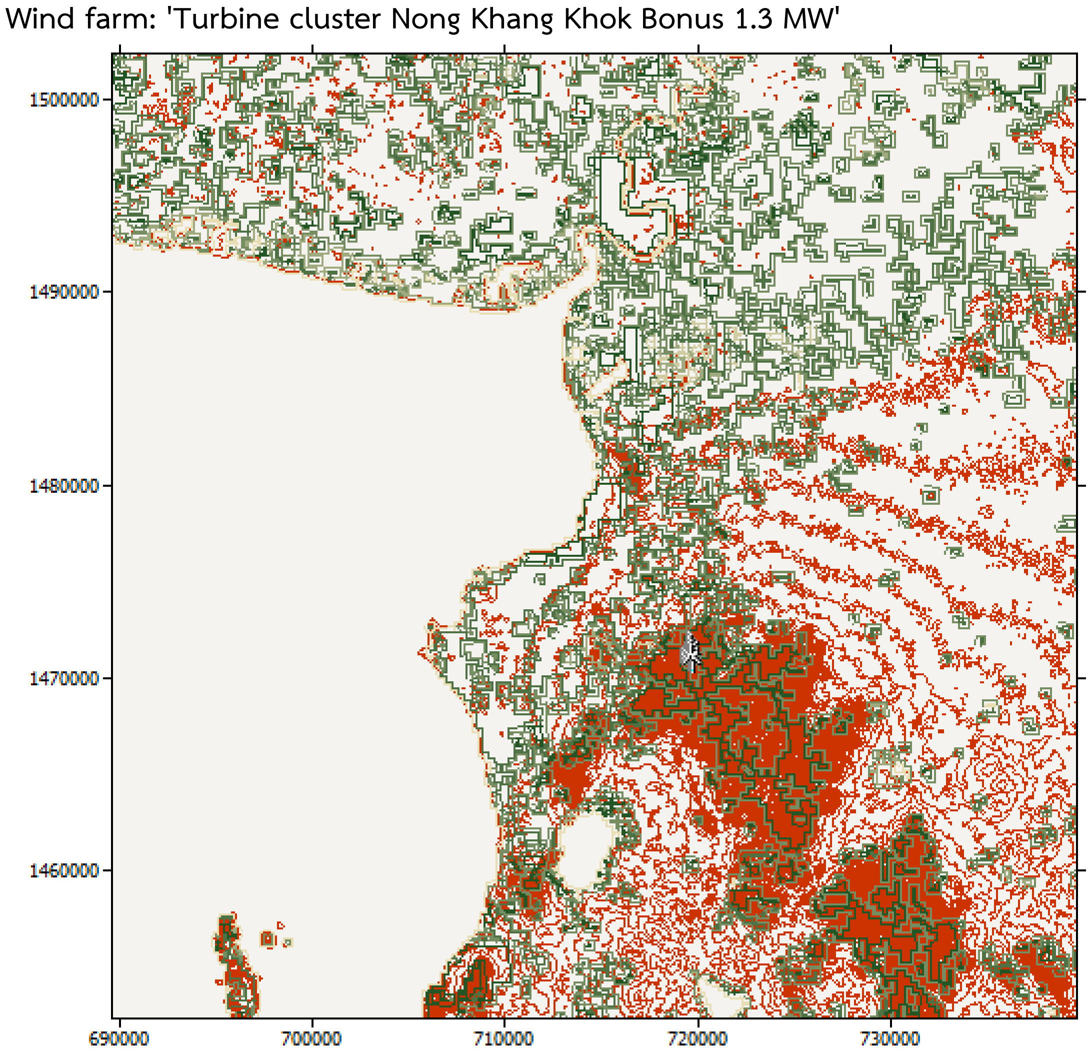


Figure 4-18 Wind farm: 'Turbine cluster Nong Khang Khok Bonus 1.3 MW'

Table 4-21 Summary results Wind farm: 'Turbine cluster Nong Khang Khok Bonus 1.3 MW'

Parameter	Total	Average	Minimum	Maximum
Net AEP [GWh]	6.667	1.111	0.967	1.280
Gross AEP [GWh]	7.172	1.195	1.006	1.326
Wake loss [%]	7.04	-	-	-
Capacity factor [%]	9.8	-	8.5	11.2

Table 4-22 *Site results Wind farm: 'Turbine cluster Nong Khang Khok Bonus 1.3 MW'*

Site	Elevation [m] a.s.l.	Height [m] a.g.l.	Air density [kg/m&sup3]	Net AEP [GWh]	Wake loss [%]	Capacity factor [%]
Turbine site 001	525.4	60.0	1.096	0.967	3.89	8.5
Turbine site 002	590.0	60.0	1.090	1.233	6.65	10.8
Turbine site 003	585.0	60.0	1.090	1.110	14.19	9.7
Turbine site 004	600.1	60.0	1.089	1.280	3.49	11.2
Turbine site 005	567.4	60.0	1.092	1.023	11.04	9.0
Turbine site 006	545.8	60.0	1.094	1.054	1.93	9.3

Table 4-23 *Site wind climates Wind farm: 'Turbine cluster Nong Khang Khok Bonus 1.3 MW'*

Site	H [m]	A [m/s]	k	U [m/s]	E [W/m²]	RIX [%]	dRIX [%]
Turbine site 001	60.0	4.1	1.23	3.86	120	24.4	24.4
Turbine site 002	60.0	4.6	1.22	4.32	170	27.6	27.6
Turbine site 003	60.0	4.5	1.21	4.27	169	27.6	27.6
Turbine site 004	60.0	4.6	1.22	4.32	170	28.9	28.9
Turbine site 005	60.0	4.3	1.23	4.06	139	26.8	26.8
Turbine site 006	60.0	4.2	1.22	3.93	128	26.3	26.3

Wind farm: 'Turbine cluster Ban Bueng SWT-1.3-62'

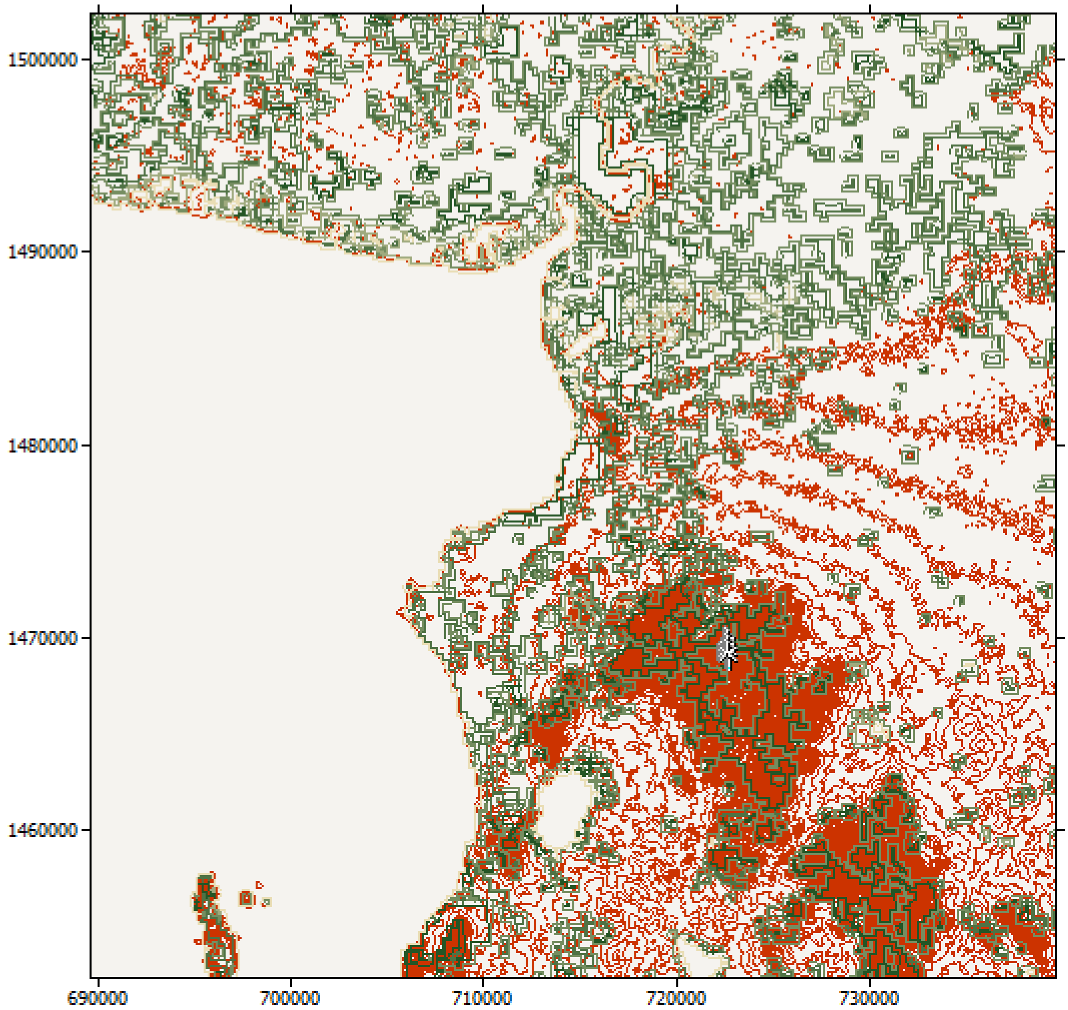


Figure 4-19 *Wind farm: 'Turbine cluster Ban Bueng SWT-1.3-62'*

Table 4-24 *Summary results Wind farm: 'Turbine cluster Ban Bueng SWT-1.3-62'*

Parameter	Total	Average	Minimum	Maximum
Net AEP [GWh]	6.265	1.044	0.975	1.132
Gross AEP [GWh]	6.550	1.092	1.006	1.169
Wake loss [%]	4.36	-	-	-
Capacity factor [%]	9.2	-	8.6	9.9

Table 4-25 Site results Wind farm: 'Turbine cluster Ban Bueng SWT-1.3-62'

Site	Elevation [m] a.s.l.	Height [m] a.g.l.	Air density [kg/m&sup3]	Net AEP [GWh]	Wake loss [%]	Capacity factor [%]
Turbine site 001	682.2	60.0	1.081	1.132	3.12	9.9
Turbine site 002	688.6	60.0	1.081	1.034	1.75	9.1
Turbine site 003	720.8	60.0	1.078	1.017	7.27	8.9
Turbine site 004	734.4	60.0	1.076	0.975	3.08	8.6
Turbine site 005	754.6	60.0	1.074	1.066	8.53	9.4
Turbine site 006	745.7	60.0	1.075	1.042	1.92	9.1

Table 4-26 Site wind climates Wind farm: 'Turbine cluster Ban Bueng SWT-1.3-62'

Site	H [m]	A [m/s]	k	U [m/s]	E [W/m^2]	RIX [%]	dRIX [%]
Turbine site 001	60.0	4.2	1.21	3.98	134	24.5	24.4
Turbine site 002	60.0	4.1	1.22	3.81	116	23.5	23.4
Turbine site 003	60.0	4.2	1.24	3.91	120	23.6	23.5
Turbine site 004	60.0	4.1	1.27	3.81	106	24.8	24.8
Turbine site 005	60.0	4.3	1.23	4.00	130	26.0	25.9
Turbine site 006	60.0	4.1	1.24	3.86	116	25.5	25.5

Wind farm: 'Turbine cluster Nong Khang Khok SWT-1.3-62'

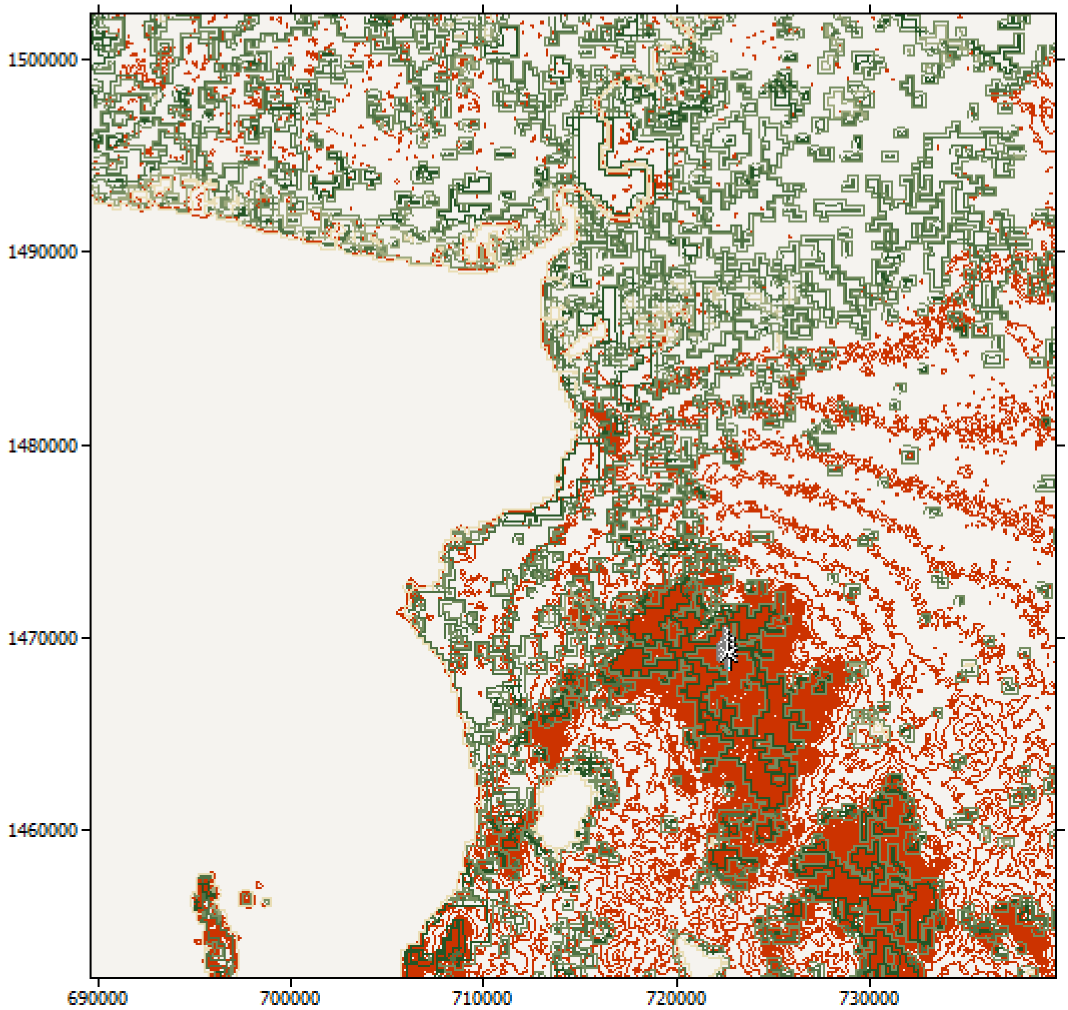


Figure 4-20 *Wind farm: 'Turbine cluster Nong Khang Khok SWT-1.3-62'*

Table 4-27 *Summary results Wind farm: 'Turbine cluster Nong Khang Khok SWT-1.3-62'*

Parameter	Total	Average	Minimum	Maximum
Net AEP [GWh]	6.962	1.160	1.020	1.304
Gross AEP [GWh]	7.435	1.239	1.032	1.366
Wake loss [%]	6.36	-	-	-
Capacity factor [%]	10.2	-	8.9	11.4

Table 4-28 ***Table 4-28*** *Site results Wind farm: 'Turbine cluster Nong Khang Khok SWT-1.3-62'*

Site	Elevation [m] a.s.l.	Height [m] a.g.l.	Air density [kg/m&sup3]	Net AEP [GWh]	Wake loss [%]	Capacity factor [%]
Turbine site 001	531.7	60.0	1.095	1.072	4.11	9.4
Turbine site 002	583.7	60.0	1.090	1.304	4.55	11.4
Turbine site 003	580.9	60.0	1.091	1.173	12.53	10.3
Turbine site 004	587.7	60.0	1.090	1.273	4.48	11.2
Turbine site 005	570.1	60.0	1.092	1.120	10.04	9.8
Turbine site 006	515.7	60.0	1.097	1.020	1.19	8.9

Table 4-29 *Site wind climates Wind farm: 'Turbine cluster Nong Khang Khok SWT-1.3-62'*

Site	H [m]	A [m/s]	k	U [m/s]	E [W/m²]	RIX [%]	dRIX [%]
Turbine site 001	60.0	4.2	1.22	3.91	126	24.9	24.8
Turbine site 002	60.0	4.6	1.22	4.27	164	28.0	27.9
Turbine site 003	60.0	4.5	1.21	4.22	162	28.1	28.0
Turbine site 004	60.0	4.5	1.23	4.22	156	28.5	28.5
Turbine site 005	60.0	4.4	1.23	4.09	141	26.6	26.6
Turbine site 006	60.0	4.0	1.20	3.73	114	25.8	25.8

Wind farm: 'Turbine cluster Ban Bueng SWT-2.3-82 VS'

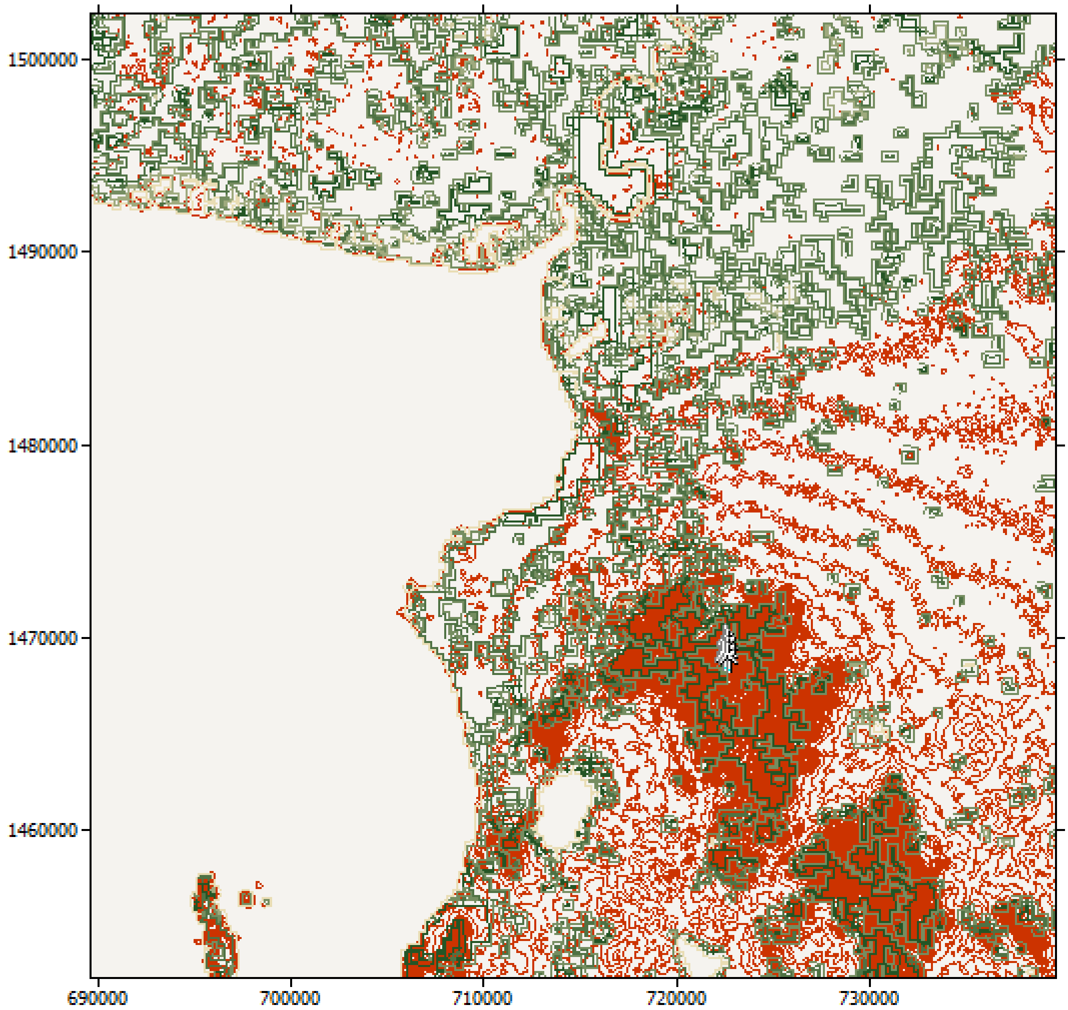


Figure 4-21 *Wind farm: 'Turbine cluster Ban Bueng SWT-2.3-82 VS'*

Table 4-30 *Summary results Wind farm: 'Turbine cluster Ban Bueng SWT-2.3-82 VS'*

Parameter	Total	Average	Minimum	Maximum
Net AEP [GWh]	10.748	1.791	1.533	2.029
Gross AEP [GWh]	11.333	1.889	1.612	2.084
Wake loss [%]	5.16	-	-	-
Capacity factor [%]	8.9	-	7.6	10.1

Table 4-31 *Site results Wind farm: 'Turbine cluster Ban Bueng SWT-2.3-82 VS'*

Site	Elevation [m] a.s.l.	Height [m] a.g.l.	Air density [kg/m&sup3]	Net AEP [GWh]	Wake loss [%]	Capacity factor [%]
Turbine site 001	678.0	80.0	1.080	2.029	2.64	10.1
Turbine site 002	683.3	80.0	1.079	1.784	1.17	8.8
Turbine site 003	737.5	80.0	1.074	1.811	7.10	9.0
Turbine site 004	713.4	80.0	1.076	1.533	4.92	7.6
Turbine site 005	756.0	80.0	1.072	1.815	11.79	9.0
Turbine site 006	743.3	80.0	1.074	1.777	2.63	8.8

Table 4-32 *Site wind climates Wind farm: 'Turbine cluster Ban Bueng SWT-2.3-82 VS'*

Site	H [m]	A [m/s]	k	U [m/s]	E [W/m²]	RIX [%]	dRIX [%]
Turbine site 001	80.0	4.4	1.23	4.12	144	25.5	25.5
Turbine site 002	80.0	4.2	1.26	3.91	118	23.4	23.4
Turbine site 003	80.0	4.4	1.28	4.06	127	24.5	24.4
Turbine site 004	80.0	4.1	1.29	3.78	101	25.4	25.4
Turbine site 005	80.0	4.4	1.25	4.11	137	25.6	25.6
Turbine site 006	80.0	4.2	1.27	3.94	118	26.3	26.2

Wind farm: 'Turbine cluster Nong Khang Khok SWT-2.3-82 VS'

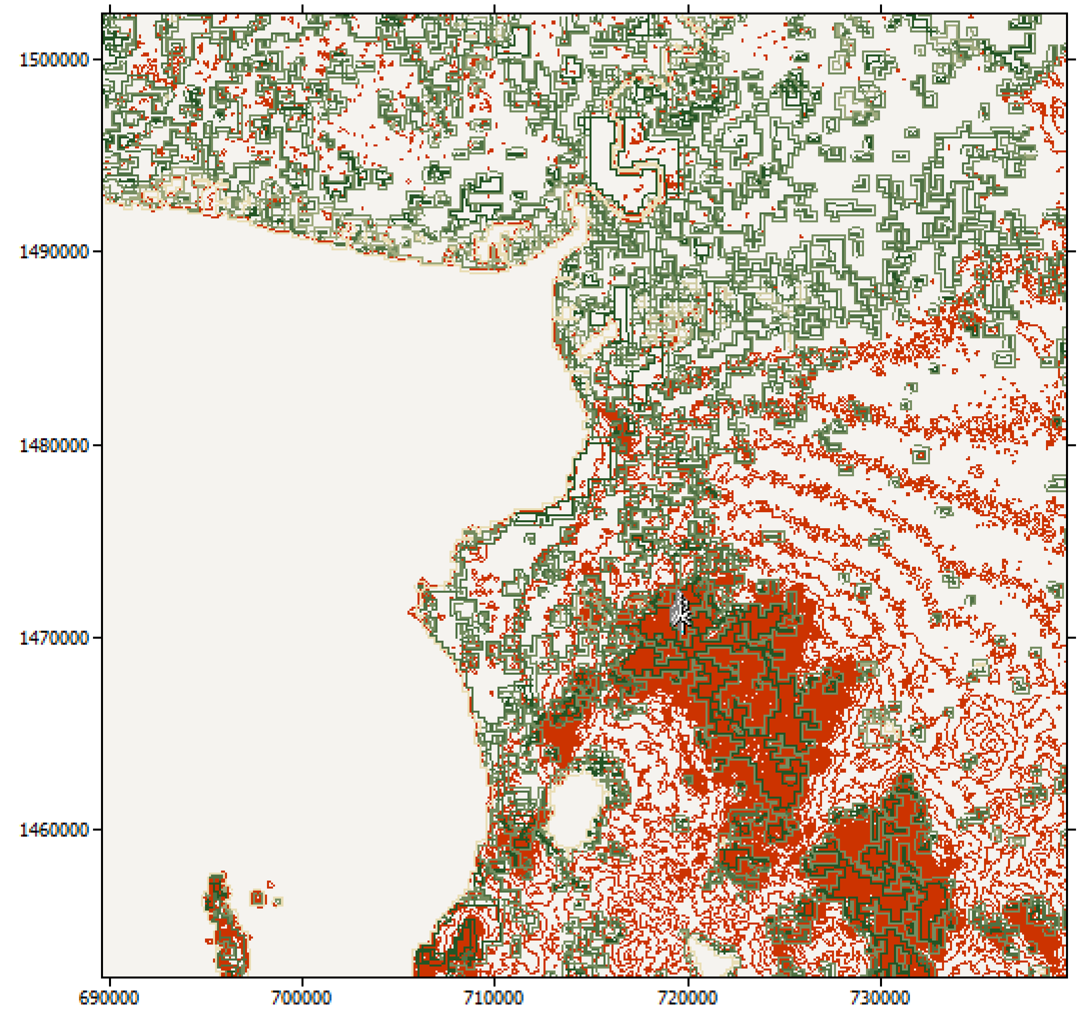


Figure 4-22 *Wind farm: 'Turbine cluster Nong Khang Khok SWT-2.3-82 VS'*

Table 4-33 *Summary results Wind farm: 'Turbine cluster Nong Khang Khok SWT-2.3-82 VS'*

Parameter	Total	Average	Minimum	Maximum
Net AEP [GWh]	12.333	2.055	1.782	2.334
Gross AEP [GWh]	13.215	2.202	1.854	2.450
Wake loss [%]	6.68	-	-	-
Capacity factor [%]	10.2	-	8.8	11.6

Table 4-34 *Site results Wind farm: 'Turbine cluster Nong Khang Khok SWT-2.3-82 VS'*

Site	Elevation [m] a.s.l.	Height [m] a.g.l.	Air density [kg/m&sup3]	Net AEP [GWh]	Wake loss [%]	Capacity factor [%]
Turbine site 001	510.4	80.0	1.095	1.782	3.91	8.8
Turbine site 002	590.9	80.0	1.088	2.334	4.74	11.6
Turbine site 003	578.9	80.0	1.089	1.992	15.47	9.9
Turbine site 004	597.4	80.0	1.087	2.334	4.74	11.6
Turbine site 005	570.2	80.0	1.090	2.036	8.49	10.1
Turbine site 006	513.4	80.0	1.095	1.856	1.27	9.2

Table 4-35 *Site wind climates Wind farm: 'Turbine cluster Nong Khang Khok SWT-2.3-82 VS'*

Site	H [m]	A [m/s]	k	U [m/s]	E [W/m²]	RIX [%]	dRIX [%]
Turbine site 001	80.0	4.2	1.26	3.93	121	23.9	23.8
Turbine site 002	80.0	4.8	1.26	4.43	173	27.5	27.5
Turbine site 003	80.0	4.6	1.24	4.33	165	27.9	27.9
Turbine site 004	80.0	4.7	1.25	4.42	173	28.6	28.6
Turbine site 005	80.0	4.5	1.26	4.23	151	26.6	26.6
Turbine site 006	80.0	4.2	1.23	3.90	124	25.6	25.6

4.2.3.2. Ko Sichang station

The turbine clusters, Khao Kaya Sira Hill and Hat Tham Phang, utilize Bonus 1.3 MW wind turbines, SWT-1.3-62 and SWT-2.3-82 VS respectively. These clusters are located in the Ko Sichang station area within the Chonburi province, as depicted in Figures 4-23 to 4-28, with the site location coordinates given in UTM/USNG (m) and Zone 47, as detailed in Table 4-36.

Table 4-36 *Ko Sichang Turbine Cluster Site Location*

Turbine cluster	Site Location (UTM/USNG (m), Zone 47)	
	Khao Kaya Sira Hill	Hat Tham Phang
Turbine site 001	(695560.9,1457065.0)	(695522.8,1453179.0)
Turbine site 002	(695670.5,1456983.0)	(695617.3,1453025.0)
Turbine site 003	(695551.4,1456949.0)	(695688.2,1453179.0)
Turbine site 004	(695655.1,1456855.0)	(695754.1,1453026.0)
Turbine site 005	(695546.5,1456811.0)	(695866.9,1453185.0)
Turbine site 006	(695645.2,1456737.0)	(695902.8,1453047.0)

Wind farm: 'Turbine cluster Khao Kaya Sira Hill Bonus 1.3 MW'

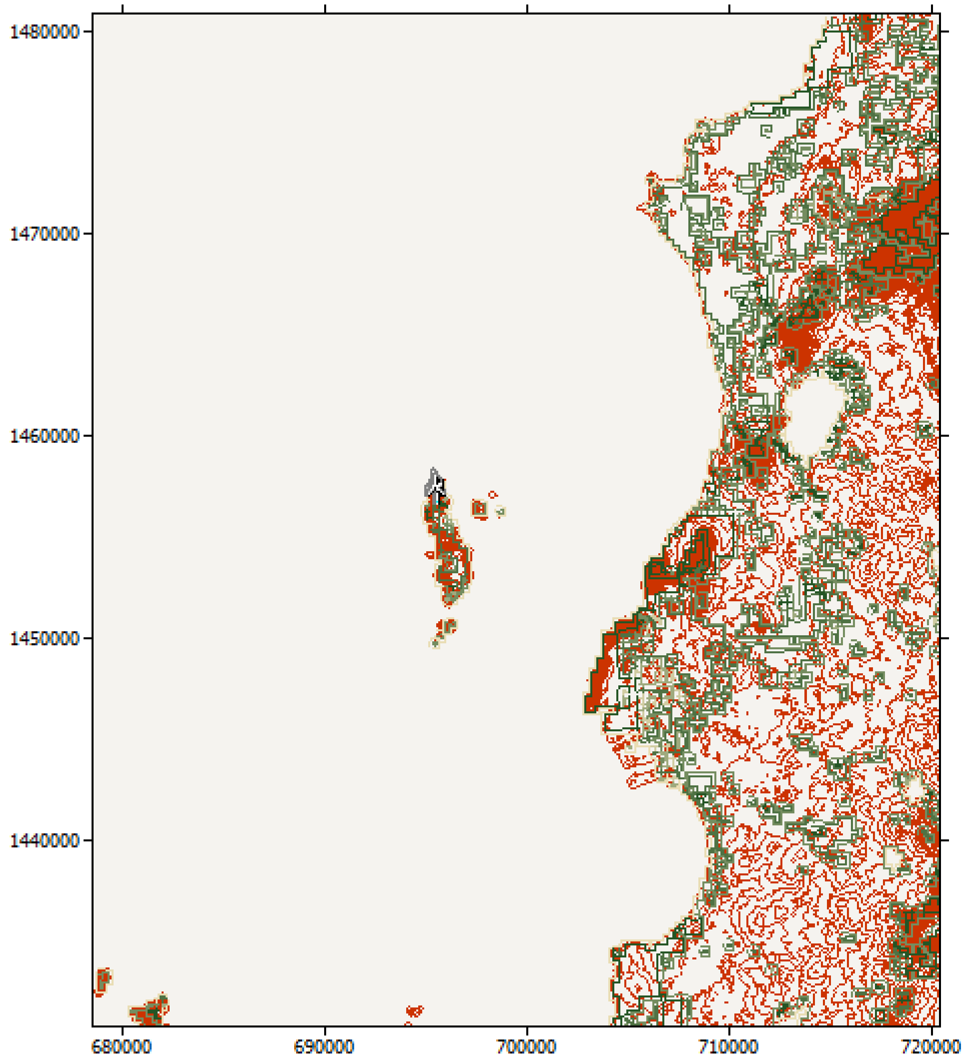


Figure 4-23 *Wind farm: 'Turbine cluster Khao Kaya Sira Hill Bonus 1.3 MW'*

Table 4-37 *Summary results Wind farm: 'Turbine cluster Khao Kaya Sira Hill Bonus 1.3 MW'*

Parameter	Total	Average	Minimum	Maximum
Net AEP [GWh]	12.460	2.077	1.855	2.573
Gross AEP [GWh]	15.676	2.613	2.434	2.874
Wake loss [%]	20.52	-	-	-
Capacity factor [%]	18.2	-	16.3	22.6

Table 4-38 *Site results Wind farm: 'Turbine cluster Khao Kaya Sira Hill Bonus 1.3 MW'*

Site	Elevation [m] a.s.l.	Height [m] a.g.l.	Air density [kg/m&sup3]	Net AEP [GWh]	Wake loss [%]	Capacity factor [%]
Turbine site 001	138.5	60.0	1.135	2.178	13.26	19.1
Turbine site 002	150.8	60.0	1.134	1.855	28.27	16.3
Turbine site 003	148.7	60.0	1.134	1.888	22.44	16.6
Turbine site 004	166.4	60.0	1.132	1.893	30.64	16.6
Turbine site 005	161.0	60.0	1.133	2.074	18.44	18.2
Turbine site 006	177.9	60.0	1.131	2.573	10.49	22.6

Table 4-39 *Site wind climates Wind farm: 'Turbine cluster Khao Kaya Sira Hill Bonus 1.3 MW'*

Site	H [m]	A [m/s]	k	U [m/s]	E [W/m²]	RIX [%]	dRIX [%]
Turbine site 001	60.0	7.1	1.84	6.30	296	6.2	N/A
Turbine site 002	60.0	7.2	1.91	6.41	299	6.4	N/A
Turbine site 003	60.0	7.1	1.91	6.26	278	6.6	N/A
Turbine site 004	60.0	7.4	1.99	6.58	311	6.8	N/A
Turbine site 005	60.0	7.2	2.02	6.40	280	6.9	N/A
Turbine site 006	60.0	7.6	2.05	6.73	322	7.7	N/A

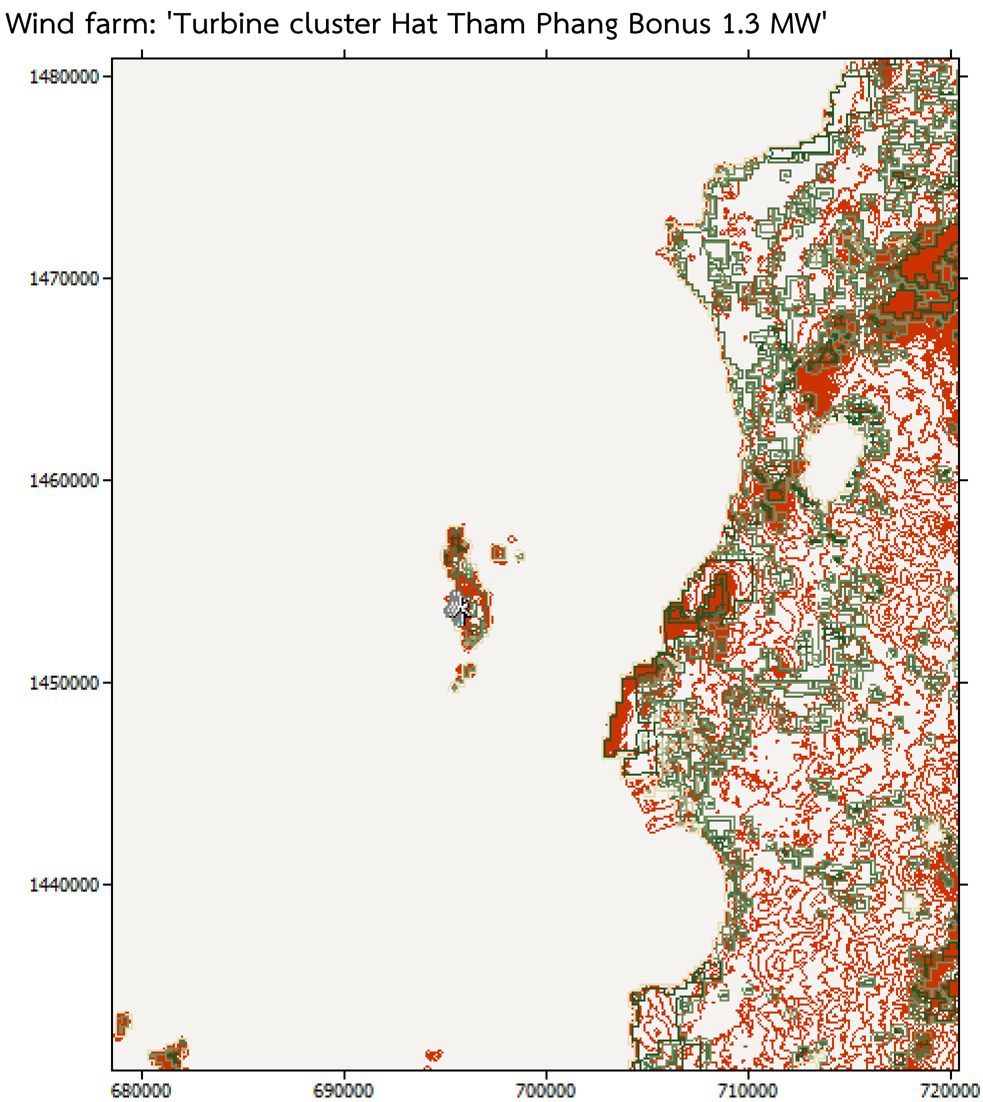


Figure 4-24 Wind farm: 'Turbine cluster Hat Tham Phang Bonus 1.3 MW'

Table 4-40 Summary results Wind farm: 'Turbine cluster Hat Tham Phang Bonus 1.3 MW'

Parameter	Total	Average	Minimum	Maximum
Net AEP [GWh]	9.043	1.507	1.083	1.834
Gross AEP [GWh]	10.690	1.782	1.278	2.267
Wake loss [%]	15.41	-	-	-
Capacity factor [%]	13.2	-	9.5	16.1

Table 4-41 *Site results Wind farm: 'Turbine cluster Hat Tham Phang Bonus 1.3 MW'*

Site	Elevation [m] a.s.l.	Height [m] a.g.l.	Air density [kg/m&sup3]	Net AEP [GWh]	Wake loss [%]	Capacity factor [%]
Turbine site 001	33.0	60.0	1.145	1.581	3.59	13.9
Turbine site 002	31.7	60.0	1.145	1.083	15.21	9.5
Turbine site 003	80.0	60.0	1.140	1.834	19.13	16.1
Turbine site 004	59.9	60.0	1.142	1.468	17.37	12.9
Turbine site 005	63.1	60.0	1.142	1.253	28.27	11.0
Turbine site 006	70.3	60.0	1.141	1.824	7.95	16.0

Table 4-42 *Site wind climates Wind farm: 'Turbine cluster Hat Tham Phang Bonus 1.3 MW'*

Site	H [m]	A [m/s]	k	U [m/s]	E [W/m²]	RIX [%]	dRIX [%]
Turbine site 001	60.0	6.1	2.16	5.41	161	1.5	N/A
Turbine site 002	60.0	5.7	2.17	5.02	128	2.1	N/A
Turbine site 003	60.0	6.9	2.13	6.08	231	3.6	N/A
Turbine site 004	60.0	6.3	2.11	5.57	179	2.4	N/A
Turbine site 005	60.0	6.3	2.14	5.54	174	2.1	N/A
Turbine site 006	60.0	6.5	2.10	5.77	201	1.7	N/A

Wind farm: 'Turbine cluster Khao Kaya Sira Hill SWT-1.3-62'

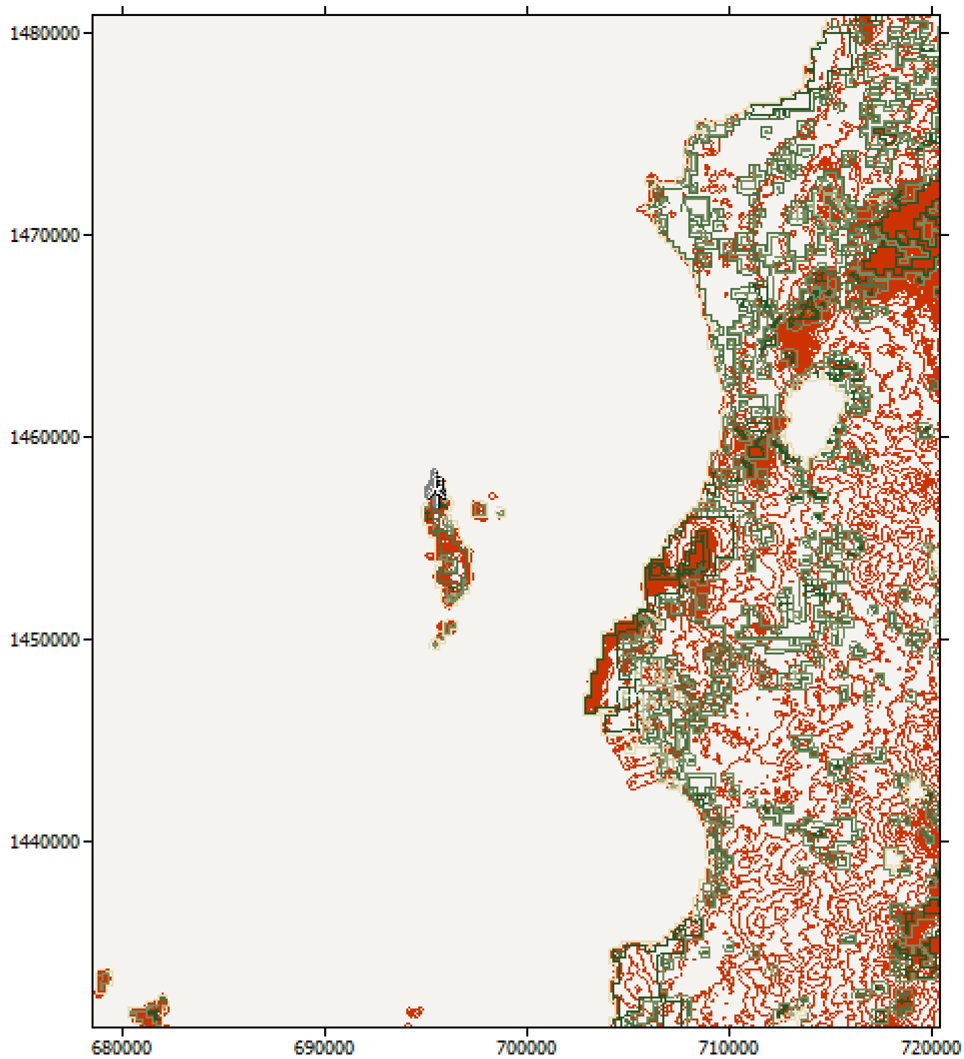


Figure 4-25 *Wind farm: 'Turbine cluster Khao Kaya Sira Hill SWT-1.3-62'*

Table 4-43 *Summary results Wind farm: 'Turbine cluster Khao Kaya Sira Hill SWT-1.3-62'*

Parameter	Total	Average	Minimum	Maximum
Net AEP [GWh]	13.384	2.231	1.987	2.682
Gross AEP [GWh]	16.214	2.702	2.532	2.943
Wake loss [%]	17.46	-	-	-
Capacity factor [%]	19.6	-	17.4	23.5

Table 4-44 *Site results Wind farm: 'Turbine cluster Khao Kaya Sira Hill SWT-1.3-62'*

Site	Elevation [m] a.s.l.	Height [m] a.g.l.	Air density [kg/m&sup3]	Net AEP [GWh]	Wake loss [%]	Capacity factor [%]
Turbine site 001	127.5	60.0	1.136	2.331	8.49	20.5
Turbine site 002	152.0	60.0	1.134	2.053	24.50	18.0
Turbine site 003	146.5	60.0	1.134	1.987	21.53	17.4
Turbine site 004	165.0	60.0	1.132	2.144	25.64	18.8
Turbine site 005	155.8	60.0	1.133	2.188	15.52	19.2
Turbine site 006	169.5	60.0	1.132	2.682	8.89	23.5

Table 4-45 *Site wind climates Wind farm: 'Turbine cluster Khao Kaya Sira Hill SWT-1.3-62'*

Site	H [m]	A [m/s]	k	U [m/s]	E [W/m²]	RIX [%]	dRIX [%]
Turbine site 001	60.0	7.0	1.85	6.18	277	5.9	N/A
Turbine site 002	60.0	7.2	1.87	6.38	303	6.4	N/A
Turbine site 003	60.0	7.0	1.94	6.20	267	6.6	N/A
Turbine site 004	60.0	7.4	1.99	6.57	309	6.7	N/A
Turbine site 005	60.0	7.1	2.07	6.28	260	6.7	N/A
Turbine site 006	60.0	7.5	2.06	6.63	307	7.6	N/A

Wind farm: 'Turbine cluster Hat Tham Phang SWT-1.3-62'

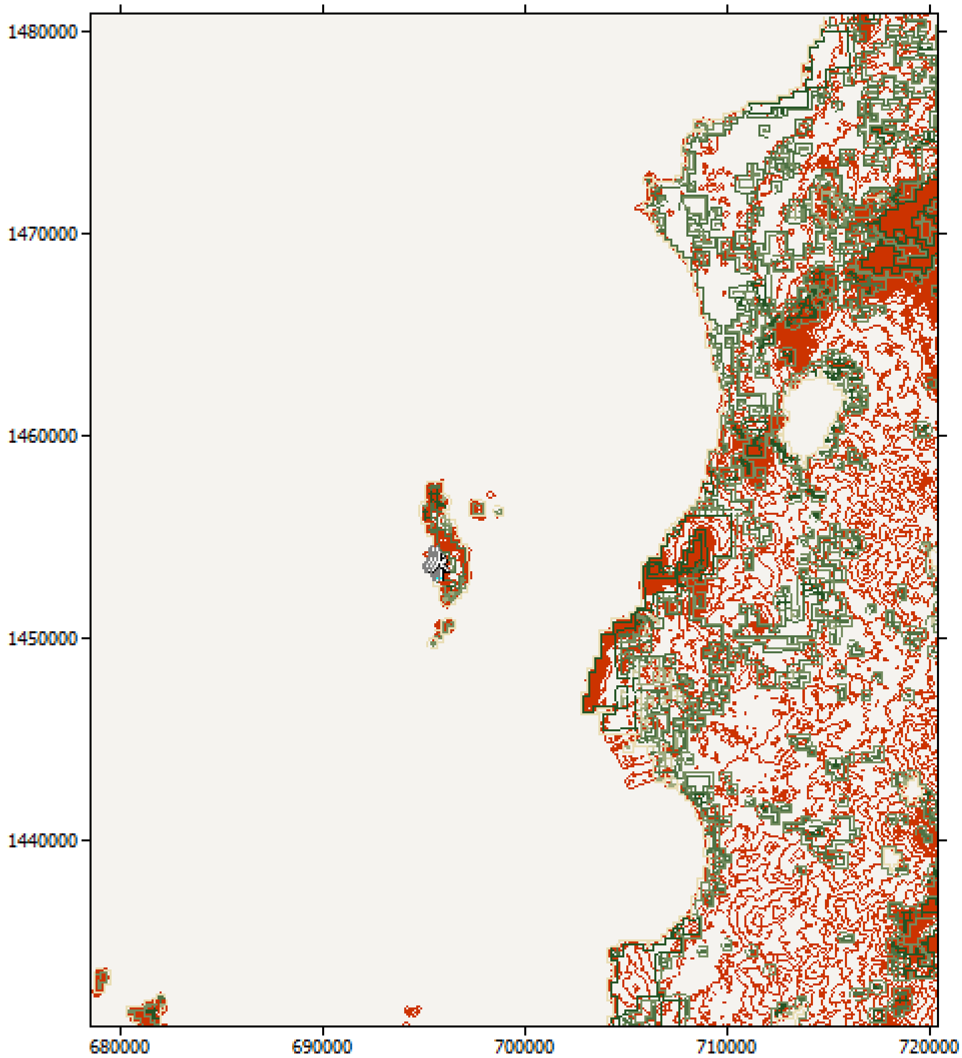


Figure 4-26 *Wind farm: 'Turbine cluster Hat Tham Phang SWT-1.3-62'*

Table 4-46 *Summary results Wind farm: 'Turbine cluster Hat Tham Phang SWT-1.3-62'*

Parameter	Total	Average	Minimum	Maximum
Net AEP [GWh]	9.691	1.615	1.147	1.976
Gross AEP [GWh]	11.344	1.891	1.358	2.416
Wake loss [%]	14.58	-	-	-
Capacity factor [%]	14.2	-	10.1	17.3

Table 4-47 *Site results Wind farm: 'Turbine cluster Hat Tham Phang SWT-1.3-62'*

Site	Elevation [m] a.s.l.	Height [m] a.g.l.	Air density [kg/m&sup3]	Net AEP [GWh]	Wake loss [%]	Capacity factor [%]
Turbine site 001	29.2	60.0	1.145	1.689	3.30	14.8
Turbine site 002	28.4	60.0	1.145	1.147	15.55	10.1
Turbine site 003	79.7	60.0	1.141	1.957	19.00	17.2
Turbine site 004	57.6	60.0	1.143	1.537	18.23	13.5
Turbine site 005	60.2	60.0	1.142	1.385	23.52	12.2
Turbine site 006	70.7	60.0	1.141	1.976	7.37	17.3

Table 4-48 *Site wind climates Wind farm: 'Turbine cluster Hat Tham Phang SWT-1.3-62'*

Site	H [m]	A [m/s]	k	U [m/s]	E [W/m²]	RIX [%]	dRIX [%]
Turbine site 001	60.0	6.1	2.15	5.37	157	1.4	N/A
Turbine site 002	60.0	5.6	2.17	4.95	123	2.1	N/A
Turbine site 003	60.0	6.9	2.13	6.07	230	3.6	N/A
Turbine site 004	60.0	6.2	2.11	5.52	174	2.3	N/A
Turbine site 005	60.0	6.2	2.15	5.45	165	2.1	N/A
Turbine site 006	60.0	6.5	2.10	5.77	200	1.7	N/A

Wind farm: 'Turbine cluster Khao Kaya Sira Hill SWT-2.3-82 VS'

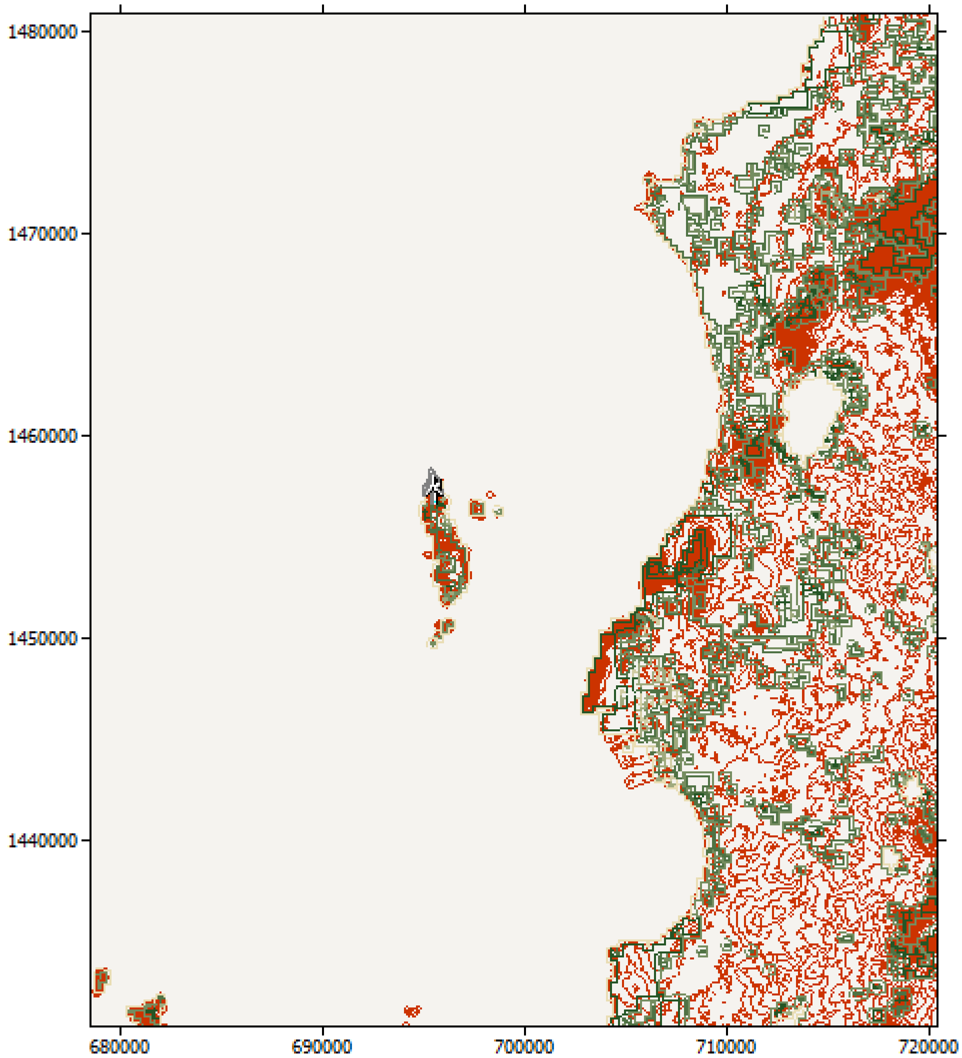


Figure 4-27 *Wind farm: 'Turbine cluster Khao Kaya Sira Hill SWT-2.3-82 VS'*

Table 4-49 *Summary results Wind farm: 'Turbine cluster Khao Kaya Sira Hill SWT-2.3-82 VS'*

Parameter	Total	Average	Minimum	Maximum
Net AEP [GWh]	20.197	3.366	2.869	4.382
Gross AEP [GWh]	27.496	4.583	4.271	4.992
Wake loss [%]	26.55	-	-	-
Capacity factor [%]	16.7	-	14.2	21.7

Table 4-50 *Site results Wind farm: 'Turbine cluster Khao Kaya Sira Hill SWT-2.3-82 VS'*

Site	Elevation [m] a.s.l.	Height [m] a.g.l.	Air density [kg/m&sup3]	Net AEP [GWh]	Wake loss [%]	Capacity factor [%]
Turbine site 001	131.0	80.0	1.134	3.750	15.19	18.6
Turbine site 002	155.3	80.0	1.131	2.981	35.81	14.8
Turbine site 003	142.2	80.0	1.133	2.869	33.38	14.2
Turbine site 004	167.4	80.0	1.130	2.992	38.43	14.8
Turbine site 005	150.5	80.0	1.132	3.222	24.56	16.0
Turbine site 006	179.4	80.0	1.129	4.382	12.22	21.7

Table 4-51 *Site wind climates Wind farm: 'Turbine cluster Khao Kaya Sira Hill SWT-2.3-82 VS'*

Site	H [m]	A [m/s]	k	U [m/s]	E [W/m²]	RIX [%]	dRIX [%]
Turbine site 001	80.0	7.1	1.97	6.32	277	5.9	N/A
Turbine site 002	80.0	7.3	2.00	6.47	293	6.5	N/A
Turbine site 003	80.0	7.1	2.04	6.28	263	6.7	N/A
Turbine site 004	80.0	7.5	2.08	6.61	301	6.7	N/A
Turbine site 005	80.0	7.1	2.16	6.28	249	6.7	N/A
Turbine site 006	80.0	7.6	2.16	6.69	301	7.8	N/A

Wind farm: 'Turbine cluster Hat Tham Phang SWT-2.3-82 VS'

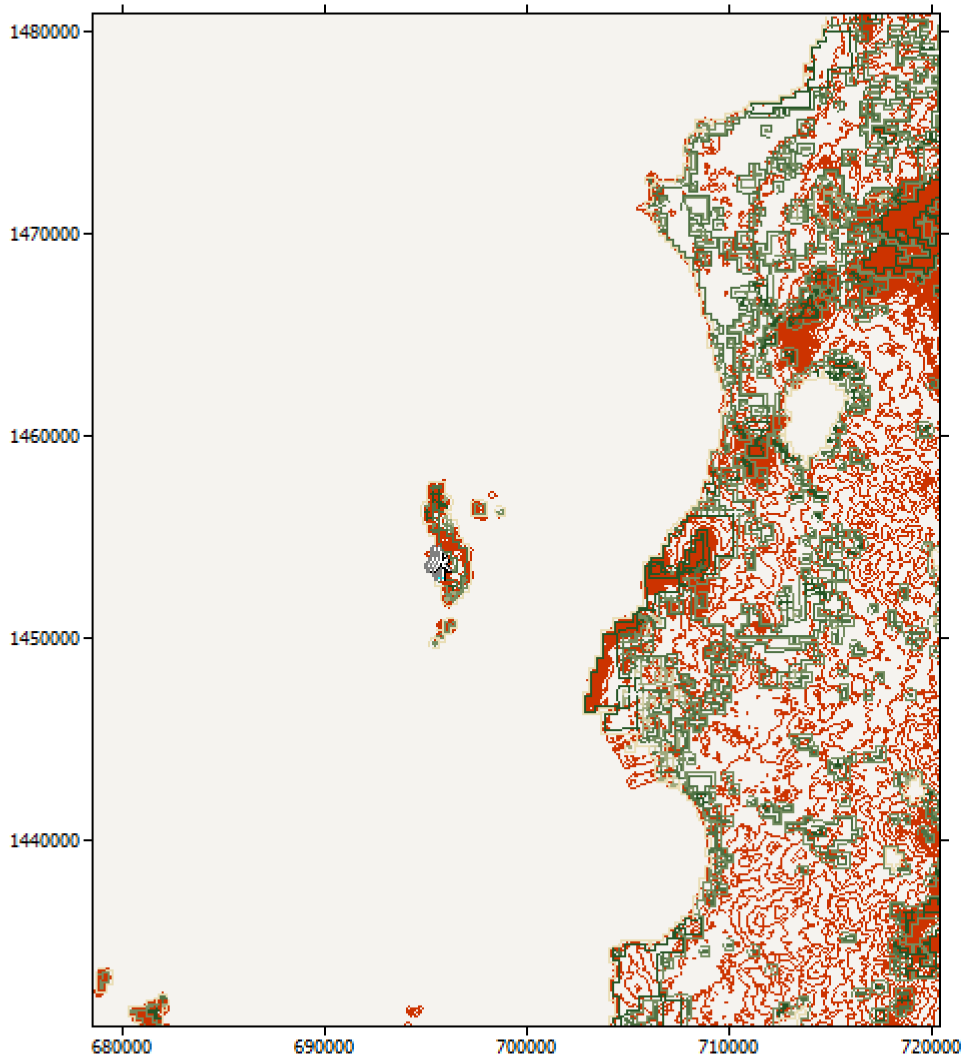


Figure 4-28 *Wind farm: 'Turbine cluster Hat Tham Phang SWT-2.3-82 VS'*

Table 4-52 *Summary results Wind farm: 'Turbine cluster Hat Tham Phang SWT-2.3-82 VS'*

Parameter	Total	Average	Minimum	Maximum
Net AEP [GWh]	16.498	2.750	2.155	3.210
Gross AEP [GWh]	20.070	3.345	2.702	4.052
Wake loss [%]	17.80	-	-	-
Capacity factor [%]	13.6	-	10.7	15.9

Table 4-53 *Site results Wind farm: 'Turbine cluster Hat Tham Phang SWT-2.3-82 VS'*

Site	Elevation [m] a.s.l.	Height [m] a.g.l.	Air density [kg/m&sup3]	Net AEP [GWh]	Wake loss [%]	Capacity factor [%]
Turbine site 001	33.3	80.0	1.143	2.913	7.42	14.4
Turbine site 002	32.5	80.0	1.143	2.155	20.27	10.7
Turbine site 003	80.3	80.0	1.139	3.101	23.48	15.4
Turbine site 004	58.8	80.0	1.141	2.696	20.73	13.4
Turbine site 005	63.0	80.0	1.140	2.423	27.76	12.0
Turbine site 006	63.4	80.0	1.140	3.210	5.97	15.9

Table 4-54 *Site wind climates Wind farm: 'Turbine cluster Hat Tham Phang SWT-2.3-82 VS'*

Site	H [m]	A [m/s]	k	U [m/s]	E [W/m²]	RIX [%]	dRIX [%]
Turbine site 001	80.0	6.3	2.23	5.58	171	1.6	N/A
Turbine site 002	80.0	6.0	2.25	5.32	148	2.2	N/A
Turbine site 003	80.0	6.9	2.21	6.12	227	3.6	N/A
Turbine site 004	80.0	6.5	2.19	5.74	189	2.2	N/A
Turbine site 005	80.0	6.5	2.22	5.71	185	2.0	N/A
Turbine site 006	80.0	6.5	2.17	5.74	190	1.0	N/A

4.2.3.3. Pattaya station

The turbine clusters, Phra Tamnak Mountain and Ko Lan, utilize Bonus 1.3 MW wind turbines, SWT-1.3-62 and SWT-2.3-82 VS respectively. These clusters are located in the Pattaya station area within the Chonburi province, as depicted in Figures 4-29 to 4-34, with the site location coordinates given in UTM/USNG (m) and Zone 47, as detailed in Table 4-55.

Table 4-55 *Pattaya Turbine Cluster Site Location*

Turbine cluster	Site Location (UTM/USNG (m), Zone 47)	
	Phra Tamnak Mountain	Ko Lan
Turbine site 001	(702329.2,1429457.0)	(692750.1,1429007.0)
Turbine site 002	(702301.6,1429299.0)	(692819.1,1428945.0)
Turbine site 003	(702456.8,1429247.0)	(692746.2,1428859.0)
Turbine site 004	(702367.2,1429126.0)	(683500.1,1409364.0)
Turbine site 005	(702480.9,1429061.0)	(692826.7,1428840.0)
Turbine site 006	(702370.6,1428950.0)	(692770.5,1428760.0)

Wind farm: 'Turbine cluster Phra Tamnak Mountain Bonus 1.3 MW'

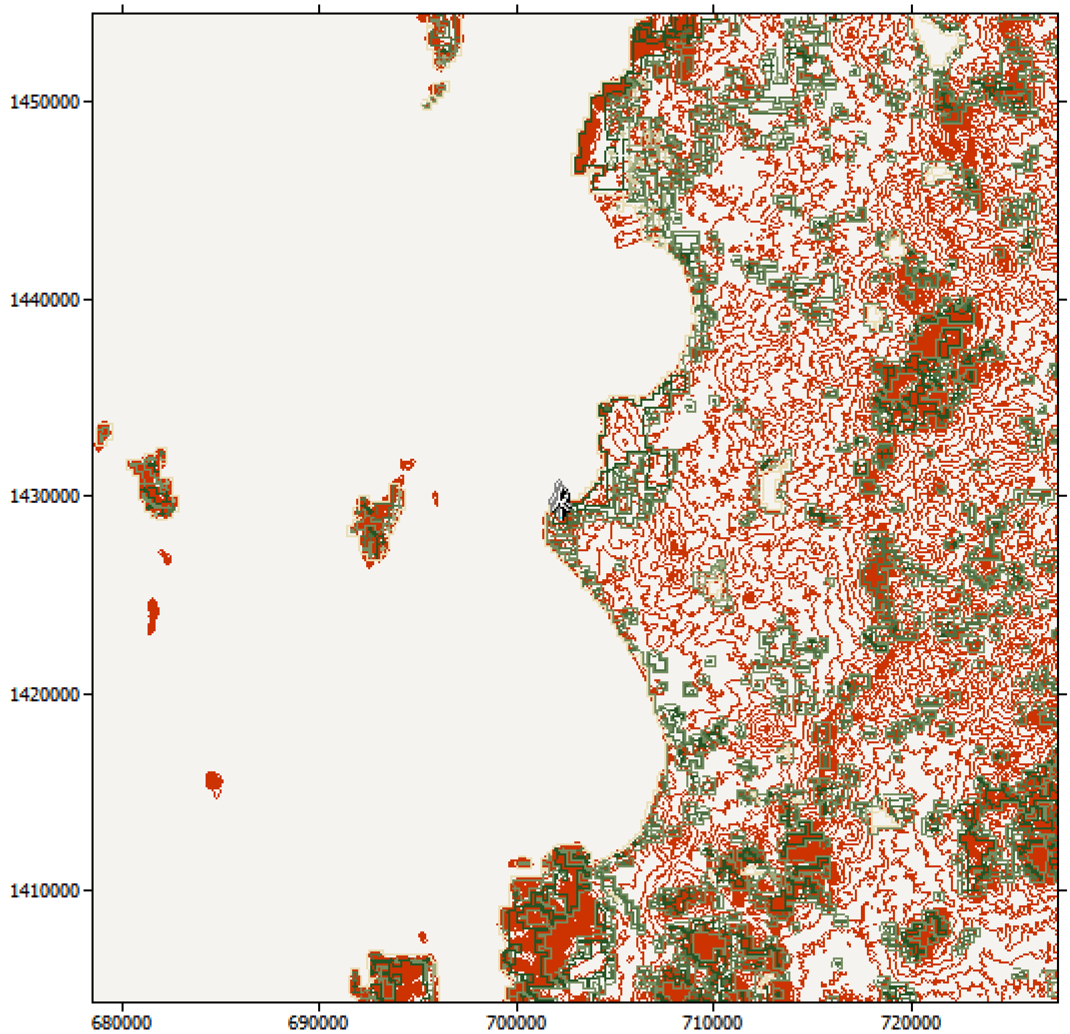


Figure 4-29 *Wind farm: 'Turbine cluster Phra Tamnak Mountain Bonus 1.3 MW'*

Table 4-56 *Summary results Wind farm: 'Turbine cluster Phra Tamnak Mountain Bonus 1.3 MW'*

Parameter	Total	Average	Minimum	Maximum
Net AEP [MWh]	207.098	34.516	23.348	44.548
Gross AEP [MWh]	301.348	50.225	39.379	65.820
Wake loss [%]	31.28	-	-	-
Capacity factor [%]	0.3	-	0.2	0.4

Table 4-57 *Site results Wind farm: 'Turbine cluster Phra Tamnak Mountain Bonus 1.3 MW'*

Site	Elevation [m] a.s.l.	Height [m] a.g.l.	Air density [kg/m&sup3]	Net AEP [MWh]	Wake loss [%]	Capacity factor [%]
Turbine site 001	53.6	60.0	1.138	38.080	12.04	0.3
Turbine site 002	54.8	60.0	1.138	26.442	32.85	0.2
Turbine site 003	82.2	60.0	1.135	44.548	32.32	0.4
Turbine site 004	63.4	60.0	1.137	23.348	49.73	0.2
Turbine site 005	82.3	60.0	1.135	40.095	37.72	0.4
Turbine site 006	58.1	60.0	1.137	34.586	17.72	0.3

Table 4-58 *Site wind climates Wind farm: 'Turbine cluster Phra Tamnak Mountain Bonus 1.3 MW'*

Site	H [m]	A [m/s]	k	U [m/s]	E [W/m²]	RIX [%]	dRIX [%]
Turbine site 001	60.0	2.3	1.79	2.02	10	0.3	-0.1
Turbine site 002	60.0	2.2	1.79	1.98	9	0.5	0.1
Turbine site 003	60.0	2.5	1.79	2.19	13	0.8	0.4
Turbine site 004	60.0	2.3	1.78	2.04	10	0.9	0.5
Turbine site 005	60.0	2.4	1.78	2.17	13	0.8	0.4
Turbine site 006	60.0	2.2	1.77	1.99	10	0.6	0.2

Wind farm: 'Turbine cluster Ko Lan Bonus 1.3 MW'

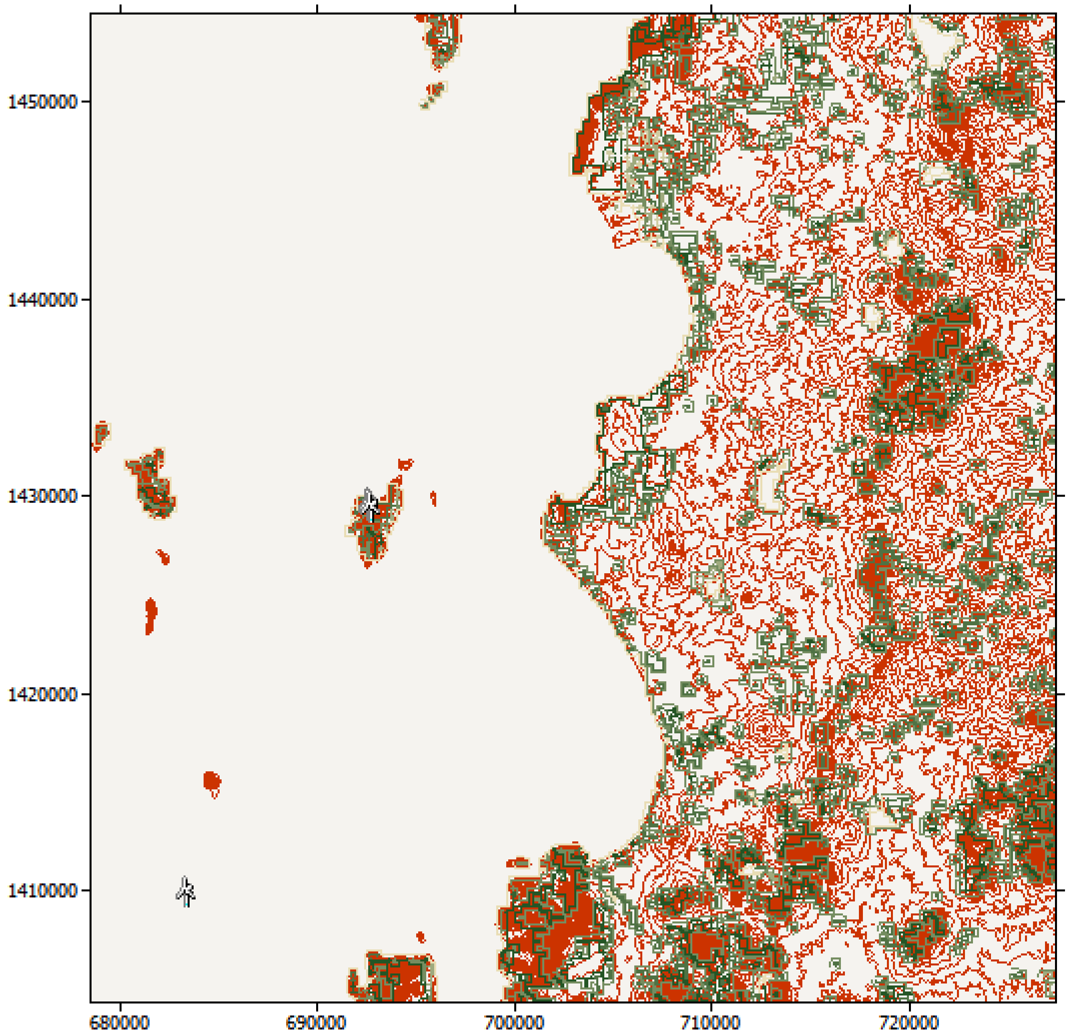


Figure 4-30 *Wind farm: 'Turbine cluster Ko Lan Bonus 1.3 MW'*

Table 4-59 *Summary results Wind farm: 'Turbine cluster Ko Lan Bonus 1.3 MW'*

Parameter	Total	Average	Minimum	Maximum
Net AEP [MWh]	906.299	151.050	57.394	212.349
Gross AEP [MWh]	1275.749	212.625	59.881	265.021
Wake loss [%]	28.96	-	-	-
Capacity factor [%]	1.3	-	0.5	1.9

Table 4-60 *Site results Wind farm: 'Turbine cluster Ko Lan Bonus 1.3 MW'*

Site	Elevation [m] a.s.l.	Height [m] a.g.l.	Air density [kg/m&sup3]	Net AEP [MWh]	Wake loss [%]	Capacity factor [%]
Turbine site 001	156.5	60.0	1.127	143.107	30.58	1.3
Turbine site 002	165.1	60.0	1.126	172.243	27.06	1.5
Turbine site 003	190.0	60.0	1.123	137.509	48.11	1.2
Turbine site 004	0.0	60.0	1.143	57.394	4.15	0.5
Turbine site 005	183.2	60.0	1.124	183.697	29.53	1.6
Turbine site 006	174.1	60.0	1.125	212.349	14.34	1.9

Table 4-61 *Site wind climates Wind farm: 'Turbine cluster Ko Lan Bonus 1.3 MW'*

Site	H [m]	A [m/s]	k	U [m/s]	E [W/m²]	RIX [%]	dRIX [%]
Turbine site 001	60.0	3.0	1.63	2.72	28	6.2	5.8
Turbine site 002	60.0	3.1	1.62	2.81	31	7.0	6.6
Turbine site 003	60.0	3.3	1.65	2.93	34	7.6	7.2
Turbine site 004	60.0	2.3	1.66	2.04	12	-	-
Turbine site 005	60.0	3.2	1.64	2.91	33	7.1	6.7
Turbine site 006	60.0	3.2	1.63	2.85	32	6.4	6.0

Wind farm: 'Turbine cluster Phra Tamnak Mountain SWT-1.3-62'

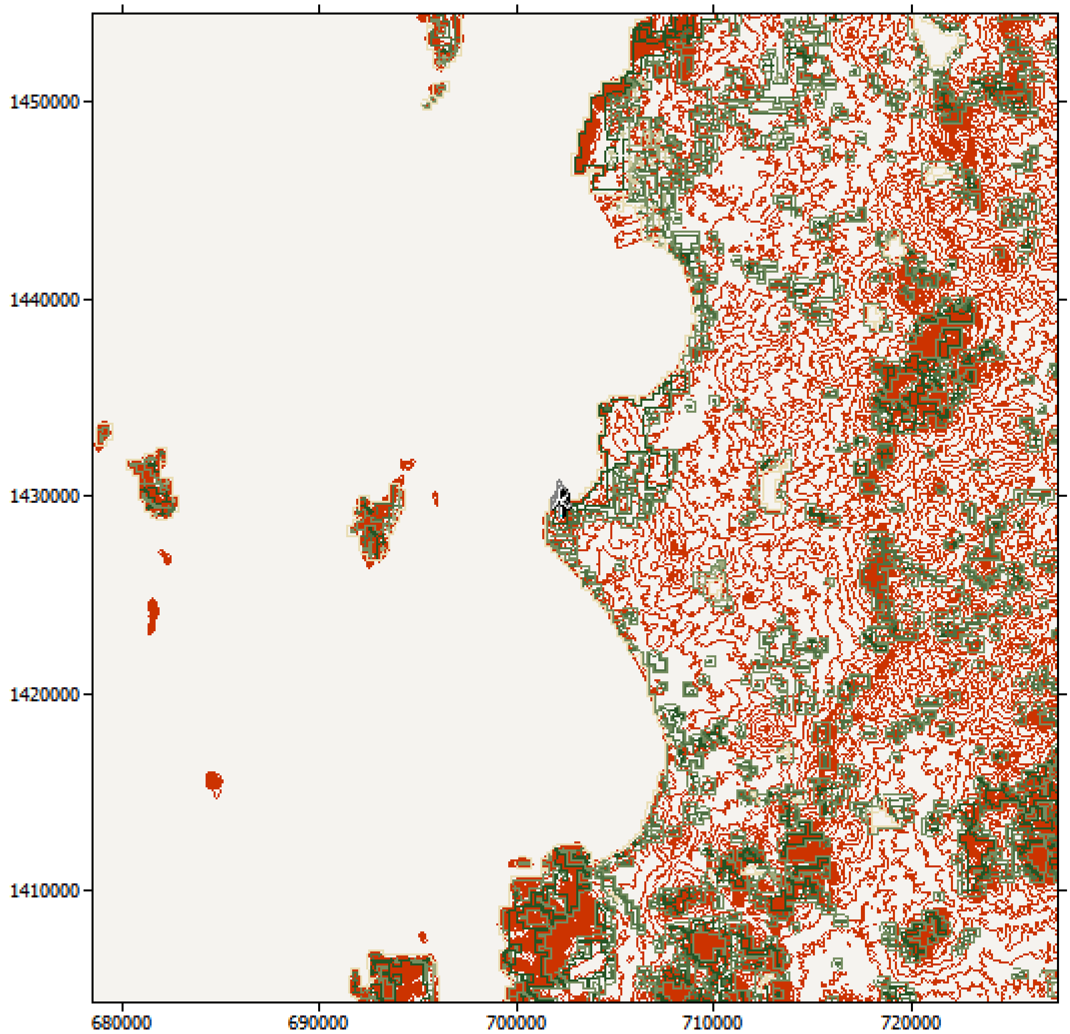


Figure 4-31 *Wind farm: 'Turbine cluster Phra Tamnak Mountain SWT-1.3-62'*

Table 4-62 *Summary results Wind farm: 'Turbine cluster Phra Tamnak Mountain SWT-1.3-62'*

Parameter	Total	Average	Minimum	Maximum
Net AEP [MWh]	252.545	42.091	30.053	54.561
Gross AEP [MWh]	368.748	61.458	49.781	79.895
Wake loss [%]	31.51	-	-	-
Capacity factor [%]	0.4	-	0.3	0.5

Table 4-63 *Site results Wind farm: 'Turbine cluster Phra Tamnak Mountain SWT-1.3-62'*

Site	Elevation [m] a.s.l.	Height [m] a.g.l.	Air density [kg/m&sup3]	Net AEP [MWh]	Wake loss [%]	Capacity factor [%]
Turbine site 001	52.8	60.0	1.143	46.810	11.77	0.4
Turbine site 002	55.5	60.0	1.143	30.053	39.63	0.3
Turbine site 003	81.4	60.0	1.141	54.561	31.71	0.5
Turbine site 004	56.9	60.0	1.143	30.460	39.75	0.3
Turbine site 005	81.7	60.0	1.141	51.744	33.41	0.5
Turbine site 006	63.6	60.0	1.142	38.917	32.62	0.3

Table 4-64 *Site wind climates Wind farm: 'Turbine cluster Phra Tamnak Mountain SWT-1.3-62'*

Site	H [m]	A [m/s]	k	U [m/s]	E [W/m²]	RIX [%]	dRIX [%]
Turbine site 001	60.0	2.3	1.79	2.02	10	0.3	-0.1
Turbine site 002	60.0	2.2	1.79	2.00	10	0.5	0.1
Turbine site 003	60.0	2.5	1.79	2.19	13	0.8	0.4
Turbine site 004	60.0	2.2	1.78	1.99	10	0.8	0.4
Turbine site 005	60.0	2.4	1.78	2.18	13	1.0	0.6
Turbine site 006	60.0	2.3	1.77	2.04	11	0.7	0.3

Wind farm: 'Turbine cluster Ko Lan SWT-1.3-62'

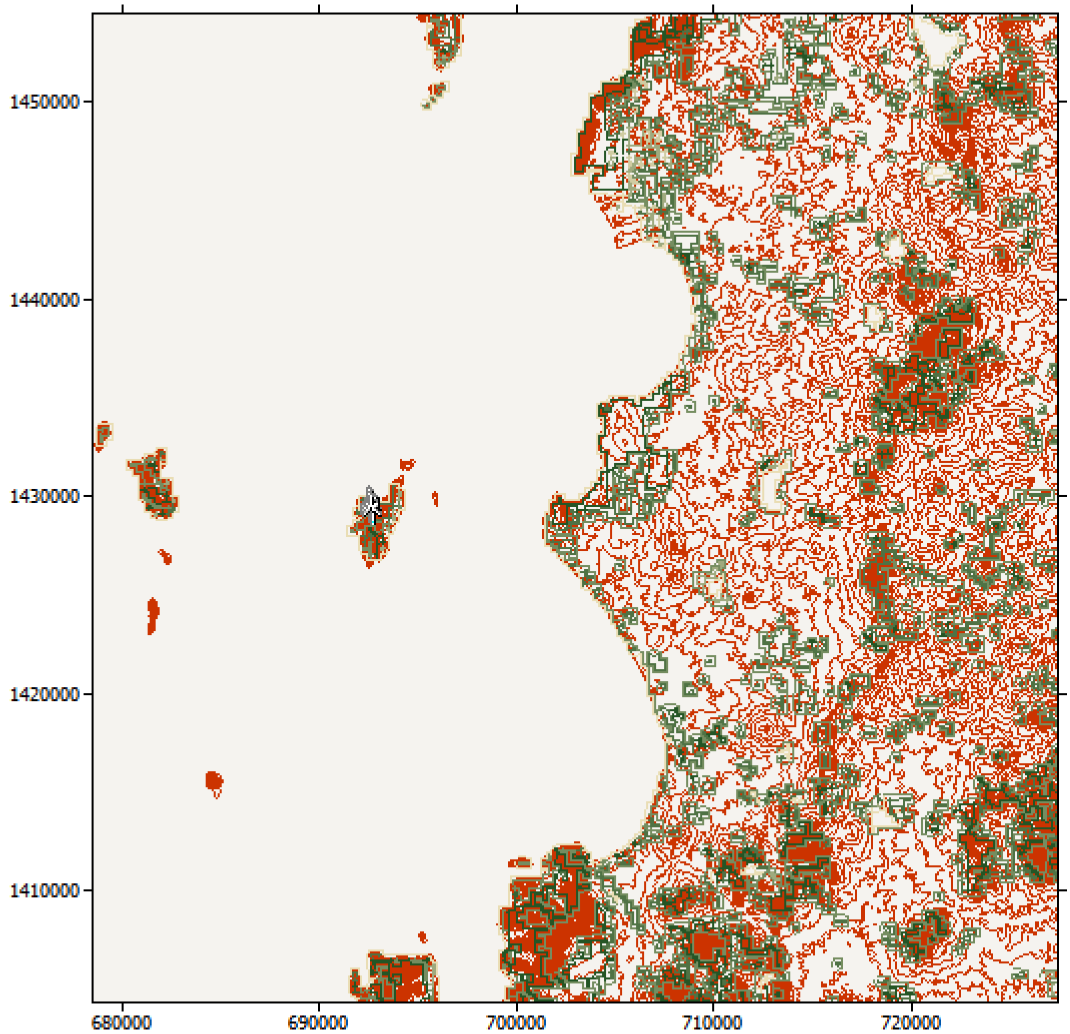


Figure 4-32 *Wind farm: 'Turbine cluster Ko Lan SWT-1.3-62'*

Table 4-65 *Summary results Wind farm: 'Turbine cluster Ko Lan SWT-1.3-62'*

Parameter	Total	Average	Minimum	Maximum
Net AEP [MWh]	1106.243	184.374	101.889	228.531
Gross AEP [MWh]	1448.369	241.395	146.801	283.522
Wake loss [%]	23.62	-	-	-
Capacity factor [%]	1.6	-	0.9	2.0

Table 4-66 *Site results Wind farm: 'Turbine cluster Ko Lan SWT-1.3-62'*

Site	Elevation [m] a.s.l.	Height [m] a.g.l.	Air density [kg/m&sup3]	Net AEP [MWh]	Wake loss [%]	Capacity factor [%]
Turbine site 001	110.5	60.0	1.138	101.889	30.59	0.9
Turbine site 002	127.0	60.0	1.136	178.076	17.81	1.6
Turbine site 003	171.2	60.0	1.132	198.953	25.03	1.7
Turbine site 004	178.2	60.0	1.132	228.531	19.40	2.0
Turbine site 005	167.7	60.0	1.133	173.322	33.57	1.5
Turbine site 006	164.7	60.0	1.133	225.472	18.04	2.0

Table 4-67 *Site wind climates Wind farm: 'Turbine cluster Ko Lan SWT-1.3-62'*

Site	H [m]	A [m/s]	k	U [m/s]	E [W/m²]	RIX [%]	dRIX [%]
Turbine site 001	60.0	2.7	1.65	2.41	19	4.9	4.5
Turbine site 002	60.0	2.9	1.57	2.59	25	5.2	4.8
Turbine site 003	60.0	3.1	1.65	2.81	30	7.0	6.6
Turbine site 004	60.0	3.2	1.65	2.86	32	7.0	6.6
Turbine site 005	60.0	3.1	1.64	2.79	29	6.5	6.1
Turbine site 006	60.0	3.1	1.62	2.81	31	5.9	5.5

Wind farm: 'Turbine cluster Phra Tamnak Mountain SWT-2.3-82 VS'

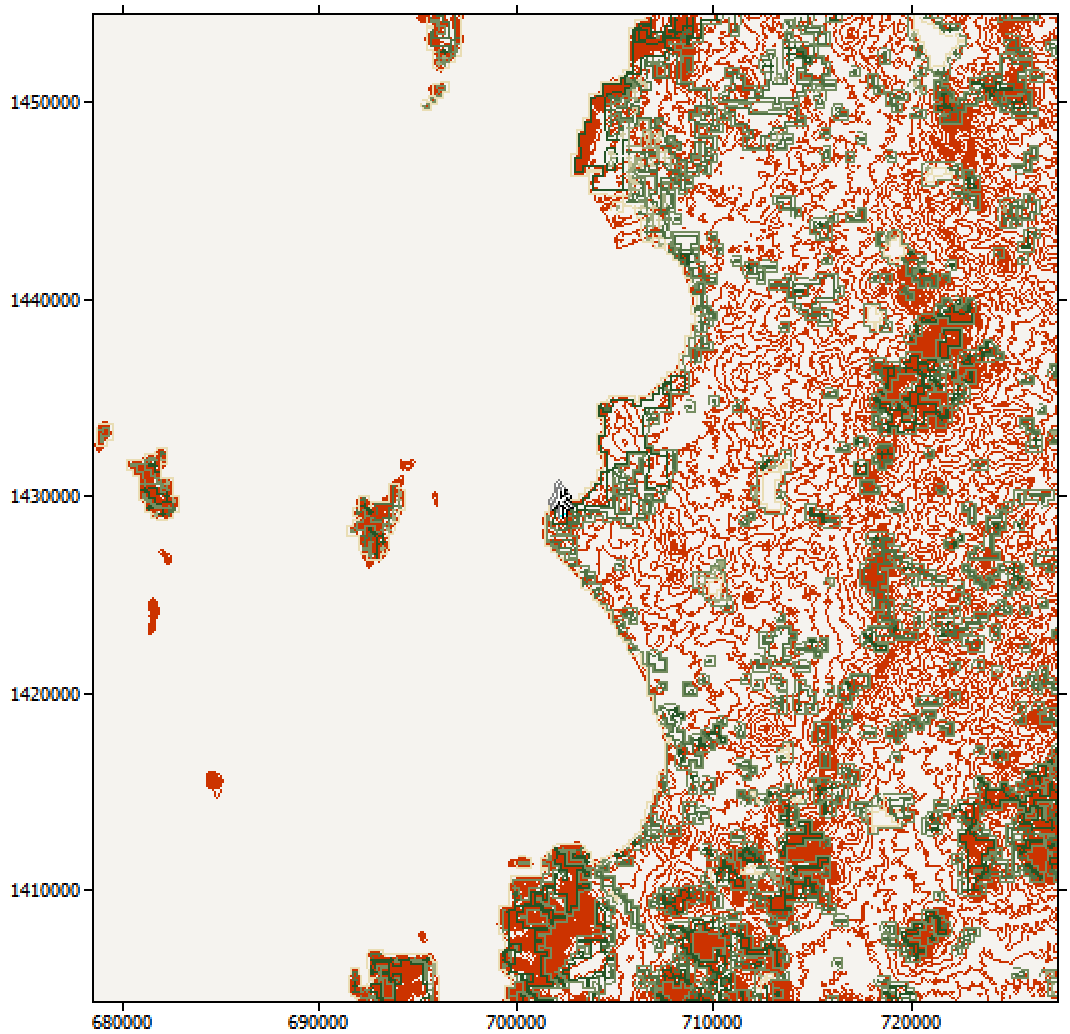


Figure 4-33 *Wind farm: 'Turbine cluster Phra Tamnak Mountain SWT-2.3-82 VS'*

Table 4-68 *Summary results Wind farm: 'Turbine cluster Phra Tamnak Mountain SWT-2.3-82 VS'*

Parameter	Total	Average	Minimum	Maximum
Net AEP [MWh]	400.010	66.668	46.990	88.028
Gross AEP [MWh]	639.403	106.567	88.043	138.543
Wake loss [%]	37.44	-	-	-
Capacity factor [%]	0.3	-	0.2	0.4

Table 4-69 *Site results Wind farm: 'Turbine cluster Phra Tamnak Mountain SWT-2.3-82 VS'*

Site	Elevation [m] a.s.l.	Height [m] a.g.l.	Air density [kg/m&sup3]	Net AEP [MWh]	Wake loss [%]	Capacity factor [%]
Turbine site 001	54.1	80.0	1.141	80.223	13.03	0.4
Turbine site 002	54.4	80.0	1.141	46.990	46.63	0.2
Turbine site 003	82.0	80.0	1.139	73.549	42.42	0.4
Turbine site 004	56.3	80.0	1.141	47.353	47.80	0.2
Turbine site 005	90.0	80.0	1.138	88.028	36.46	0.4
Turbine site 006	63.9	80.0	1.140	63.867	37.47	0.3

Table 4-70 *Site wind climates Wind farm: 'Turbine cluster Phra Tamnak Mountain SWT-2.3-82 VS'*

Site	H [m]	A [m/s]	k	U [m/s]	E [W/m²]	RIX [%]	dRIX [%]
Turbine site 001	80.0	2.4	1.82	2.10	11	0.3	-0.1
Turbine site 002	80.0	2.3	1.82	2.09	11	0.6	0.2
Turbine site 003	80.0	2.5	1.81	2.25	14	0.8	0.4
Turbine site 004	80.0	2.3	1.81	2.09	11	0.8	0.4
Turbine site 005	80.0	2.6	1.81	2.28	14	0.9	0.5
Turbine site 006	80.0	2.4	1.80	2.14	12	0.7	0.3

Wind farm: 'Turbine cluster Ko Lan SWT-2.3-82 VS'

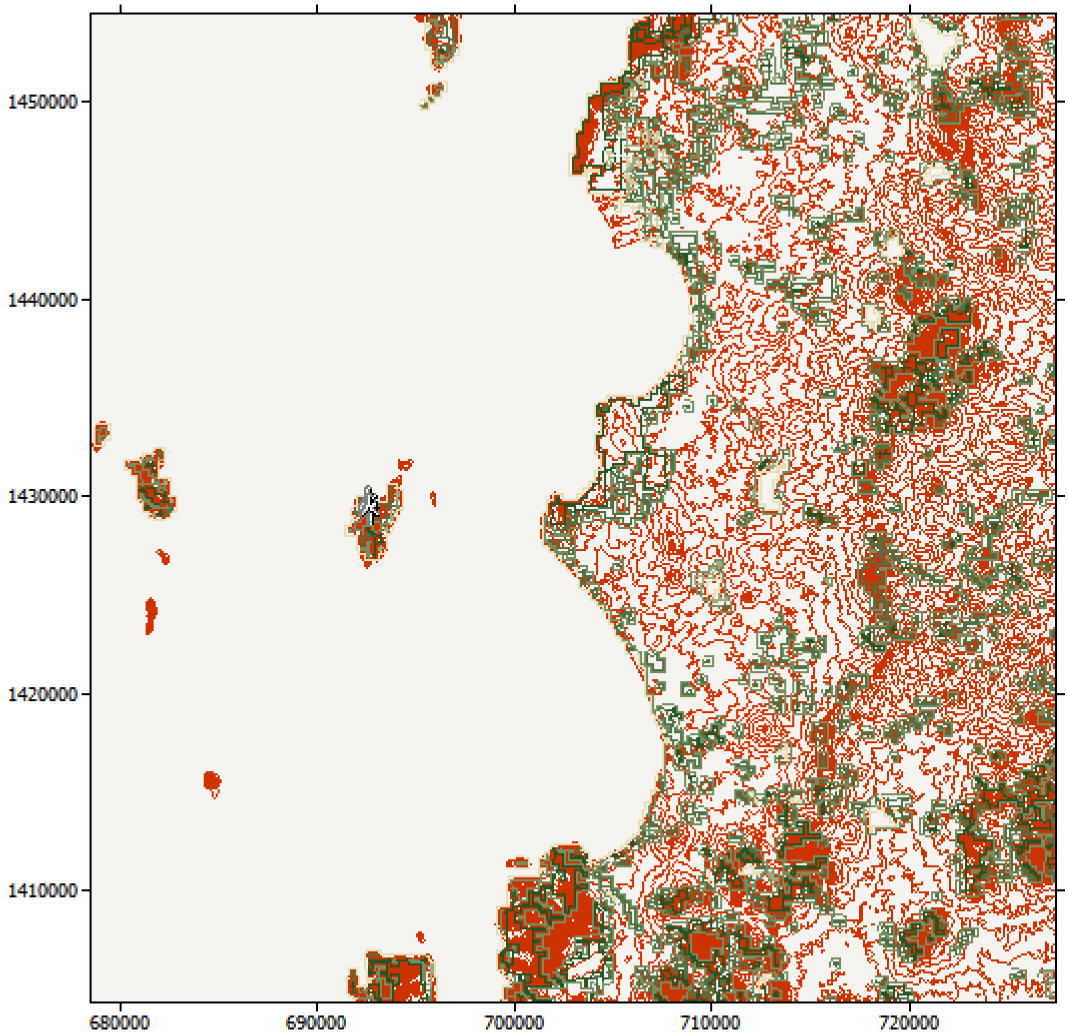


Figure 4-34 *Wind farm: 'Turbine cluster Ko Lan SWT-2.3-82 VS'*

Table 4-71 *Summary results Wind farm: 'Turbine cluster Ko Lan SWT-2.3-82 VS'*

Parameter	Total	Average	Minimum	Maximum
Net AEP [MWh]	1560.725	260.121	141.305	343.371
Gross AEP [MWh]	2194.673	365.779	249.845	433.843
Wake loss [%]	28.89	-	-	-
Capacity factor [%]	1.3	-	0.7	1.7

Table 4-72 *Site results Wind farm: 'Turbine cluster Ko Lan SWT-2.3-82 VS'*

Site	Elevation [m] a.s.l.	Height [m] a.g.l.	Air density [kg/m&sup3]	Net AEP [MWh]	Wake loss [%]	Capacity factor [%]
Turbine site 001	115.0	80.0	1.136	141.305	43.44	0.7
Turbine site 002	133.6	80.0	1.134	258.962	24.88	1.3
Turbine site 003	167.9	80.0	1.131	279.169	29.51	1.4
Turbine site 004	182.2	80.0	1.129	343.371	20.85	1.7
Turbine site 005	158.6	80.0	1.132	226.475	39.75	1.1
Turbine site 006	162.6	80.0	1.131	311.443	21.01	1.5

Table 4-73 *Site wind climates Wind farm: 'Turbine cluster Ko Lan SWT-2.3-82 VS'*

Site	H [m]	A [m/s]	k	U [m/s]	E [W/m²]	RIX [%]	dRIX [%]
Turbine site 001	80.0	2.8	1.68	2.49	21	4.9	4.5
Turbine site 002	80.0	3.0	1.62	2.65	26	5.0	4.6
Turbine site 003	80.0	3.1	1.67	2.79	29	6.9	6.5
Turbine site 004	80.0	3.2	1.68	2.87	31	7.2	6.8
Turbine site 005	80.0	3.1	1.67	2.75	28	6.1	5.7
Turbine site 006	80.0	3.1	1.66	2.78	29	5.8	5.4

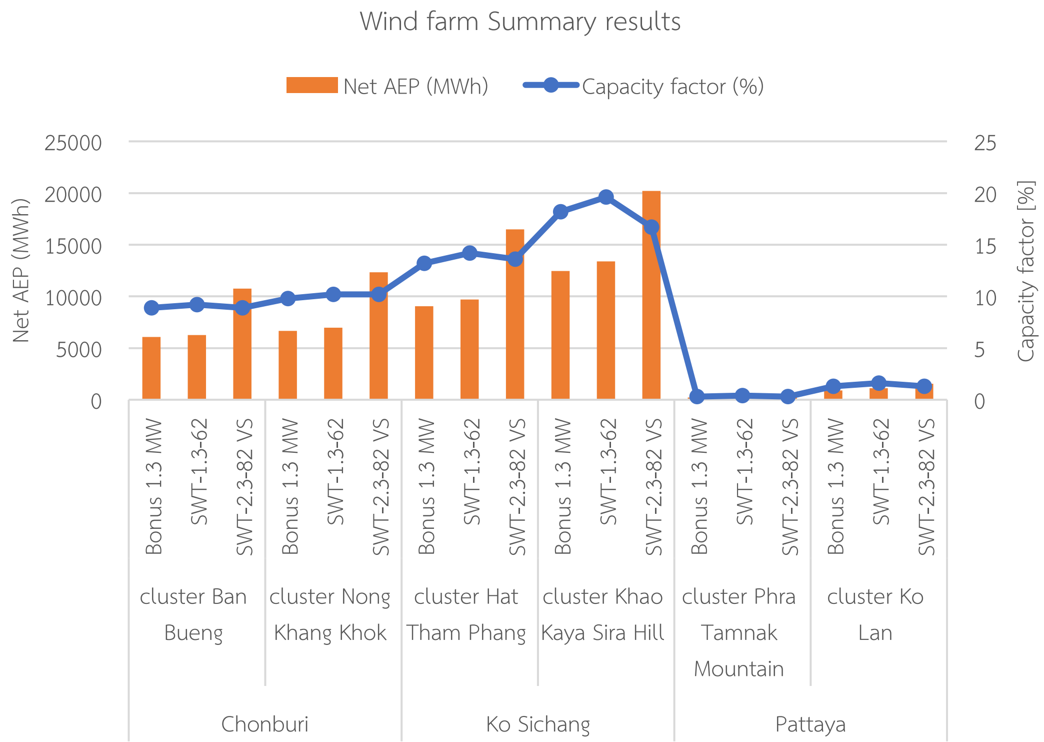


Figure 4-35 *Wind farm Summary results*

Bonus 1.3 MW, SWT-1.3-62, and SWT-2.3-82 VS wind turbines in the Chonburi area can generate a maximum Net Annual Energy Production (AEP) of 12,333 MWh on the Nong Khang Khok cluster from wind turbines model SWT-2.3-82 VS, and capacity factor (%) is the highest at 10.2 % on the Nong Khang Khok cluster from wind turbines model SWT-1.3-62 and SWT-2.3-82 VS. Ko Sichang can generate the highest Net Annual Energy Production (AEP) at 20,197 MWh on the Khao Kaya Sira Hill cluster from wind turbines. Model SWT-2.3-82 VS and capacity factor (%) are highest at 19.6 % on Khao Kaya Sira Hill cluster from wind turbine model SWT-1.3-62, and Pattaya can generate the highest net annual energy production (AEP) at 1,560.725 MWh on Ko. Lan cluster from wind turbine model SWT-2.3-82 VS and the highest capacity factor (%) at 1.6 % on Ko Lan cluster from wind turbine model SWT-1.3-62.

However, the difference in Figure 4-35 shows the suitability of the wind turbine generation in three areas, namely the SWT-2.3-82 VS wind turbine with a higher net annual energy production (AEP) capacity than the other two comparison models.

4.3. Economic analysis of site area and decision-making criteria for investment

Economics of wind power in Thailand and decision-making criteria for investment. Figure 4-36 presents a picture of the research process. by using data that has been collected for 3 years (2019–2021) from the Meteorological Station in Chonburi Province. Data were recorded at 10-minute intervals every day [13], where they were collected, classified, and extracted in the NumPy Python tool. The processed data was fed into the WAsP software for further processing.

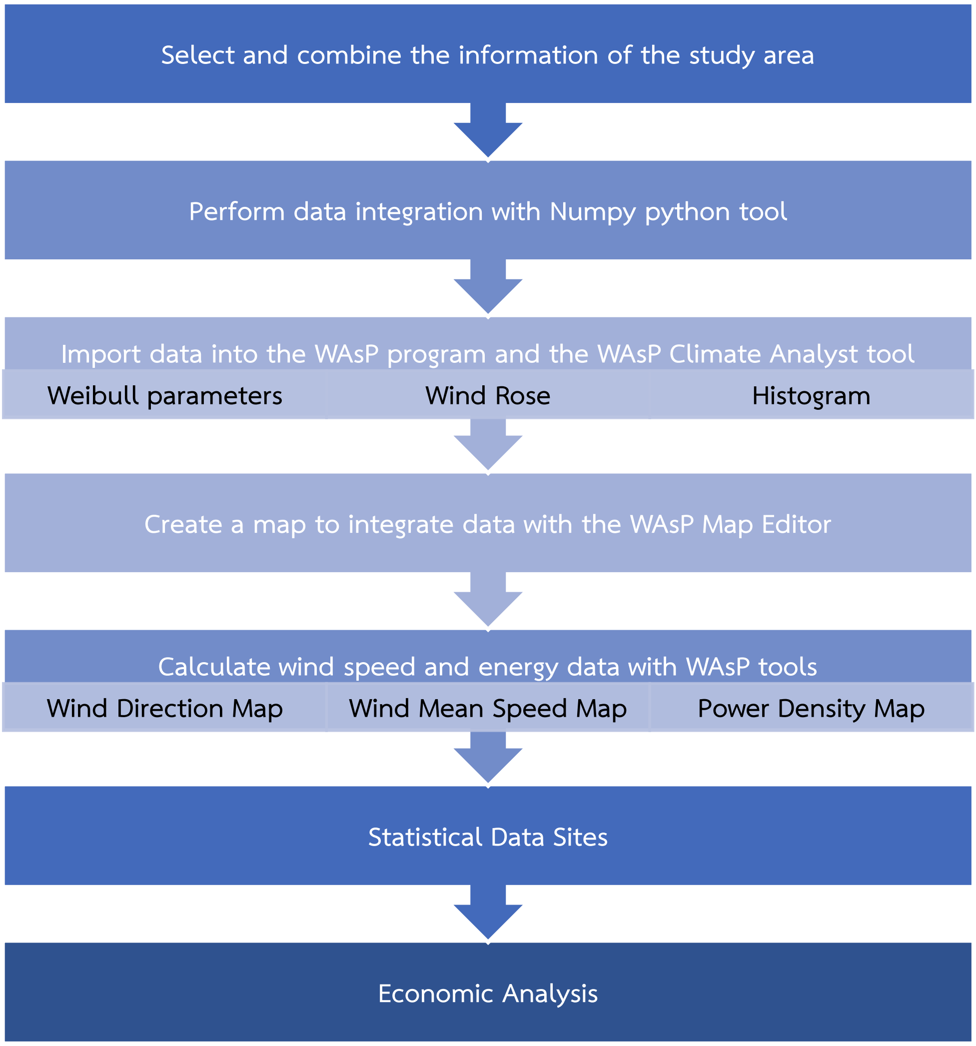


Figure 4-36 *Framework for analyzing selected sites*

Table 4-74 Cost elements in the calculation of the levelized cost of energy [97]

	Economic analysis (public sector)	Financial analysis (private sector)
Viewpoint	Overall society	Investor / Developer
Decision criteria	Positive net present value	Payback or internal rate of return
Timeframe	Life cycle (technical life)	Often shorter term
Discount rate	Reflects social preferences and other factors	Reflects costs of borrowing, desired returns (normally higher than the economic discount rate)
Energy prices (benefits)	Social values reflect willingness to pay; alternative uses	Prevailing market prices
Costs	Overall costs to society	Private, prevailing market prices
Taxes and subsidies	Ignored	Considered
Social infrastructure (e.g. roads)	Considered	Ignored, if not part of investment
External impacts	Analyzed as much as possible	Ignored

In this research, economic analysis (public sector) will be emphasized, using the educational perspective in Table 4-74 as a perspective, including additional decision-making criteria, a payback period, and an internal rate of return to support investment decision-making. in the research area.

Table 4-75 *Discount rate*

Source	Organization	Discount rate
[97]	the Danish Finance Ministry for socio-economic analysis.	4%
[97]	IEA, 2015	3 %, 7 % and 10 %
[98]	The Directorate-General for Energy (DG Ener), or ENER, is a Directorate-General of the European Commission	2% - 4% for domestic systems
[98]	The Directorate-General for Energy (DG Ener), or ENER, is a Directorate-General of the European Commission	6-8% for all other technologies
[99]	IEA, 2022	7 % Central case

The discount rate from Table 4-75, when calculated, found that the average is 5.40% and the median is 5.00%.

Table 4-76 *Energy production in the year*

	Capacity factor (%)	Gross AEP (MWh)	Net AEP (MWh)	Wake loss (%)
Chonburi				
cluster Ban Bueng				
Bonus 1.3 MW	8.90	6,303.00	6,061.00	3.84
SWT-1.3-62	9.20	6,550.00	6,265.00	4.36
SWT-2.3-82 VS	8.90	11,333.00	10,748.00	5.16
cluster Nong Khang Khok				
Bonus 1.3 MW	9.80	7,172.00	6,667.00	7.04
SWT-1.3-62	10.20	7,435.00	6,962.00	6.36
SWT-2.3-82 VS	10.20	13,215.00	12,333.00	6.68
Ko Sichang				
cluster Hat Tham Phang				
Bonus 1.3 MW	13.20	10,690.00	9,043.00	15.41
SWT-1.3-62	14.20	11,344.00	9,691.00	14.58
SWT-2.3-82 VS	13.60	20,070.00	16,498.00	17.80
cluster Khao Kaya Sira Hill				
Bonus 1.3 MW	18.20	15,676.00	12,460.00	20.52
SWT-1.3-62	19.60	16,214.00	13,384.00	17.46

	Capacity factor (%)	Gross AEP (MWh)	Net AEP (MWh)	Wake loss (%)
SWT-2.3-82 VS	16.70	27,496.00	20,197.00	26.55
Pattaya				
cluster Phra Tamnak Mountain				
Bonus 1.3 MW	0.30	301.35	207.10	31.28
SWT-1.3-62	0.40	368.75	252.55	31.51
SWT-2.3-82 VS	0.30	639.40	400.01	37.44
cluster Ko Lan				
Bonus 1.3 MW	1.30	1,275.75	906.30	28.96
SWT-1.3-62	1.60	1,448.37	1,106.24	23.62
SWT-2.3-82 VS	1.30	2,194.67	1,560.73	28.89

According to 4.2.3, the wind farm simulation data for electricity generation by area can be summarized in Table 4-76 and Figure 4-35 by using Total Parameter Net AEP (GWh), Gross AEP (GWh), Wake Loss (%), and Capacity Factor (%).

Table 4-77 *Asset's lifetime*

Source	Sub-Energy	Technology Project	Lifetime (Year)
[98]	FF-Coal / Lignite	Coal/Lignite	40
[98]	FF-Natural gas	CCGT and OCGT	30
[98]	Nuclear	Nuclear	60
[98]	RES-Biogas	RES-Biogas & Biomass	25
[98]	RES-Solar	Solar concentrated solar power (CSP)	25
[98]	RES-Solar	Solar PV – Rooftop	25
[98]	RES-Solar	Solar PV - Utility-scale	25
[98]	RES-Wind	Wind off-shore	25
[98]	RES-Wind	Wind on-shore	25
[98]	RES-Hydro	Hydropower	50
[98]	n.a.	Domestic heating systems	25
[97]	Nuclear	Nuclear	60
[97]	Solar	Solar PV	25
[97]	Wind	Wind	25

From Table 4-77, we learn the lifetime of each type of power plant, where the lifetime of a wind power plant is 25 years.

Table 4-78 Total Installed cost ranges and weighted averages for onshore wind projects by country/region, 2010 and 2021 [100]

	2010			2021		
	5th percentile	Weighted average	95th percentile	5th percentile	Weighted average	95th percentile
	(2021 USD/kW)					
Africa	1,440	1,667	3,145	1,149	1,892	2,924
Central America and the Caribbean	2,618	2,776	2,922	1,583	1,583	1,583
Eurasia	2,534	2,534	2,534	888	1,349	1,738
Europe	1,832	2,517	3,671	1,127	1,623	2,182
North America	1,962	2,563	3,329	1,079	1,388	2,325
Oceania	3,176	3,647	4,010	1,136	1,256	1,371
Other Asia	1,920	2,606	2,860	1,232	1,545	2,260
Other South America	2,513	2,739	2,863	1,146	1,663	2,292
Brazil	2,461	2,734	3,008	842	1,150	1,960
China	1,311	1,554	1,819	968	1,157	1,514
India	927	1,415	1,673	755	926	1,057

When the total installed cost from Table 4-78 is calculated, the average for the year 2021 is 1,412 USD and the median is 1,388 USD.

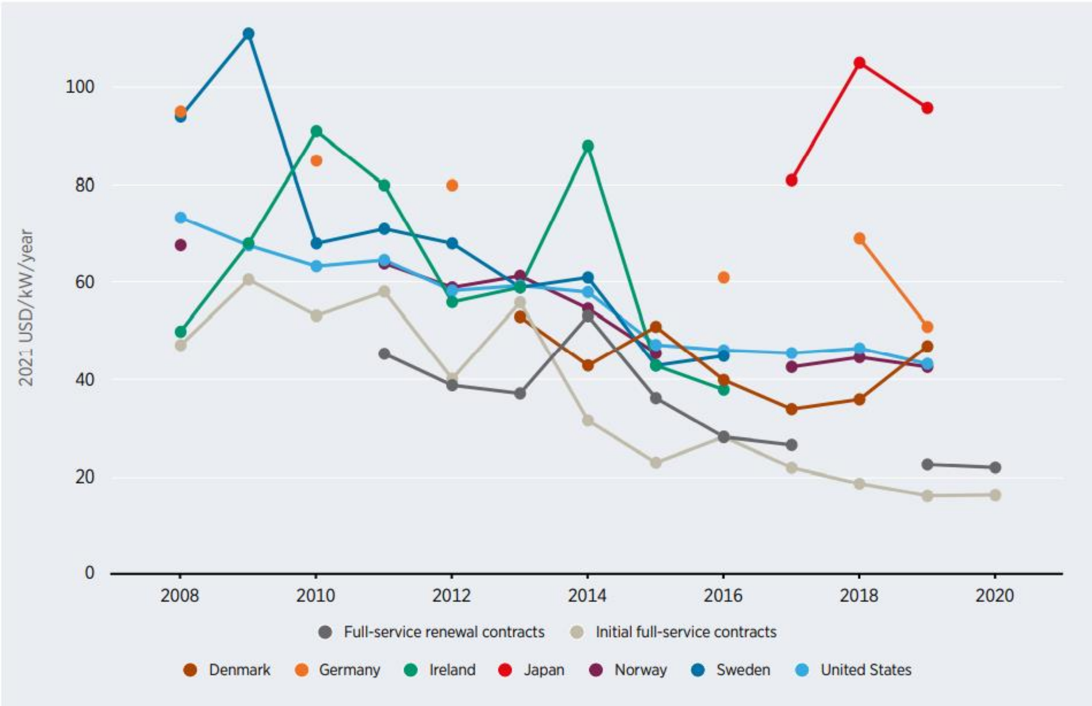


Figure 4-37 *Full-service (initial and renewal) O&M pricing indexes and weighted average O&M costs in Denmark, Germany, Ireland, Japan, Norway, Sweden and the United States, 2008-2020*
(Source: [Renewable Power Generation Costs in 2021 (irena.org)]).

Operation and maintenance costs Between 2016 and 2018, the O&M cost for onshore wind was $33 per kilowatt per year. Additional operating costs that are not covered by the service contract (such as insurance, land rent payments, local taxes, and other factors) will result in differences between the contract price and O&M costs in each country [100].

On May 6, 2022, the Energy Policy and Planning Office (EPPO) [101] approved the bidding plan for a new renewable energy power plant project, which will commence commercial operation (COD) between 2022 to 2030, under the Power Development Plan 2018, Revision 1 (PDP2018Rev1). In addition, the Energy Regulatory Commission (ERC) has established a Feed-In Tariff (FiT) structure for the period of 2022 to 2030. This structure will cover non-firm Power Purchase Agreements (PPAs) for renewable energy projects, including solar power plants, wind farms, biogas (waste water), and partial power purchase agreements for hybrid solar farms and battery energy storage systems (Solar+BESS), with PPA terms ranging between 20 to 25 years. The total PPA capacity for projects with a COD between 2024 to 2030 will be 5.2GW.

The FiT structure for this auction sets the lowest ever tariff rates for renewable energy projects in Thailand. The biogas tariff rate is set at Bt 2.07/kWh, wind farms at Bt 3.1/kWh, solar farms at Bt2.17/kWh, and solar farm+BESS at 2.83 baht/kWh.

Table 4-79 *Renewable capacity breakdown by type and COD year*

Project type	PPA type	FiT (THB/kWh)	PPA period	FiT for four southernmost provinces*
Biogas (wastewater)	Non-firm	2.0724	20	2.4724
Wind	Non-firm	3.1014	25	3.5014
Solar farm	Non-firm	2.1679	25	2.5679
Solar farm+BESS (10-90MW)**	Partial-firm	2.8331	25	3.2331

*For projects in the four southernmost provinces of Yala, Narathivas, Pattani, and four districts in Songkhla (Chana, Thepa, Sabayoi, and Nathawee)

**Partial-firm PPAs for solar farm+BESS projects are:

1) 09.00-16.00: purchase 100% of PPA electricity production;
2) 18.01-06.00: purchase based on availability at 60% of PPA contract for two hours
3) 06.01-09.00 and 16.01-18.00: purchase 100% of PPA electricity production Source: ERC

This research focuses on wind energy and utilizes the Feed-In Tariff (FiT) structure for renewable energy projects in Thailand. The current exchange rate United States Dollar to Thai Baht (USD/THB) 3-year average (2019–2021) is 31.4395 THB/USD (Appendix B, Rates of Exchange of Commercial Banks [96]), and the FiT for wind farms is set at 0.0986 USD/kWh. This tariff will be utilized to calculate income estimates and address economic issues, such as the levelized energy cost (LCOE), net present value (NPV), cost-benefit ratio or benefit-cost ratio (BCR or B/C ratio), payback period (PBP), Internal Rate of Return (IRR), Financial Internal Rate of Return (FIRR), and Economics Internal Rate of Return (EIRR).

To summarize the benefits of the wind farm project in the Chonburi, Ko Sichang, and Pattaya Station areas, Table 4-80 has been created using the information presented in Table 4-76, which shows the energy production for the reference year of wind farm operations, and Table 4-79, which breaks down the renewable capacity by type and COD year for revenue reference. In addition, Figure 4-37 provides information on the full-service (initial and renewal) O&M pricing indexes and weighted average O&M

costs in Denmark, Germany, Ireland, Japan, Norway, Sweden, and the United States from 2008-2020, which can be used as a reference for the cost of operating a wind farm.

Table 4-80 *Cost and Benefits of wind farms in the area of Chonburi Station, Koh Si Chang Station, and Pattaya Station*

Wind farm Station	Turbine	Average Net AEP (MWh)	FiT (T$/MWh)	initial investment cost (T$)	O&M (USD/kW per year)
Chonburi					
cluster Ban Bueng	Bonus 1.3 MW	1,010.00	99.63	1,835.60	42,900.00
cluster Nong Khang Khok	Bonus 1.3 MW	1,111.00	109.60	1,835.60	42,900.00
cluster Ban Bueng	SWT-1.3-62	1,044.00	102.99	1,835.60	42,900.00
cluster Nong Khang Khok	SWT-1.3-62	1,160.00	114.43	1,835.60	42,900.00
cluster Ban Bueng	SWT-2.3-82 VS	1,791.00	176.68	3,247.60	75,900.00
cluster Nong Khang Khok	SWT-2.3-82 VS	2,055.00	202.72	3,247.60	75,900.00
Ko Sichang					
cluster Khao Kaya Sira Hill	Bonus 1.3 MW	2,077.00	204.89	1,835.60	42,900.00
cluster Hat Tham Phang	Bonus 1.3 MW	1,507.00	148.66	1,835.60	42,900.00
cluster Khao Kaya Sira Hill	SWT-1.3-62	2,231.00	220.08	1,835.60	42,900.00
cluster Hat Tham Phang	SWT-1.3-62	1,615.00	159.31	1,835.60	42,900.00
cluster Khao Kaya Sira Hill	SWT-2.3-82 VS	3,366.00	332.04	3,247.60	75,900.00
cluster Hat Tham Phang	SWT-2.3-82 VS	2,750.00	271.28	3,247.60	75,900.00
Pattaya					
cluster Phra Tamnak Mountain	Bonus 1.3 MW	34.52	3.40	1,835.60	42,900.00
cluster Ko Lan	Bonus 1.3 MW	151.05	14.90	1,835.60	42,900.00
cluster Phra Tamnak Mountain	SWT-1.3-62	42.09	4.15	1,835.60	42,900.00
cluster Ko Lan	SWT-1.3-62	184.37	18.19	1,835.60	42,900.00
cluster Phra Tamnak Mountain	SWT-2.3-82 VS	66.67	6.58	3,247.60	75,900.00
cluster Ko Lan	SWT-2.3-82 VS	260.12	25.66	3,247.60	75,900.00

Note ;

*T$ means Trillion USD

4.3.1. Levelized Cost of Energy (LCOE)

In calculating the Levelized Cost of Energy (LCOE) to determine the production cost ratio of wind power plants as specified in Equation (11-12), using the average in Table 4-75 Discount rate, Table 4-77 Asset's lifetime, and Table 4-80 Cost and Benefits of wind farms in the area of Chonburi Station, Koh Si Chang Station, and Pattaya Station to calculate the proportion of The Levelized Cost of Energy (LCOE), an economic estimate of the average total cost of building and operating an electric generating system over the entire lifetime of the system's total energy generated over its lifetime [37], is given in Table 4-81.

Table 4-81 *LOCE of Chonburi, Ko Sichang, and Pattaya on different levels Discount rates of 7%, 5.4%, and 5%*

(Unit: USD/MWh)

Area and wind turbine models	Discount rates					
	7%		5.4%		5%	
	Average Net AEP (MWh)	LOCE (USD/MWh)	Average Net AEP (MWh)	LOCE (USD/MWh)	Average Net AEP (MWh)	LOCE (USD/MWh)
Chonburi						
cluster Ban Bueng						
Bonus 1.3 MW	1,010.00	184.82	1,010.00	166.79	1,010.00	162.42
SWT-1.3-62	1,044.00	178.80	1,044.00	161.36	1,044.00	157.13
SWT-2.3-82 VS	1,791.00	184.40	1,791.00	166.42	1,791.00	162.05
cluster Nong Khang Khok						
Bonus 1.3 MW	1,111.00	168.02	1,111.00	151.63	1,111.00	147.65
SWT-1.3-62	1,160.00	160.92	1,160.00	145.23	1,160.00	141.41
SWT-2.3-82 VS	2,055.00	160.71	2,055.00	145.04	2,055.00	141.23
Ko Sichang						
cluster Hat Tham Phang						
Bonus 1.3 MW	1,507.00	123.87	1,507.00	111.79	1,507.00	108.85
SWT-1.3-62	1,615.00	115.58	1,615.00	104.31	1,615.00	101.57
SWT-2.3-82 VS	2,750.00	120.09	2,750.00	108.38	2,750.00	105.54
cluster Khao Kaya Sira Hill						
Bonus 1.3 MW	2,077.00	89.87	2,077.00	81.11	2,077.00	78.98

Area and wind turbine models	Discount rates					
	7%		5.4%		5%	
	Average Net AEP (MWh)	LOCE (USD/MWh)	Average Net AEP (MWh)	LOCE (USD/MWh)	Average Net AEP (MWh)	LOCE (USD/MWh)
SWT-1.3-62	2,231.00	83.67	2,231.00	75.51	2,231.00	73.53
SWT-2.3-82 VS	3,366.00	98.12	3,366.00	88.55	3,366.00	86.22
Pattaya						
cluster Ko Lan						
Bonus 1.3 MW	151.05	1,235.81	151.05	1,115.28	151.05	1,085.99
SWT-1.3-62	184.37	1,012.45	184.37	913.70	184.37	889.71
SWT-2.3-82 VS	260.12	1,269.64	260.12	1,145.81	260.12	1,115.73
cluster Phra Tamnak Mountain						
Bonus 1.3 MW	34.52	5,408.18	34.52	4,880.72	34.52	4,752.56
SWT-1.3-62	42.09	4,434.88	42.09	4,002.35	42.09	3,897.26
SWT-2.3-82 VS	66.67	4,953.80	66.67	4,470.66	66.67	4,353.27

By calculating the leveled cost of energy (LCOE), it is possible to obtain an accurate estimate of energy costs [65] and the average total cost of building and operating a power generation system over the total energy life cycle. The generated cost of the system over its lifetime [37] converts the unit of cost of production into USD/MWh, with wind turbine investment in the first year and O&M expenses in the following year. Until the end of the 25-year project, all three wind turbines at each plant will generate electricity on average. At 5% discount rates, it was discovered that there is a potential area that can make the lowest LOCE value of 73.53 USD/MWh by wind turbine generation SWT-1.3-62 (cluster Khao Kaya Sira Hill). And in the area of Chonburi station, the lowest LOCE is 141.23 USD/MWh for the SWT-2.3-82 VS (cluster Nong Khang Khok) wind turbine at a discount rate of 5%, and the highest is 184.82 USD/MWh for the wind turbine. Bonus model 1.3 MW (cluster Ban Bueng) at discount rates of 7%, in the area of Ko Sichang Station, has the lowest LOCE at 73.53 USD/MWh. Wind turbine model SWT-1.3-62 (cluster Khao Kaya Sira Hill) at Discount rates of 5% and highest at 123.87 USD/MWh by Bonus 1.3 MW wind turbine (cluster Hat Tham Phang) at Discount rates of 7%, and Pattaya station area has the lowest LOCE at 889.71 USD/MWh. by wind turbine model SWT-1.3-62 (cluster Ko Lan) at discounted rates of 5% and highest at 5,408.18 USD/MWh by wind turbine model Bonus 1.3 MW (cluster Phra Tamnak Mountain) at discounted rates of 7%

Table 4-82 *The weighting of these two dimensions is reflected by the following color coding* [97]

	LOW UNCERTAINTY	MEDIUM UNCERTAINTY	HIGH UNCERTAINTY
HIGH COST			
MEDIUM COST			
LOW COST			

Table 4-83 *Cost components of particular importance to the LCOE* [97]

Technology	Capital costs	Fuel price/Availability of local resources	Heat sales	System costs	Climate change costs	Air pollution/ other environmental costs
Coal			Potentially important revenue stream		Depends on climate regulation	Depends on emission control/filtration equipment costs
Natural gas CCGT		Significant regional differences	Potentially important revenue stream		Depends on climate regulation	
Biomass		Varies with access to local resources	Potentially important revenue stream			Depends on emission control/filtration equipment costs
Nuclear	Large differences in investment costs. Discount rate important			Back-up costs		Storage of radioactive waste. Risk of accidents.
Wind		Access to good wind sites		Depends on wind share and system flexibility		

Technology	Capital costs	Fuel price/Availability of local resources	Heat sales	System costs	Climate change costs	Air pollution/ other environmental costs
PV	Considerable technological development	Solar irradiation		Depends on PV share and system flexibility		

Table 4-82 - 4-83 variations in the LCOE display that can be expressed in USD/MWh, where numbers correspond to the resources and potential of the area. And in terms of wind energy, there are medium-high costs in terms of system costs and medium-high uncertainties in terms of fuel price/Availability of local resources. Thus, in some areas, the LCOE (in Table 4-81) is so high that it cannot compete with the areas where there are advantages in terms of resources and potential.

4.3.2. Net Present Value (NPV)

In order to know the net worth of all benefits (cash inflows) and costs (cash outflows) of the project [19] in the research area. Using the net present value in Equation (13-14) and the average values in Table 4-75 Discount rate, Table 4-77 Asset's lifetime, and Table 4-80 Cost and Benefits of wind farms in the area of Chonburi Station, Koh Si Chang Station, and Pattaya Station, including the regulation of the Energy Regulatory Commission on electricity supply from renewable energy, In the form of a Feed-in Tariff (FiT) 2022 - 2030 for groups without fuel costs in Thailand [102], [103] with the purchase rate of electricity according to the resolution of the National Energy Policy Council. In meeting No. 3/2022 (No. 158) on May 6, 2022, [104], [105] according to Table 4-84 and using the exchange rate United States Dollar to Thai Baht (USD/THB) 3-year average (2019–2021) from the Bank of Thailand [106] (Appendix B), with an average median rate of 31.4395 THB/USD in the calculation.

Table 4-84 *Purchase rate of FiT renewable energy for the years 2022 – 2030*

Fuel type	FiT (Baht/unit)			Support period (year)
	FiT_F	FiT_V	FiT	
1) Biogas (Wastewater/Waste)				
Contract production capacity of all sizes	2.0724	-	2.0724	20
2) Wind power				
Contract production capacity of all sizes	3.1014	-	3.1014	25
3) Solar Farm				
ground-mounted Contract production capacity of all sizes	2.1679	-	2.1679	25
Ground-mounted solar power in combination with energy storage systems. (Solar+BESS)(2) Contract capacity >10 - 90 MW	2.8331	-	2.8331	25

Note

1) For projects in the southern border provinces, namely Yala, Pattani, Narathiwat, and 4 districts in Songkhla Province (Chana District, Thepha District, Saba Yoi District, and Na Thawi District), to receive a FiT Premium rate of 0.5 baht per unit throughout the project's life.

2) A partial firm contract for ground-mounted solar energy with an energy storage system (Solar + BESS) is being negotiated.
   Specify the form of power purchase as follows:
   a) During the period of 9.00 a.m.–4.00 p.m., 100% of the electricity sold to the system and purchased power is generated according to the power purchase agreement.
   b) From 6.01 p.m. to 6:00 a.m., ready to deliver electricity to the system in an amount of energy equal to 60% of the amount of electricity offered for sale according to the power purchase agreement for 2 hours (60% of the contracted capacity * 2 hours), whereby the Electricity Authority buys all and can pay The maximum power capacity is not more than 60% of the amount of electricity sold according to the power purchase agreement.
   c) During the periods 06.01 a.m.–09.00 a.m. and 4.01 p.m.–6.00 p.m., the transmission and purchase of electricity are not more than 100% of the electricity sold under the power purchase agreement.

Table 4-85 *NPV of Chonburi, Ko Sichang, and Pattaya on different levels Discount rates of 7%, 5.4%, and 5%*

(Unit: USD)

Area and wind turbine models	**Discount rates**		
	5.0%	**5.4%**	**7.0%**
Chonburi			
cluster Ban Bueng			
Bonus 1.3 MW	(1,036,007.21)	(1,067,103.25)	(1,174,456.41)
SWT-1.3-62	(988,736.34)	(1,021,670.73)	(1,135,370.48)
SWT-2.3-82 VS	(1,827,267.61)	(1,882,504.11)	(2,073,197.65)
cluster Nong Khang Khok			
Bonus 1.3 MW	(895,584.91)	(932,141.95)	(1,058,348.18)
SWT-1.3-62	(827,459.24)	(866,665.68)	(1,002,018.45)
SWT-2.3-82 VS	(1,460,223.18)	(1,529,733.98)	(1,769,706.83)
Ko Sichang			
cluster Hat Tham Phang			
Bonus 1.3 MW	(345,018.27)	(402,986.75)	(603,111.95)
SWT-1.3-62	(194,863.73)	(258,671.70)	(478,956.62)
SWT-2.3-82 VS	(493,950.91)	(601,039.89)	(970,744.25)
cluster Khao Kaya Sira Hill			
Bonus 1.3 MW	447,464.02	358,676.03	52,152.32
SWT-1.3-62	661,573.27	564,458.60	229,188.63
SWT-2.3-82 VS	362,486.09	222,090.41	(262,599.01)
Pattaya			

Area and wind turbine models	Discount rates		
	5.0%	5.4%	7.0%
cluster Ko Lan			
Bonus 1.3 MW	(2,230,222.41)	(2,214,875.61)	(2,161,893.69)
SWT-1.3-62	(2,183,891.40)	(2,170,346.40)	(2,123,584.87)
SWT-2.3-82 VS	(3,955,679.01)	(3,928,141.93)	(3,833,075.39)
cluster Phra Tamnak Mountain			
Bonus 1.3 MW	(2,392,241.94)	(2,370,594.23)	(2,295,859.59)
SWT-1.3-62	(2,381,710.27)	(2,360,472.13)	(2,287,151.48)
SWT-2.3-82 VS	(4,224,640.55)	(4,186,643.60)	(4,055,466.33)

The net present value (NPV) of the project is calculated as shown in Table 4-85. To calculate the NPV per plant, the wind turbines are invested in the first year, and O&M costs are incurred in the following years until the end of the 25th project. years from each of the three wind turbine generations For determining whether the plan was useful within the analysis period or not, it was found that only the area around Ko Sichang station could show a positive value, while the Station area of Chonburi has a negative value of up to -2,073,197.65 USD by wind turbine model SWT-2.3-82 VS (cluster Ban Bueng) at discount rates of 7% and the lowest at -827,459.24 USD by wind turbine model SWT-1.3-62 (cluster Nong Khang Khok). at discounted rates of 5%, Station area of Ko Si Chang The maximum negative value was -970,744.25 USD by the SWT-2.3-82 VS (cluster Hat Tham Phang) wind turbine at discount rates of 7%, and the highest positive value was 661,573.27 USD by the SWT-1.3-62 wind turbine model (cluster Khao Kaya Sira Hill) at discount rates of 5%, and the Station area of Pattaya has a negative value of up to -4,224,640.55 USD by wind turbine model SWT-2.3-82 VS (cluster Phra Tamnak Mountain) at discount rates of 5% and the lowest at -2,123,584.87 USD by wind turbine model SWT-1.3-62 (cluster Ko Lan). at discounted rates of 7%

4.3.3. Cost-benefit ratio or rate of return on expenses (BCR or B/C ratio)

Analytical evaluation for the cost-benefit ratio (BCR) of interesting projects including the cost of the investment as well, even if the investment has passed. or available only in the first year of operation as a tool for making economic decisions. indicated to reduce misunderstandings that may occur in using NPV according to Equation (17-18) and using data in Table 4-75 Discount rate, Table 4-77 Asset's lifetime, and Table 4-80 Cost and Benefits of wind farms in the area of Chonburi Station, Koh Si Chang Station, and Pattaya Station, showing the results of the analysis separated from discount. rates of 5.0%, 5.4%, and 7.0%, according to Table 4-86.

Table 4-86 *BCR of Chonburi, Ko Sichang, and Pattaya on different levels Discount rates of 7%, 5.4%, and 5%*

Area and wind turbine models	Discount rates		
	5.0%	**5.4%**	**7.0%**
Chonburi			
cluster Ban Bueng			
Bonus 1.3 MW	(1.36)	(1.26)	(0.99)
SWT-1.3-62	(1.47)	(1.37)	(1.06)
SWT-2.3-82 VS	(1.36)	(1.27)	(0.99)
cluster Nong Khang Khok			
Bonus 1.3 MW	(1.72)	(1.59)	(1.21)
SWT-1.3-62	(1.95)	(1.79)	(1.33)
SWT-2.3-82 VS	(1.96)	(1.80)	(1.33)
Ko Sichang			
cluster Hat Tham Phang			
Bonus 1.3 MW	(6.07)	(5.00)	(2.87)
SWT-1.3-62	(11.52)	(8.34)	(3.88)
SWT-2.3-82 VS	(7.74)	(6.11)	(3.26)
cluster Khao Kaya Sira Hill			
Bonus 1.3 MW	6.45	7.74	45.78
SWT-1.3-62	4.69	5.28	11.19
SWT-2.3-82 VS	12.91	20.25	(14.74)
Pattaya			
cluster Ko Lan			

Area and wind turbine models	Discount rates		
	5.0%	**5.4%**	**7.0%**
Bonus 1.3 MW	(0.09)	(0.09)	(0.08)
SWT-1.3-62	(0.12)	(0.11)	(0.10)
SWT-2.3-82 VS	(0.09)	(0.09)	(0.08)
cluster Phra Tamnak Mountain			
Bonus 1.3 MW	(0.02)	(0.02)	(0.02)
SWT-1.3-62	(0.02)	(0.02)	(0.02)
SWT-2.3-82 VS	(0.02)	(0.02)	(0.02)

Table 4-86 shows the ratio of the cumulative present value of all benefits to the cumulative present value of all costs. This includes the initial investment. This investment is only made in the first year of operation. Wind turbines generate electricity in all three areas, according to the data, but only the area around Ko Sichang Station had positive values. The details in each area are: The area of Chonburi Station has the lowest BCR value at -1.96 for the SWT-2.3-82 VS wind turbine model (cluster Nong Khang Khok) at discount rates of 5% and the highest at -0.99 for the Bonus 1.3 MW wind turbine model. and SWT-2.3-82 VS (cluster Ban Bueng) at discounted rates of 7%, The area of Ko Sichang station has the lowest BCR at -14.74 for the SWT-2.3-82 VS (cluster Khao Kaya Sira Hill) wind turbine at a discount rate of 7% and the highest at 45.78 for the Bonus 1.3 MW wind turbine. (cluster Khao Kaya Sira Hill) at a discount rate of 7%, And the area of Pattaya station has the lowest BCR at -0.12 for the SWT-1.3-62 (cluster Ko Lan) wind turbine at a discount rate of 5% and the highest at -0.02 for the Bonus 1.3 MW wind turbine., SWT-1.3-62, and SWT-2.3-82 VS (cluster Phra Tamnak Mountain) at discount rates of 5%, 5.4%, and 7%, respectively.

4.3.4. Payback Period (PBP)

Estimating the time, it takes to get back on investment This will inform you of the year in which profits will begin to be generated for investors. As specified in (18-21), the proportion of investment will be used for the income that will come from the sale of electricity from wind turbines. and the data in Table 4-75 Discount rate, Table 4-77 Asset's lifetime, Table 4-80 Cost and Benefits of wind farms in the area of Chonburi Station, Koh Si Chang Station, and Pattaya Station, and Figure 4-37 Full-service (initial and renewal) O&M pricing indexes and weighted average O&M costs in Denmark, Germany, Ireland, Japan, Norway, Sweden and the United States, 2008-2020, and there are two types of revenue from direct sales. and revenue generated from sales minus annual O&M costs

Table 4-87 *PBP of Chonburi, Ko Sichang, and Pattaya*

(Unit: Year)

Area and wind turbine models	PBP without O&M	PBP with O&M
Chonburi		
cluster Ban Bueng		
Bonus 1.3 MW	18.42	32.36
SWT-1.3-62	17.82	30.55
SWT-2.3-82 VS	18.38	32.23
cluster Nong Khang Khok		
Bonus 1.3 MW	16.75	27.52
SWT-1.3-62	16.04	25.66
SWT-2.3-82 VS	16.02	25.61
Ko Sichang		
cluster Hat Tham Phang		
Bonus 1.3 MW	12.35	17.36
SWT-1.3-62	11.52	15.77
SWT-2.3-82 VS	11.97	16.62
cluster Khao Kaya Sira Hill		
Bonus 1.3 MW	8.96	11.33
SWT-1.3-62	8.34	10.36
SWT-2.3-82 VS	9.78	12.68

Area and wind turbine models	PBP without O&M	PBP with O&M
Pattaya		
cluster Ko Lan		
Bonus 1.3 MW	123.19	(65.56)
SWT-1.3-62	100.92	(74.28)
SWT-2.3-82 VS	126.56	(64.64)
cluster Phra Tamnak Mountain		
Bonus 1.3 MW	539.11	(46.48)
SWT-1.3-62	442.09	(47.37)
SWT-2.3-82 VS	493.81	(46.85)

The presentation of the above information (Table 4-87) has made known the period to recover profits from projects to be invested in developed areas. In the area of Chonburi station, the PBP without O&M was the lowest at 16.02 years, with the highest wind turbine model SWT-2.3-82 VS (cluster Nong Khang Khok) being at 18.42 years, and the highest wind turbine model 1.3 MW (cluster Ban Bueng). The PBP with O&M was the lowest at 25.61 years, with the highest wind turbine model SWT-2.3-82 VS (cluster Nong Khang Khok) at 32.36, with the highest wind turbine model 1.3 MW (cluster Ban Bueng), The area of Ko Sichang station had the lowest PBP without O&M at 8.34 years, with the highest wind turbine model SWT-1.3-62 (cluster Khao Kaya Sira Hill) at 12.35 and the highest wind turbine model 1.3 MW (cluster Hat Tham Phang). and the lowest PBP with O&M was 10.36 years, with the highest wind turbine model SWT-1.3-62 (cluster Khao Kaya Sira Hill) at 17.36, and the highest Bonus 1.3 MW wind turbine model (cluster Hat Tham Phang), And the area of Pattaya station had the lowest PBP without O&M at 100.92 years, with the highest wind turbine model SWT-1.3-62 (cluster Ko Lan) at 539.11 and the bonus wind turbine model 1.3 MW (cluster Phra Tamnak). Mountain) and PBP with O&M was the shortest at -74.28 years, with the longest being 46.48 years for the wind turbine model SWT-1.3-62 (cluster Ko Lan), followed by the wind turbine model Bonus 1.3 MW (cluster Phra Tamnak Mountain).

4.3.5. Internal rate of return (IRR)

Another important economic criterion of a project is the internal rate of return (IRR), which is the discount rate at which the accumulated present value of all costs equals the benefits [19] or at which the net present value (NPV) of the project is zero. and the highest interest rate (realistic) that the investment can earn can be obtained from Equation (32-33), and the data in Table 4-77 Asset's lifetime, Table 4-80 Cost and Benefits of wind farms in the area of Chonburi Station, Koh Si Chang Station, and Pattaya Station, can be calculated and shown in Table 4-88.

Table 4-88 *IRR of Chonburi, Ko Sichang, and Pattaya*

Area and wind turbine models	IRR 25 Year
Chonburi	
cluster Ban Bueng	
Bonus 1.3 MW	2.50%
SWT-1.3-62	2.79%
SWT-2.3-82 VS	2.52%
cluster Nong Khang Khok	
Bonus 1.3 MW	3.35%
SWT-1.3-62	3.75%
SWT-2.3-82 VS	3.76%
Ko Sichang	
cluster Hat Tham Phang	
Bonus 1.3 MW	6.37%
SWT-1.3-62	7.13%
SWT-2.3-82 VS	6.70%
cluster Khao Kaya Sira Hill	
Bonus 1.3 MW	10.17%
SWT-1.3-62	11.13%
SWT-2.3-82 VS	9.05%
Pattaya	
cluster Ko Lan	
Bonus 1.3 MW	-9.76%
SWT-1.3-62	-8.73%

Area and wind turbine models	IRR 25 Year
SWT-2.3-82 VS	-9.89%
cluster Phra Tamnak Mountain	
Bonus 1.3 MW	-16.46%
SWT-1.3-62	-15.63%
SWT-2.3-82 VS	-16.10%

The calculation results shown in Table 4-88 show the IRR capability of the area and model of the wind turbine. It was found that at Chonburi Station, the highest IRR was 3.76% for the SWT-2.3-82 VS wind turbine (cluster Nong Khang Khok) and the lowest was 2.50% for the Bonus 1.3 MW wind turbine. (cluster Ban Bueng), the area at Ko Sichang station has the highest IRR at 11.13% by the SWT-1.3-62 wind generator (cluster Khao Kaya Sira Hill) and the lowest at 6.37% by the wind generator. Bonus 1.3 MW (cluster Hat Tham Phang), and the Pattaya Station area has the highest IRR at -8.73% with the wind turbine model SWT-1.3-62 (cluster Ko Lan) and the lowest at -16.46% with wind turbine model Bonus 1.3 MW wind turbine (cluster Phra Tamnak Mountain).

4.3.5.1. Financial Internal Rate of Return (FIRR)

The time estimation will take into account the operating and maintenance costs as well as the revenue generated by the project. As stated in (insert reference), the proportion of investment per revenue generated from the sale of electricity from wind turbines will be determined using information from several sources, including Table 4-77 Asset lifetime, and Table 4-80 Cost and Benefits of wind farms in the area of Chonburi Station, Koh Si Chang Station, and Pattaya Station, as well as Figure 4-37 Full-service (initial and renewal) O&M pricing indexes and weighted average O&M costs in Denmark, Germany, Ireland, Japan, Norway, Sweden, and the United States from 2008-2020. These sources are summarized in the table below.

Table 4-89 FIRR of Chonburi, Ko Sichang, and Pattaya

Area and wind turbine models	Financial Internal Rate of Return (FIRR) 25 Year
Chonburi	
cluster Ban Bueng	
Bonus 1.3 MW	-6.11%
SWT-1.3-62	-5.78%
SWT-2.3-82 VS	-6.08%
cluster Nong Khang Khok	
Bonus 1.3 MW	-5.17%
SWT-1.3-62	-4.76%
SWT-2.3-82 VS	-4.75%
Ko Sichang	
cluster Hat Tham Phang	
Bonus 1.3 MW	-2.30%
SWT-1.3-62	-1.65%
SWT-2.3-82 VS	-2.01%
cluster Khao Kaya Sira Hill	
Bonus 1.3 MW	0.74%
SWT-1.3-62	1.44%
SWT-2.3-82 VS	-0.10%
Pattaya	
cluster Ko Lan	
Bonus 1.3 MW	213,889,102,905,353.00%
SWT-1.3-62	213,889,102,905,353.00%
SWT-2.3-82 VS	213,889,102,905,353.00%
cluster Phra Tamnak Mountain	
Bonus 1.3 MW	213,889,102,905,353.00%
SWT-1.3-62	213,889,102,905,353.00%
SWT-2.3-82 VS	213,889,102,905,353.00%

The provided information presents the 25-year internal financial rate of return (FIRR) for various clusters in the Chonburi area of Thailand, which includes Ban Bueng, Nong Kwang Khok, Koh Sichang, and Pattaya. The FIRR values are reported for three different wind turbine models, namely, Bonus 1.3 MW, SWT-1.3-62, and SWT-2.3-82 VS.

The Ban Bueng and Nong Kwang Khok clusters report negative FIRR values for all three models, whereas the FIRR values in the Koh Sichang area vary depending on the cluster and turbine model. Notably, the Pattaya area shows significantly higher FIRR values for all three turbine models.

In the Ban Bueng cluster, the FIRR values for Bonus 1.3 MW, SWT-1.3-62, and SWT-2.3-82 VS are -6.11%, -5.78%, and -6.08%, respectively. In the Nong Khang Khok cluster, the FIRR values for these three models are -5.17%, -4.76%, and -4.75%, respectively.

Moving on to the Ko Sichang area, the FIRR values for Bonus 1.3 MW, SWT-1.3-62, and SWT-2.3-82 VS are -2.30%, -1.65%, and -2.01%, respectively, in the Hat Tham Phang cluster. In the Khao Kaya Sira Hill cluster, the FIRR values for these three models are 0.74%, 1.44%, and -0.10%, respectively.

Lastly, the Pattaya area has two clusters - Ko Lan and Phra Tamnak Mountain - with significantly higher FIRR values for all three turbine models, namely, Bonus 1.3 MW, SWT-1.3-62, and SWT-2.3-82 VS. The FIRR values are reported to be 213,889,102,905,353.00% for all three models in both clusters.

The data suggest that wind turbines operate differently in different clusters in the Chonburi area, with some clusters having negative FIRRs and others having very high FIRRs. The reason for this disparity may be attributed to several factors, including wind patterns, topography, and turbine efficiency. It is possible that project benefits cannot be generated during the project's duration, leading to low or negative 25-year FIRR values. This may occur due to high initial investments, longer payback periods, or external factors such as changes in the market or economic conditions.

Therefore, it is crucial to consider these factors when assessing the profitability of long-term investments. The 25-year internal FIRR values may not accurately represent a project's long-term profitability if it requires extended time frames to materialize returns. Thus, it is essential to conduct a comprehensive analysis of the project's feasibility to avoid misinterpretation of the FIRR values.

4.3.5.2. Economics Internal Rate of Return (EIRR)

The Economics Internal Rate of Return (EIRR) is a financial metric used to assess the profitability of an investment project. The EIRR refers to the discount rate that equals the net present value (NPV) of the total cash flows from the project. As specified in the cited source (add the citation), the proportion of investment per revenue that will come from the sales of electricity generated by wind turbines is utilized, and information from several tables and a figure is presented. Table 4-77 Asset lifetime, and Table 4-80 Cost and Benefits of wind farms in the area of Chonburi Station, Koh Si Chang Station, and Pattaya Station, as well as Figure 4-37 Full-service (initial and renewal) O&M pricing indexes and weighted average O&M costs in Denmark, Germany, Ireland, Japan, Norway, Sweden, and the United States from 2008-2020. These sources are summarized in the table below.

These data provide insights into the profitability of investment projects in the wind energy sector. By analyzing the EIRR, investors can determine whether an investment in a particular wind energy project is financially viable. The tables and figure presented in the research paper provide essential information that can help investors make informed decisions.

Table 4-90 *EIRR of Chonburi, Ko Sichang, and Pattaya*

Area and wind turbine models	Economics Internal Rate of Return (EIRR) 25 Year
Chonburi	
cluster Ban Bueng	
Bonus 1.3 MW	-1.89%
SWT-1.3-62	-1.49%
SWT-2.3-82 VS	-1.86%
cluster Nong Khang Khok	
Bonus 1.3 MW	-0.73%
SWT-1.3-62	-0.20%
SWT-2.3-82 VS	-0.18%
Ko Sichang	
cluster Hat Tham Phang	

Area and wind turbine models	Economics Internal Rate of Return (EIRR) 25 Year
Bonus 1.3 MW	3.03%
SWT-1.3-62	3.91%
SWT-2.3-82 VS	3.42%
cluster Khao Kaya Sira Hill	
Bonus 1.3 MW	7.31%
SWT-1.3-62	8.35%
SWT-2.3-82 VS	6.09%
Pattaya	
cluster Ko Lan	
Bonus 1.3 MW	202,416,880,057.23%
SWT-1.3-62	188,396,928,380.03%
SWT-2.3-82 VS	330,532,487,739.65%
cluster Phra Tamnak Mountain	
Bonus 1.3 MW	218,831,863,489.33%
SWT-1.3-62	218,882,878,021.15%
SWT-2.3-82 VS	354,111,883,901.22%

Based on the given table, it can be observed that in most of the listed projects and clusters, there was a negative Economics Internal Rate of Return (EIRR) which indicates that the project was not economically viable. A negative EIRR means that the project is not generating sufficient revenue to cover operating and maintenance expenses, let alone profitable. EIRR is a financial metric used to calculate the profitability of an investment by considering the time value of money and the net present value of cash flows over the life of the investment.

In the Chonburi and Pattaya areas, the data represents the 25-year EIRR for various clusters. The areas are briefly described as follows based on the provided data:

- In the Ban Bueng cluster in Chonburi, all three wind turbine models have negative EIRR values ranging from -1.49% to -1.89%, indicating that these investments are not economically viable.
- In the Nong Khang Khok cluster in Chonburi, the EIRR values for all three wind turbine models are negative as well, but with smaller magnitudes than

the Ban Bueng cluster. The values range from -0.18% to -0.73%, indicating that these investments may not be highly profitable.

- In Ko Sichang, the Hat Tham Phang cluster has positive EIRR values for all three wind turbine models, ranging from 3.03% to 3.91%, suggesting that these investments have the potential to be profitable over a 25-year period.
- In the Khao Kaya Sira Hill cluster in Ko Sichang, all three wind turbine models have positive EIRR values, ranging from 6.09% to 8.35%, indicating that the investments in this cluster have the potential to be highly profitable over a 25-year period.
- In Pattaya, both the Ko Lan and Phra Tamnak Mountain clusters have extremely high positive EIRR values for all three wind turbine models, ranging from 188,396,928,380.03% to 354,111,883,901.22%.

It is important to note that a high EIRR is not always a positive sign. A high EIRR may be caused by negative earnings, which indicates that the project is not generating enough income to cover operating and maintenance costs. This can lead to an unusually low or negative EIRR. Several factors such as high initial investment, longer payback periods, or changes in market or economic conditions can contribute to this. Therefore, it is crucial to consider these factors when evaluating the profitability and long-term benefit potential of a project.

If there is a clear plan to increase the project's revenue or reduce expenses, it may be possible to turn the project around and make it profitable. However, if negative revenues are caused by unchangeable factors such as unfavorable market conditions or poor project design, sustainability may not be achieved. Hence, it is important to carefully assess the underlying reasons for negative earnings and to consider financial metrics and other qualitative factors when evaluating a project's viability. A negative EIRR should cause serious concern and should be used with caution in its interpretation.

Studies have shown that FIRR and EIRR are more suitable than IRR for evaluating projects with longer lifespans or significant social and environmental impacts. For instance, Kim and Lee (2016) [107] found that FIRR is a more appropriate measure for evaluating the financial feasibility of solar photovoltaic projects in Korea. Similarly, Ha et al. (2017) [108] found that EIRR is a more appropriate measure for evaluating the economic viability of forestry projects in Vietnam.

In conclusion, although IRR is the most commonly used indicator to measure the financial return of an investment project, FIRR and EIRR provide a more comprehensive evaluation of a project's financial and economic viability by considering the time value of money, opportunity cost of capital, and economic costs and benefits. Therefore, the choice of which indicator to use depends on the specific characteristics of the investment project under evaluation.

4.4. Impact of wind energy on carbon dioxide (CO_2) emissions reduction

Wind power generally has zero direct air pollution, but there is CO_2 emitted by it during the construction and maintenance phases. However, this amount of CO_2 is much less than that from other fossil fuel power plants. [109] Wind power's potential to reduce CO_2 emissions is dependent on the energy distribution of each region [110]. The procedure to be assessed and analyzed has an average CO_2 emission per unit of 640 g CO_2/kWh for CO_2 emissions per unit. [88]–[91] are calculated according to Equation (38–39), and the data in Table 4-76 Energy production in the year show the analytical results in Table 4-89.

Table 4-91 *CO_2 emission of Chonburi, Ko Sichang, and Pattaya*

Area and wind turbine models	Average Net AEP (kWh)	CO_2 emission (ton CO_2/GWh)
Chonburi		
cluster Ban Bueng		
Bonus 1.3 MW	1,010,000	646.40
SWT-1.3-62	1,044,000	668.16
SWT-2.3-82 VS	1,791,000	1,146.24
cluster Nong Khang Khok		
Bonus 1.3 MW	1,111,000	711.04
SWT-1.3-62	1,160,000	742.40
SWT-2.3-82 VS	2,055,000	1,315.20
Ko Sichang		
cluster Hat Tham Phang		

Area and wind turbine models	Average Net AEP (kWh)	CO_2 emission (ton CO_2/GWh)
Bonus 1.3 MW	1,507,000	964.48
SWT-1.3-62	1,615,000	1,033.60
SWT-2.3-82 VS	2,750,000	1,760.00
cluster Khao Kaya Sira Hill		
Bonus 1.3 MW	2,077,000	1,329.28
SWT-1.3-62	2,231,000	1,427.84
SWT-2.3-82 VS	3,366,000	2,154.24
Pattaya		
cluster Ko Lan		
Bonus 1.3 MW	151,050	96.67
SWT-1.3-62	184,374	118.00
SWT-2.3-82 VS	260,121	166.48
cluster Phra Tamnak Mountain		
Bonus 1.3 MW	34,516	22.09
SWT-1.3-62	42,091	26.94
SWT-2.3-82 VS	66,668	42.67

In Table 4-89, the CO_2 reduction potential of wind power is presented in each area, answering the question of CO_2 emission reduction for every area. But there will be variations according to the energy level that each area can produce. The area at Chonburi station has the highest CO_2 emission at 1,315.20 ton CO_2/GWh by the SWT-2.3-82 VS wind turbine (cluster Nong Khang Khok) and the lowest at 646.40 20 ton CO_2/GWh by the wind turbine Bonus model 1.3 MW (cluster Ban Bueng), the area at Ko Sichang station has the highest CO_2 emission at 2,154.24 ton CO_2/GWh by the wind turbine model SWT-2.3-82 VS (cluster Khao Kaya Sira Hill) and the lowest at 964.48 ton CO_2/GWh by the wind turbine model Bonus 1.3 MW (cluster Hat Tham Phang), and the area at Pattaya Station has the highest CO_2 emission at 166.48 ton CO_2/GWh by the wind turbine model SWT-2.3-82 VS (cluster Ko Lan) and the lowest at 22.09 ton CO_2/GWh the wind turbine model Bonus 1.3 MW (cluster Phra Tamnak Mountain).

The BP Statistical Review of World Energy 2022 [111] highlights the increasing trend of global CO_2 emissions from energy use. Despite a decrease in coal consumption, the report shows that global CO_2 emissions reached a record 33.6 billion tonnes in 2021, largely driven by a recovery in oil and gas use. This emphasizes the need to accelerate the transition to low-carbon energy sources and reduce carbon emissions from energy use. Thailand, which heavily relies on fossil fuels for its energy mix, is projected to experience a 3.3% increase in CO_2 emissions from energy use in 2021, despite a decline in coal consumption. Therefore, it is critical for Thailand to increase the share of renewable energy in its energy mix and promote sustainable energy production and consumption to combat climate change.

Fortunately, Thailand has an opportunity to increase the proportion of renewable energy in its energy mix, as its energy consumption is expected to grow by only 2.5% in 2021, which is below the 10-year average growth rate of 3.4%. One viable solution is investing in wind turbines to generate electricity without greenhouse gas emissions. BP provides information on potential CO_2 emission reductions for various wind turbines, such as the SWT-2.3-82 VS wind turbine in the Khao Kaya Sira Hill Turbine Cluster, which can produce an average net AEP of 3,366,000 kWh and reduce CO_2 emissions by 2,154.24 tons CO_2/GWh.

Renewable energy sources like wind power are becoming increasingly viable alternatives in Thailand. Wind turbines installed in clusters in Chonburi station, Ko Sichang station, and Pattaya station have shown promising results in terms of CO_2 emission reductions. These turbines have achieved an average net AEP ranging from 1,010,000 kWh to 3,366,000 kWh, and reduced CO_2 emissions by an average of 22.09 to 2,154.24 tons per GWh.

Sustainable energy production plays a critical role in promoting responsible tourism in popular tourist destinations such as Chonburi, Ko Sichang, and Pattaya. Sustainable tourism aims to minimize the negative impacts of tourism on the environment and society while maximizing its positive impact. Using renewable energy sources like wind power can help reduce tourism's carbon footprint and make it a more sustainable industry.

The government can promote renewable energy production and consumption by implementing policies that support the import duty rate for excess renewable energy sold to the grid. Additionally, educating the public on sustainable energy practices, such as using energy-efficient devices, reducing energy loss in buildings, and promoting the use of public transport and electric vehicles, can promote energy conservation.

In conclusion, Thailand must increase the proportion of renewable energy in its energy mix to reduce carbon emissions from energy use, as its energy consumption is expected to increase. By investing in wind and solar energy systems, implementing policies that support the production and use of renewable energy, and educating the public on sustainable energy practices, Thailand can address the global challenge of climate change and move towards a low-carbon future.

4.5. Summary of research results

All three locations (Chonburi station area, Koh Sichang station area, and Pattaya station area) are classified as Wind Power Class 1 (as shown in Table 4-6). However, the capacity factor (as shown in Figure 4-35) of each area varies according to the wind resources present, with the Chonburi station having the highest capacity factor of 10.2%, the Ko Sichang station having the highest capacity factor of 19.6%, and the Pattaya station having the highest capacity factor of 1.6%.

Mean value of wind resource data at a height of 10 m above the ground. In the Chonburi station area, it was found that Air density was 1.146 kg/m³, Weibull-A 1.9 m/s, Weibull-k 1.07, Mean speed 1.88 m/s, and Power density 23 W/m². In the Ko Sichang station area, it was found that Air density was 1.152 kg. /m³, Weibull-A 1.6 m/s, Weibull-k 1.37, Mean speed 1.48 m/s, and Power density 6 W/m². In the Pattaya Station area, it was found that Air density was 1.152 kg/m³, Weibull-A 1.6 m/s. , Weibull-k 1.49, Mean speed 1.42 m/s, and Power density 5 W/m².

Mean value of wind resource data at a height of 60 m above the ground. In the Chonburi station area, it was found that Air density was 1.141 kg/m³, Weibull-A 2.9 m/s, Weibull-k 1.22, Mean speed 2.68 m/s, and Power density 44 W/m². In the Ko Sichang station area, it was found that Air density was 1.148 kg. /m³, Weibull-A 2.1 m/s, Weibull-k 152.00%, Mean speed 1.90 m/s, and Power density 11 W/m². In the Pattaya station area, it was found that Air density was 1.147 kg/m³, Weibull-A 2.1 m/. s, Weibull-k 171.00%, Mean speed 1.88 m/s, and Power density 9 W/m².

Mean value of wind resource data at a height of 90 m above the ground. In the Chonburi station area, it was found that Air density was 1.138 kg/m³, Weibull-A 3.1 m/s, Weibull-k 1.25, Mean speed 2.93 m/s, and Power density 54 W/m². In the Ko Sichang station area, it was found that Air density was 1.145 kg. /m³, Weibull-A 2.3 m/s, Weibull-k 1.54, Mean speed 2.03 m/s, and Power density 13 W/m². In the Pattaya station area, it was found that Air density was 1.144 kg/m³, Weibull-A 2.3 m/s. , Weibull-k 1.75, Mean speed 2.02 m/s, and Power density 11 W/m².

In the economic analysis (public sector) stage, this research has an educational perspective as shown in Table 4-71, with additional decision criteria including positive net present value, payback period, and internal rate of return to support investment decision-making. in the research area The result of the calculation indicates the unsuitability of setting up a wind farm to produce electricity. which can be analyzed by

Adjusted Cost of Energy (LCOE) and Total Cost of Energy (USD/MWh) for the 25-year project from all 3 wind turbines The calculation shows that the LOCE at 5% discount rates in the Pattaya Station area is up to 889.71 USD/MWh, while the Chonburi Station area is 889.71 USD/MWh. and Ko Sichang Station have LOCE at 141.23 USD/MWh and 73.53 USD/MWh respectively and based on discount rates of 5.4%, found to have the lowest values at 913.70, 145.04, and 75.51 USD/MWh respectively of the area of Pattaya Station, Chonburi, and Ko Sichang station, if using discount rates at 7%, it was found that the lowest values were 1,012.45, 160.71, and 83.67 USD/MWh of the area of Pattaya Station, Chonburi Station, and Ko Sichang Station, respectively, from the report IRENA [86] In renewable power generation costs in 2021, the average LCOE of onshore wind is 33 USD/MWh, and according to Lazard's [94] Levelized Cost of Energy, the average LCOE of onshore wind is 26–50 USD/MWh in the study area. The comparison is still very far from the average for the currently developed technology, which is inconsistent with the space potential.

Net Present Value (NPV) in Economic Possibilities from the calculation results can be concluded that Economically viable areas (positive NPV) are the area of Ko Sichang station on the Khao Kaya Sira Hill cluster in the Bonus 1.3 MW and SWT-1.3-62 wind turbines for discount rates of 5.0%, 5.4%, and 7.0%, and In wind turbine model SWT-2.3-82 VS for discount rates, the probability is only 5.0% and 5.4% vice versa in the area of Chonburi station. And Pattaya station area has negative NPV for all discount rates, highest at -2,073,197.65 (7%) and -4,224,640.55 (5%) respectively.

Benefit-Cost Ratio (BCR) In order to reduce misunderstanding from the numbers shown on the NPV, the BCR calculation value has been used to support the results. The calculated values are shown. positive and negative values similar to the negative NPV values shown on the NPV in the Pattaya station area. with more negative values Chonburi Station Area When considering based on BCR, it was found that the area of Pattaya station had fewer negative values than the area of Chonburi station, so if it is necessary to consider it in order of Ko Sichang station area, Pattaya station area, and the area of Chonburi station, respectively, From the analysis in Sections 4.3.2 and 4.3.3, it was found that there was only the Khao Kaya Sira Hill cluster in the area of Ko Sichang station. Only then can the potential be positive. However, it will vary according to the discount rates. An observation is that at discount rates of 7%, the SWT-2.3-82 VS wind turbine model shows very negative NPV and BCR values of -262,599.01 and -14.74, respectively. Rank and BCR have the lowest values of all three areas. Another observation of the area around Pattaya Station is the proportion of cost expressed in the BCR. If the cost is managed below that of education, then the BCR can be positive.

Payback Period (PBP) in the study area and the comparable area. The calculation results show a very different range of periods. The area with the fastest PBP potential was at 8.34 years for the PBP without the O&M model, and for the PBP with the O&M model, the fastest PBP was at 10.36 years. SWT -1.3.62 in the area of Ko Sichang station (cluster Khao Kaya Sira Hill). Only this can shorten the payback period. The value of PBP without O&M cannot be paid back within the specified period, in the Pattaya station area, and the value of PBP with O&M indicates that the payback cannot be made (a negative value), and in the Chonburi station area, PBP without O&M can be paid back within the specified period, but PBP with O&M cannot be paid back within the specified period.

Internal Rate of Return (IRR): The discount rate for projects that will be accepted or the maximum possible value for setting up a project By using the average discount rates of 5.0%, 5.4%, and 7.0%, a simulation of the possible IRR rate for the project is created. From the calculations, it was found that the area around Chonburi station and Ko Sichang station can show positive values. with an average of 3.11% and 8.43% respectively. From all 3 stations, it was found that there were SWT-1.3-62 wind turbines (cluster Hat Tham Phang, Ko Sichang) with an IRR of 7.13%, Bonus 1.3 MW, SWT-1.3-62, and SWT-2.3-82 VS (cluster Khao Kaya Sira Hill, Ko Sichang) with an IRR of 10.17%, 11.13%, and 9.05% respectively.which can create an IRR higher than the IEA Central case of 7% [99] depending on the situation of the value of the purchase to the system at a FiT of 3.1014 Baht/unit [104], [105]. From this study, the IRR of the Pattaya Station area was negative for both cluster Ko Lan and cluster Phra Tamnak Mountain, with the highest negative value of -16.46% for the Bonus 1.3 MW wind turbine (cluster Phra Tamnak Mountain) and the lowest negative value of -8.73% for the SWT-1.3-62 (cluster Ko Lan).

The Financial Internal Rate of Return (FIRR) is a discount rate that represents the probability value which can make the Net Present Value (NPV) equal to the initial investment cost in the first year. In a study conducted on wind energy projects in Thailand, it was found that only the Khao Kaya Sira Hill cluster in the Ko Sichang station area, using Bonus 1.3 MW and SWT-1.3-62 wind turbines, had a positive FIRR of 0.74% and 1.44%, respectively. In the Pattaya area, the FIRR values were volatile due to the annual expenses that could not generate more revenue, resulting in losses throughout the project life of 25 years.

The Economics Internal Rate of Return (EIRR) is a discount rate that represents the likelihood of making the NPV value equal to 0. The same study found that only the Ko Sichang station area showed a positive EIRR value for the Bonus 1.3 MW, SWT-1.3-62, and SWT-2.3-82 VS wind turbines in the Hat Tham Phang cluster, with values of 3.03%, 3.91%, and 3.42%, respectively, and in the Khao Kaya Sira Hill cluster, the values were 7.31%, 8.35%, and 6.09%, respectively. Similarly, in the Pattaya area, the EIRR values were volatile and showed a higher swing than usual due to the annual expenses that could not generate more revenue, resulting in losses throughout the project life of 25 years.

In general, wind power has zero direct air pollution [109], and the CO_2 emission reduction potential of wind power depends on the energy distribution of each region [110]. The unit CO_2 emissions were 640 g CO_2/kWh [88]–[91]. In the area of Pattaya Station, it was found that the highest potential falls on the SWT-2.3-82 VS wind turbine (cluster Ko Lan), which can produce CO_2 emissions of 166.48 tons CO_2/GWh. But for all 3 areas, it was found that the highest value was found at the SWT-2.3.82 VS station area of Ko Sichang (cluster Khao Kaya Sira Hill) with CO_2 emissions of 2,154.24 tons CO_2/GWh, which is the only area with positive NPV, BCR, IRR, FIRR, and EIRR.

Conclusions on the establishment of large-scale wind farms in the study area were obtained from the research conducted. It was found that the Pattaya Station area is not suitable for a wind farm due to its low potential for generating attractive returns or potentially incurring losses. Factors that may contribute to this include the high-speed limit cut and low speed limit cut, a wide range of fluctuating wind power, and rotor diameters and default heights in the range of 60-90 meters. Based on observations of energy production potential in the area and project assessments using economic tools such as the levelized cost of energy (LOCE), net present value (NPV), benefit-cost ratio (BCR), payback period (PBP), internal rate of return (IRR) Financial Internal Rate of Return (FIRR), and Economics Internal Rate of Return (EIRR) it was determined that the economic feasibility of setting up a wind farm in this area was not demonstrated. Additionally, the potential for lower CO_2 emissions in this area was not comparable to other areas. This is partly due to the wind direction, as shown in Figure 5-1. Therefore, it is not recommended for businesses or the private sector to invest in a wind farm in this area.

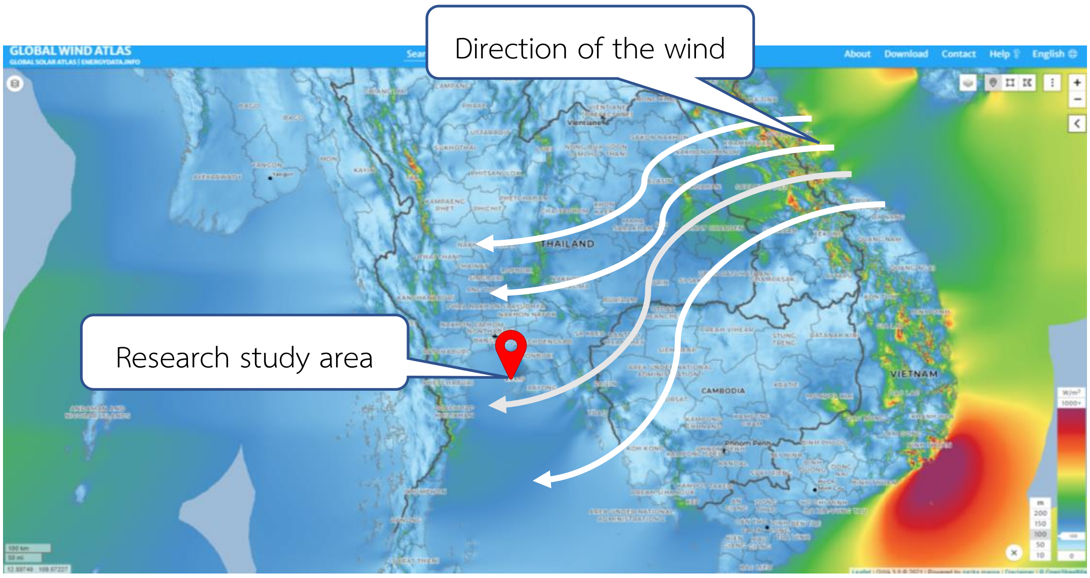


Figure 4-38 *Mean Power Density at 100 meters*

(Source: [Global Wind Atlas])

According to the spatial data (Figure 5-1) showing the mean power density at a height of 100 meters above the ground through the Global Wind Atlas [112], it was found that the wind current data was not conducive to the establishment of a wind farm in the research area. The wind was reduced from the Phu Phan Mountain range (in the areas of Kalasin Province, Mukdahan Province, Yasothon Province, and Amnat Charoen Province) to a later round in the San Kamphaeng Mountain Range due to the nature of the wind. (In the area of Nakhon Ratchasima Province, Nakhon Nayok Province, Prachin Buri Province, Sa Kaeo Province, and Buriram provinces) and the Phanom Dong Rak mountain range (in the area of Surin Province, Sisaket Province, and Ubon Ratchathani Province) by causing some winds to adjust their direction toward the central region. or along the Dong Phaya Yen Mountain range (in the area of Phetchabun Province, Chaiyaphum Province, Lopburi Province, Nakhon Ratchasima Province, and Saraburi Province).

Figure 4-39 *Phu Phan, Dong Phaya Yen, Phanom Dong Rak, and San Kamphaeng Mountain Range*

(Source: Google Maps)

On the other hand, if it is an investment by the government sector, it can also be established as an investment with multiple goals. such as the development of tourist attractions and responding to the needs of the local economy and environmental solutions, explaining SDGs, BCG, or Carbon credit, etc.

4.5.1. Advice on Legal Issues in Setting Up a Wind Farm

When establishing a wind farm in Muang District Chonburi Province (Chonburi Station Area), Ko Si Chang District Chonburi Province (Koh Si Chang Station Area), and Bang Lamung District Chonburi Province (Pattaya Station area), various legal requirements and regulations must be complied with. In this regard, wind farm developers should consider the following legal issues:

1. **Land Use and Zoning:** Wind farms typically require large areas, and therefore it is essential to ensure that the proposed site is zoned according to its intended use. Wind turbine height restrictions, failure requirements, noise levels, and other factors must be considered, depending on the location. The Town Planning Act of Thailand 1979 [113] applies to land use and zoning in Thailand. Local zoning regulations may vary by district, and it is crucial to verify with the

relevant local authority whether a proposed site is zoned for a wind farm.

2. **Environmental Regulations:** Wind farms can have significant environmental impacts, particularly in terms of noise and bird collisions. It is important to comply with relevant environmental regulations and obtain the necessary permits or approvals. This may include an environmental impact assessment, access road construction permit, and approval of the laying of wind turbines. The Environmental Quality Act B.E. 2535 [114] applies to environmental regulations in Thailand. Wind farms may be subject to an Environmental Impact Assessment (EIA) under the Act, depending on the size and scope of the project. Thailand's Ministry of Natural Resources and Environment is the primary agency responsible for implementing and enforcing environmental regulations.
3. **Licensing and Permits:** Establishing a wind farm requires various permits and licenses, including building permits, electrical licenses, and permits for the installation and operation of wind turbines. Wind farm developers must work closely with local authorities to ensure that all required permits are obtained promptly. The Electricity Generating Authority of Thailand (EGAT) [115] is the primary agency responsible for issuing licenses and permits for wind farms. EGAT requires licenses for both the construction and operation of wind turbines, including the installation of transmission lines. In addition, EGAT has established technical and safety standards that wind farm developers must comply with.
4. **Land Acquisition:** Wind farms require large amounts of land, which may involve obtaining rights to use or purchasing land from private or government landowners. The legal issues involved in acquiring land can be complex, and it is important to work with experienced legal professionals to ensure that all necessary agreements are reached. The Land Code of 1954 [116] applies to land ownership and land acquisition in Thailand. The Land Code provides for several types of land rights, including freehold and leasehold rights. Buying land for a wind farm may involve negotiations with both the private landowner and the government.

5. **Contracts:** Wind farms usually involve multiple parties, including equipment suppliers, contractors, and power purchasers. It is essential to ensure that all contracts are properly drafted and negotiated to protect the interests of the wind farm developer. The Thai Civil and Commercial Code [117] governs contracts in Thailand. Wind farm developers must ensure that all contracts related to wind farm development are drafted and properly negotiated to protect the interests of all parties involved.
6. **Financing:** Establishing a wind farm can involve significant costs and may require capital to fund the project. This could involve negotiating a loan agreement, equity investment, or other financial arrangements. Financing for wind farm development can involve a variety of options, including bank loans, equity investments, and government grants or incentives. Wind farm developers must work with experienced financing professionals to determine the most appropriate financing options for their projects. The Investment Promotion Act of 1977 [118] stipulates various incentives for foreign investment in Thailand, including tax exemption and work permit for foreign employees.

In conclusion, the establishment of a wind farm in Thailand requires careful consideration of various legal and regulatory issues, as well as a significant amount of capital investment. To ensure the success of the project, it is essential to work with experienced professionals in the fields of law, finance, and environmental regulation. In addition, wind farm developers should stay up-to-date on changes to the legal and regulatory landscape in Thailand to ensure compliance with all requirements.
Despite the challenges involved in establishing a wind farm in Thailand, the potential benefits are significant. Wind power can contribute to Thailand's efforts to reduce its reliance on fossil fuels and move towards a more sustainable energy future. In addition, wind farm development can create new jobs and support economic growth in local communities.

As Thailand continues to develop its renewable energy sector, the establishment of wind farms will likely become increasingly important. By carefully considering the legal and regulatory issues involved, and working with experienced professionals, wind farm developers can help ensure the success of their projects and contribute to a more sustainable future for Thailand.

CHAPTER 5.
CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The establishment of a wind farm for electricity generation is influenced by both external and internal factors, such as wind resources, seasons, and government policies (external factors) and wind resource assessment, area potential, and funding sources (internal factors).

For this research, wind resources in the study area in Chonburi province, Thailand were assessed using WAsP software and data from three meteorological stations. The data indicated that the potential for setting up wind farms in the study area is low, with the peaks and ridges having a slightly higher potential than the plains, which are classified as Wind Power Class 1 with a Resource Potential of Poor. The average wind speed decreases from May to October, while it increases from November to April due to the northeast monsoon, which brings strong winds to the Gulf of Thailand and the coastal areas of southeastern Thailand [93]. The prevailing wind direction is northeast and west in the Ko Si Chang station area, southeast in the Pattaya station area, and southwest and west in the Chonburi station area, as determined by the WAsP software and an output map of wind power sources. The simulated installation of a wind farm was conducted for each weather station to generate electricity.

A study in economics has shown that the annual energy production (AEP) of a wind turbine is not always the best indicator of its economic feasibility. For example, the SWT-2.3-82 VS wind turbine (located in the Khao Kaya Sira Hill cluster, Ko Sichang) had an AEP of 3.366 GWh, which resulted in a CO_2 emission potential of 2,154.24 metric tons CO_2/GWh. However, when analyzing five economic points, this turbine was not the most economical choice. Firstly, its levelized cost of energy (LOCE) was not the lowest of the three turbines studied. The SWT-1.3-62 turbine had the lowest LOCE of all three discount rates (5.0%, 5.4%, and 7.0%). Secondly, the net present value (NPV) of the SWT-1.3-62 turbine was the highest of all three turbines for all three discount rates. In contrast, the NPV for the SWT-2.3-82 VS turbine was negative (-262,599.01 USD) when the discount rate was 7.0%. Thirdly, the benefit-cost ratio (BCR) of the SWT-2.3-82 VS turbine was the lowest of the three turbines when the discount rate was 7.0%. Fourthly, the payback period (PBP) of the SWT-1.3-62 turbine was shorter, both with and without considering operation and maintenance (O&M) costs, compared to the SWT-2.3-82 VS turbine. Lastly, In the final point, it is worth noting that while IRR does not exhibit negative values like the Chonburi Station and Pattaya Station research areas, the IRR value obtained is still lower than that of the SWT-1.3-62 wind turbine. Therefore, a higher investment does not necessarily lead to higher returns. FIRR follows a similar path as IRR, but with negative values, whereas the SWT-1.3-62 wind turbine continues to demonstrate positive values. Meanwhile, the EIRR has turned positive, but it remains inferior to the SWT-1.3-62 wind turbine.

Conclusions on the establishment of large-scale wind farms in the study area were obtained from the research conducted. It was found that the Pattaya station area is not suitable for a wind farm due to its low potential for generating attractive returns or potentially incurring losses. Factors that may contribute to this include the high speed limit cut and low speed limit cut, a wide range of fluctuating wind power, and rotor diameters and default heights in the range of 60-90 meters. Based on observations of energy production potential in the area and project assessments using economic tools such as the levelized cost of energy (LOCE), net present value (NPV), benefit-cost ratio (BCR), payback period (PBP), internal rate of return (IRR), Financial Internal Rate of Return (FIRR), and Economics Internal Rate of Return (EIRR). it was determined that the economic feasibility of setting up a wind farm in this area was not demonstrated. Additionally, the potential for lower CO_2 emissions in this area was not comparable to other areas. Therefore, it is not recommended for businesses or the private sector to invest in a wind farm in this area.

5.2. Recommendation and frustration

In future analysis, the following research recommendations are proposed:

- Using the return on energy investment (EROI) calculation to jointly analyze sustainability and the energy SDGs in the future.
- Examining the challenges of optimizing mid-term forecasts, the International Energy Agency (IEA) predicts that the share of electricity consumption from renewables will increase from 18% in 2004 to 26% in 2030.
- Assessing the potential for small turbines (with rotor diameters and default heights less than 60 meters) in the area to align with the development goals of the region.
- Optimizing mid-term forecasts can help in planning and designing the energy infrastructure to accommodate the increasing share of electricity consumption

from renewables. This can lead to a more stable and efficient energy supply, reducing the frequency of power outages in the area.

- Assessing the potential for small turbines can help in developing decentralized energy production in the area, reducing the reliance on centralized power plants and transmission infrastructure. This can help in reducing transmission and distribution losses and increase the resilience of the energy infrastructure.
- Developing offshore wind farms can provide a reliable source of energy in the long term, reducing the dependency on fossil fuels and minimizing the loss in electricity due to inefficient energy production. However, it is important to examine the challenges and potential risks associated with developing offshore wind farms in Thailand to ensure their feasibility and sustainability.

REFERENCE

Bibliography

[1] M. of E. (TH) Department of Alternative Energy Development and Efficiency, "THAILAND: Alternative Energy Development Plan 2018-2037 (AEDP 2018-2037)," Bangkok, 2018. Accessed: Jun. 14, 2022. [Online]. Available: https://policy.asiapacificenergy.org/node/4351

[2] S. Traivivatana, W. Wangjiraniran, S. Junlakarn, and N. Wansophark, "Thailand Energy Outlook for the Thailand Integrated Energy Blueprint (TIEB)," *Energy Procedia*, vol. 138, pp. 399–404, Oct. 2017, doi: 10.1016/J.EGYPRO.2017.10.179.

[3] M. of A. and C. T. Department of Land Development, "Some information of Thailand." https://www.ldd.go.th/ofsweb/thaisoil/p1.htm (accessed Jul. 01, 2022).

[4] C. U. Aquatic Resources Research Institute (ARRI), "Maritime Province," 2022. http://www.mkh.in.th/index.php?option=com_content&view=article&id=324&Itemid=368&lang=en (accessed Jun. 14, 2022).

[5] Secretariat of the Cabinet (Thailand), *Pattaya City Administrative Act, 1978*. Accessed: Jun. 14, 2022. [Online]. Available: http://www.ratchakitcha.soc.go.th/DATA/PDF/2521/A/120/1.PDF

[6] Secretariat of the Cabinet (Thailand), *Eastern Special Development Zone Act, 2018*. Thailand. Accessed: Jun. 14, 2022. [Online]. Available: https://www.eeco.or.th/en/eec-act

[7] C. Chancham, J. Waewsak, T. Chaichana, M. Landry, and Y. Gagnon, "Assessment of onshore wind energy potential using regional atmospheric modeling system (rams) for thailand," in *Energy Procedia*, Elsevier Ltd, 2014, pp. 487–496. doi: 10.1016/j.egypro.2014.07.102.

[8] W. Pettongkam, W. Roynarin, and D. Intholo, "Investigation of PV and wind hybrid system for building rooftop," *International Energy Journal*, vol. 18, no. 4, pp. 331–352, 2018.

[9] N. Goudarzi, K. Mohammadi, A. S. Pé, R. Delgado, and W. Zhu, "Wind resource assessment and economic viability of conventional and unconventional small wind turbines: A case study of Maryland," *Energies (Basel)*, vol. 13, no. 22, Nov. 2020, doi: 10.3390/en13225874.

[10] B. Chang and K. Starcher, "Evaluation of wind and solar energy investments in Texas," *Renew Energy*, vol. 132, pp. 1348–1359, Mar. 2019, doi: 10.1016/j.renene.2018.09.037.

[11] J. Waewsak, C. Chancham, S. Chiwamongkhonkarn, and Y. Gagnon, "Wind resource assessment of the southernmost region of Thailand using atmospheric and computational fluid dynamics wind flow modeling," *Energies (Basel)*, vol. 12, no. 10, 2019, doi: 10.3390/en12101899.

[12] N. Thongyai and K. Assawamartbunlue, "Wind atlas of Chanthaburi and Trat provinces, Thailand," *Energy Procedia*, vol. 141, pp. 389–393, Dec. 2017, doi: 10.1016/J.EGYPRO.2017.11.048.

[13] M. of D. E. and S. Meteorological Department of Thailand, "Daily Observation Report," Bangkok, Thailand, Jun. 2022. Accessed: Jun. 18, 2022. [Online]. Available: http://www.tmd.go.th/services/downloads.php

[14] M. of E. Thailand. Department of Alternative Energy Development and Efficiency, "Energy Balance of Thailand 2020," Bangkok, 2020. Accessed: Jul. 30, 2022. [Online]. Available: https://www.dede.go.th/download/stat63/Energy_Balance_of_Thailand_2563_for_web.pdf

[15] The Electricity Generating Authority of Thailand (EGAT)., "wind current," *Nonthaburi*. http://tairgle.egat.co.th/index.php?option=com_content&view=article&id=17:wind&catid=8&Itemid=159&lang=en (accessed Oct. 05, 2021).

[16] B. Xu, D. Chen, M. Venkateshkumar, Y. Xiao, and Y. Xing, "Modeling a pumped storage power integration to a hybrid power system with solar-wind power and its stability analysis," *Energy Procedia*, vol. 158, pp. 6225–6230, Feb. 2019, doi: 10.1016/J.EGYPRO.2019.01.475.

[17] X. Wang, E. Virguez, Y. Mei, H. Yao, and D. Patiño-Echeverri, "Integrating wind and photovoltaic power with dual hydro-reservoir systems," *Energy Convers Manag*, vol. 257, p. 115425, Apr. 2022, doi: 10.1016/J.ENCONMAN.2022.115425.

[18] H. Luo, S. Cao, and V. L. Lu, "The techno-economic feasibility of a coastal zero-energy hotel building supported by the hybrid wind–wave energy system," *Sustainable Energy, Grids and Networks*, vol. 30, p. 100650, Jun. 2022, doi: 10.1016/J.SEGAN.2022.100650.

[19] Sathyajith Mathew, *Wind Energy Fundamentals, Resource Analysis and Economics*. Tavanur Malapuram, Kerala India, 2006. Accessed: Jul. 04, 2022.

[Online]. Available:
https://www.dolcera.com/wiki/images/Wind_power_energy.pdf

[20] K. Dahirul Islam, T. Chaichana, N. Dussadee, and A. Intaniwet, "Wind Speed Distribution and Estimation of Annual Energy Production (AEP) in Saint Martin's Island, Bangladesh," *12th Conference on Energy Network of Thailand*, Accessed: Nov. 27, 2022. [Online]. Available: www.Google.com

[21] K. Sasujit and N. Homdoung, "Analysis of Wind Speed Data and Annual Energy Potential at Samoeng District in Thailand," Dec. 2021. doi: https://doi.org/10.14456/jrmutp.2021.30.

[22] E. K. Akpinar and S. Akpinar, "An assessment on seasonal analysis of wind energy characteristics and wind turbine characteristics," *Energy Convers Manag*, vol. 46, no. 11, pp. 1848–1867, 2005, doi: https://doi.org/10.1016/j.enconman.2004.08.012.

[23] S. Zhang, G. Solari, Q. Yang, and M. P. Repetto, "Extreme wind speed distribution in a mixed wind climate," *Journal of Wind Engineering and Industrial Aerodynamics*, vol. 176, pp. 239–253, May 2018, doi: 10.1016/j.jweia.2018.03.019.

[24] K. Azad, M. Alam, A. K. Azad, and M. M. Alam, "A Statistical Tool for Clear Energy: Weibull's Distribution for Potentiality Analysis of Wind Energy," 2012. [Online]. Available: https://www.researchgate.net/publication/264976730

[25] K. Kaoga *et al.*, "Statistical analysis of wind speed distribution based on six Weibull Methods for wind power evaluation in Garoua, Cameroon," 2015. [Online]. Available: https://www.researchgate.net/publication/276288648

[26] T. Arslan, Y. M. Bulut, and A. Altin Yavuz, "Comparative study of numerical methods for determining Weibull parameters for wind energy potential," *Renewable and Sustainable Energy Reviews*, vol. 40, pp. 820–825, 2014, doi: 10.1016/j.rser.2014.08.009.

[27] K. Sasujit and N. Homdoung, "Analysis of Wind Speed Data and Annual Energy Potential at Samoeng District in Thailand." [Online]. Available: http://journal.rmutp.ac.th/

[28] H. Shi, Z. Dong, N. Xiao, and Q. Huang, "Wind Speed Distributions Used in Wind Energy Assessment: A Review," *Front Energy Res*, vol. 9, p. 790, Nov. 2021, doi: 10.3389/FENRG.2021.769920/BIBTEX.

[29] S. Díaz, J. A. Carta, and J. M. Matías, "Comparison of several measure-correlate-predict models using support vector regression techniques to estimate wind

power densities. A case study," *Energy Convers Manag*, vol. 140, pp. 334–354, May 2017, doi: 10.1016/J.ENCONMAN.2017.02.064.

[30] S. Carreno-Madinabeitia, G. Ibarra-Berastegi, J. Sáenz, and A. Ulazia, "Long-term changes in offshore wind power density and wind turbine capacity factor in the Iberian Peninsula (1900–2010)," *Energy*, vol. 226, p. 120364, Jul. 2021, doi: 10.1016/J.ENERGY.2021.120364.

[31] M. H. Al Buhairi, "A statistical analysis of wind speed data and an assessment of wind energy potential in Taiz-Yemen," 2006.

[32] T. Kiunke, N. Gemignani, P. Malheiro, and T. Brudermann, "Key factors influencing onshore wind energy development: A case study from the German North Sea region," *Energy Policy*, vol. 165, p. 112962, Jun. 2022, doi: 10.1016/J.ENPOL.2022.112962.

[33] S. Ratjiranukool and P. Ratjiranukool, "Wind Speed Projections for Electricity Application Over Thailand," *Energy Procedia*, vol. 79, pp. 423–429, Nov. 2015, doi: 10.1016/J.EGYPRO.2015.11.513.

[34] N. Gylling, "General rights Wind resource assessment using the WAsP software," 2009, Accessed: Mar. 24, 2023. [Online]. Available: www.vindenergi.dtu.dk

[35] B. Yitayew, "Wind Resource Assessment: A case study on Dangla Wind Farm," Jun. 2020.

[36] D. C. Bratton and C. A. Womeldorf, "The wind shear exponent: Comparing measured against simulated values and analyzing the phenomena that affect the wind shear," *ASME 2011 5th International Conference on Energy Sustainability, ES 2011*, no. PARTS A, B, AND C, pp. 2245–2251, 2011, doi: 10.1115/ES2011-54823.

[37] W. Short, D. J. Packey, and T. Holt, "A manual for the economic evaluation of energy efficiency and renewable energy technologies," Colorado, Mar. 1995. doi: 10.2172/35391.

[38] B. K. Edziah, H. Sun, P. K. Adom, F. Wang, and A. O. Agyemang, "The role of exogenous technological factors and renewable energy in carbon dioxide emission reduction in Sub-Saharan Africa," *Renew Energy*, vol. 196, pp. 1418–1428, Aug. 2022, doi: 10.1016/J.RENENE.2022.06.130.

[39] Z. Yang, M. Zhang, L. Liu, and D. Zhou, "Can renewable energy investment reduce carbon dioxide emissions? Evidence from scale and structure," *Energy Econ*, vol. 112, p. 106181, Aug. 2022, doi: 10.1016/J.ENECO.2022.106181.

[40] D.-A. Ciupăgeanu, G. Lăzăroiu, and M. Tîrşu, "Carbon dioxide emissions reduction by renewable energy employment in Romania," *2017 International Conference on Electromechanical and Power Systems (SIELMEN)*, Oct. 2017, doi: 10.1109/SIELMEN.2017.8123333.

[41] C. McCombie and M. Jefferson, "Renewable and nuclear electricity: Comparison of environmental impacts," *Energy Policy*, vol. 96, pp. 758–769, Sep. 2016, doi: 10.1016/j.enpol.2016.03.022.

[42] D. Weisser, "A guide to life-cycle greenhouse gas (GHG) emissions from electric supply technologies," *Energy*, vol. 32, no. 9, pp. 1543–1559, Sep. 2007, doi: 10.1016/J.ENERGY.2007.01.008.

[43] P. Giani, F. Tagle, M. G. Genton, S. Castruccio, and P. Crippa, "Closing the gap between wind energy targets and implementation for emerging countries," *Appl Energy*, vol. 269, Jul. 2020, doi: 10.1016/j.apenergy.2020.115085.

[44] S. Wang, S. Wang, and J. Liu, "Life-cycle green-house gas emissions of onshore and offshore wind turbines," *J Clean Prod*, vol. 210, pp. 804–810, Feb. 2019, doi: 10.1016/J.JCLEPRO.2018.11.031.

[45] S. N. Shorabeh, H. K. Firozjaei, M. K. Firozjaei, M. Jelokhani-Niaraki, M. Homaee, and O. Nematollahi, "The site selection of wind energy power plant using GIS-multi-criteria evaluation from economic perspectives," *Renewable and Sustainable Energy Reviews*, vol. 168, p. 112778, Oct. 2022, doi: 10.1016/J.RSER.2022.112778.

[46] A. S. Ahmed, "Technical and economic feasibility of the first wind farm on the coast of Mediterranean Sea," *Ain Shams Engineering Journal*, vol. 12, no. 2, pp. 2145–2151, Jun. 2021, doi: 10.1016/J.ASEJ.2020.10.017.

[47] M. Bortolini, M. Faccio, E. Ferrari, M. Gamberi, and M. Nedaei, "Techno-Economic Design of Wind Farms: A Methodology and Multi-Scenario Application," *Procedia Manuf*, vol. 39, pp. 1270–1278, Jan. 2019, doi: 10.1016/J.PROMFG.2020.01.342.

[48] C. Longjit and D. G. Pearce, "Managing a mature coastal destination: Pattaya, Thailand," *Journal of Destination Marketing & Management*, vol. 2, no. 3, pp. 165–175, Oct. 2013, doi: 10.1016/J.JDMM.2013.05.002.

[49] M. D. D. Climate Center, "ภูมิอากาศจังหวัดชลบุรี", Accessed: Apr. 05, 2023. [Online]. Available: http://climate.tmd.go.th/data/province/%E0%B8%95%E0%B8%B0%E0%B8%A7%E0%B8%B1%E0%B8%99%E0%B8%AD%E0%B8%AD%E0%B8%81/%E0%B8%A0%E0%B8%B9%E0%B8%A1%E0%B8%B4%E0%B8%AD%E0%B8%B2%E0%B8%8

1%E0%B8%B2%E0%B8%A8%E0%B8%8A%E0%B8%A5%E0%B8%9A%E0%B8%B8%E0%B8%A3%E0%B8%B5.pdf

[50] V. Nitivattananon and S. Srinonil, "Enhancing coastal areas governance for sustainable tourism in the context of urbanization and climate change in eastern Thailand," *Advances in Climate Change Research*, vol. 10, no. 1, pp. 47–58, Mar. 2019, doi: 10.1016/J.ACCRE.2019.03.003.

[51] "Wind power and its potential in Thailand | Department of Alternative Energy Development and Efficiency." https://weben.dede.go.th/webmax/content/wind-power-and-its-potential-thailand (accessed Apr. 05, 2023).

[52] W. Sridech and T. Klabklay, "Assessment of Wind Energy Potential in Thailand Based on Using the Multiple-Weibull Distribution." https://ph01.tci-thaijo.org/index.php/jit_journal/article/view/229653/156282 (accessed Apr. 05, 2023).

[53] M. Milligan, B. Frew, E. Ibanez, J. Kiviluoma, H. Holttinen, and L. Söder, "Capacity Value Assessments of Wind Power," in *Advances in Energy Systems*, John Wiley & Sons, Ltd, 2019, pp. 369–384. doi: https://doi.org/10.1002/9781119508311.ch22.

[54] Asian Development Bank, *GUIDELINES FOR WIND RESOURCE ASSESSMENT: BEST PRACTICES FOR COUNTRIES INITIATING WIND DEVELOPMENT*. Mandaluyong City, Metro Manila, Philippines., 2014. Accessed: Aug. 19, 2022. [Online]. Available: www.adb.org

[55] J. Ashcroft, "The relationship between the gust ratio, terrain roughness, gust duration and the hourly mean wind speed," *Journal of Wind Engineering and Industrial Aerodynamics*, vol. 53, no. 3, pp. 331–355, Dec. 1994, doi: 10.1016/0167-6105(94)90090-6.

[56] D. A. Bechrakis and P. D. Sparis, "Correlation of wind speed between neighboring measuring stations," *IEEE Transactions on Energy Conversion*, vol. 19, no. 2, pp. 400–406, Jun. 2004, doi: 10.1109/TEC.2004.827040.

[57] I. Kamdar, S. Ali, J. Taweekun, and H. M. Ali, "Wind farm site selection using WAsP tool for application in the tropical region," *Sustainability (Switzerland)*, vol. 13, no. 24, Dec. 2021, doi: 10.3390/su132413718.

[58] World Meteorological Organization, *Guide to Instruments and Methods of Observation*, 2018th ed. Geneva, Switzerland. Accessed: Aug. 19, 2022. [Online]. Available: http://www.songkhla.tmd.go.th/iso/SD/SD-%E0%B8%A8%E0%B8%AD-07-

37%20WMO.8%20Guide%20to%20Instruments%20and%20Methods%20of%20 Observation%20(ver.%202018%20Edition).pdf

[59] S. Sveinbjornsson, “Analysis of WAsP (Wind Atlas Analysis and Application Program) in complex topographical conditions using measured production from a large scale wind farm.”

[60] B. Ju, J. Jeong, and K. Ko, “Assessment of Wind Atlas Analysis and Application Program and computational fluid dynamics estimates for power production on a Jeju Island wind farm,” *Wind Engineering*, vol. 40, no. 1, pp. 59–68, Jan. 2016, doi: 10.1177/0309524X15624346.

[61] B. Tammelin *et al.*, “Production of the Finnish Wind Atlas,” *Wind Energy*, vol. 16, no. 1, pp. 19–35, 2013, doi: 10.1002/we.517.

[62] M. Dörenkämper *et al.*, “The Making of the New European Wind Atlas - Part 2: Production and evaluation,” *Geosci Model Dev*, vol. 13, no. 10, pp. 5079–5102, Oct. 2020, doi: 10.5194/gmd-13-5079-2020.

[63] H. Qiao, S. Wen, L. Wu, and B. Zeng, “Research on wind power project investment risk evaluation based on fuzzy-gray clustering trigonometric function,” *Energy Reports*, vol. 8, pp. 1191–1199, Aug. 2022, doi: 10.1016/J.EGYR.2022.02.222.

[64] J. C. Richstein and K. Neuhoff, “Carbon contracts-for-difference: How to de-risk innovative investments for a low-carbon industry?,” *iScience*, vol. 25, no. 8, p. 104700, Aug. 2022, doi: 10.1016/J.ISCI.2022.104700.

[65] B. Ragnarsson, G. Oddsson, R. Unnthorsson, and B. Hrafnkelsson, “Levelized Cost of Energy Analysis of a Wind Power Generation System at Búrfell in Iceland,” *Energies (Basel)*, vol. 8, pp. 9464–9485, Sep. 2015, doi: 10.3390/en8099464.

[66] J. Aldersey-Williams, I. D. Broadbent, and P. A. Strachan, “Better estimates of LCOE from audited accounts – A new methodology with examples from United Kingdom offshore wind and CCGT,” *Energy Policy*, vol. 128, pp. 25–35, May 2019, doi: 10.1016/j.enpol.2018.12.044.

[67] E. & I. S. G. of the U. Kingdom. Department for Business, “ELECTRICITY GENERATION COSTS,” London, United Kingdom, Nov. 2016. Accessed: Aug. 10, 2022. [Online]. Available: www.nationalarchives.gov.uk/doc/open-government-licence/

[68] M. Ranthodsang, J. Waewsak, C. Kongruang, and Y. Gagnon, “Offshore wind power assessment on the western coast of Thailand,” *Energy Reports*, vol. 6, pp. 1135–1146, 2020, doi: 10.1016/j.egyr.2020.04.036.

[69] I. Pani, D. D. A. Putranto, and P. K. Wardhani, "Net present value (Npv) of the rehabilitated irrigation channels to increase agricultural production," *International Journal of Advanced Technology and Engineering Exploration*, vol. 8, no. 78, pp. 576–583, May 2021, doi: 10.19101/IJATEE.2021.874034.

[70] Amy Gallo, "A Refresher on Net Present Value," Nov. 19, 2014. https://hbr.org/2014/11/a-refresher-on-net-present-value (accessed Aug. 17, 2022).

[71] The World Bank, "Notes on the Economic Evaluation of Transport Projects WHEN AND HOW TO USE NPV, IRR 2 AND MODIFIED IRR BACKGROUND TO NPV, IRR AND MODIFIED IRR," P. Mackie, J. Nellthorp, and J. Laird, Eds., Washington, DC., 2005. Accessed: Aug. 16, 2022. [Online]. Available: https://openknowledge.worldbank.org/handle/10986/11792

[72] G. Shively, "An Overview of Benefit-Cost Analysis Economic and Environmental Impacts of Lowland Agricultural Development on Poor Upland Communities in Palawan, the Philippines View project Data Envelopment Analysis View project," 2014. Accessed: Aug. 17, 2022. [Online]. Available: https://www.researchgate.net/publication/255661807

[73] A. Khastagir and N. Jayasuriya, "Investment Evaluation of Rainwater Tanks," *Water Resources Management*, vol. 25, no. 14, pp. 3769–3784, Nov. 2011, doi: 10.1007/s11269-011-9883-1.

[74] B. Yaniktepe, O. Kara, and C. Ozalp, "Technoeconomic Evaluation for an Installed Small-Scale Photovoltaic Power Plant," *International Journal of Photoenergy*, vol. 2017, 2017, doi: 10.1155/2017/3237543.

[75] G. Rosenquist, K. Coughlin, L. Dale, J. McMahon, and S. Meyers, "Life-cycle cost and payback period analysis for commercial unitary air conditioners," Mar. 2004, Accessed: Aug. 18, 2022. [Online]. Available: https://escholarship.org/uc/item/5pk732h5

[76] S. J. Garrett, "Introductory Numerical Methods," *Introduction to Actuarial and Financial Mathematical Methods*, pp. 411–463, 2015, doi: 10.1016/B978-0-12-800156-1.00013-3.

[77] "Internal Rate of Return (IRR) Rule: Definition and Example." https://www.investopedia.com/terms/i/irr.asp (accessed Apr. 07, 2023).

[78] J. C. Duvigneau and R. N. Prasad, *Guidelines for Calculating · · Financial and Economic Rates of Return for DFC Projects ·*. Accessed: Apr. 07, 2023. [Online]. Available: https://documents1.worldbank.org/curated/en/567991468782148724/pdf/Guid

elines-for-calculating-financial-and-economic-rates-of-return-for-DFC-projects.pdf
[79] K. Fujimoto and K. Suzuki, “Financial Internal Rate of Return (FIRR) ,” Japan, Oct. 1994. Accessed: Apr. 07, 2023. [Online]. Available: https://www.jica.go.jp/jica-ri/IFIC_and_JBICI-Studies/jica-ri/english/publication/archives/jbic/report/working/pdf/wp05_e.pdf
[80] น. พันทวีศักดิ์, “ECONOMICS VALUE ANALYSIS OF PROJECT INVESTMENT CASE STUDY: PTT PHENOL TRAIN II PROJECT OF PTT PHENOL COMPANY LIMITED”, Accessed: Apr. 07, 2023. [Online]. Available: http://econ.nida.ac.th/wp-content/uploads/2019/06/5610322013.pdf
[81] “Project Risk Evaluation Methods - Sensitivity Analysis.” https://www.researchgate.net/publication/46524335_Project_Risk_Evaluation_Methods_-_Sensitivity_Analysis (accessed Apr. 07, 2023).
[82] I. MIRELA and C. DIANA, “PROJECT RISK EVALUATION METHODS - SENSITIVITY ANALYSIS,” *Annals of the University of Petroşani, Economics*, vol. 9, pp. 33–38, 2009, Accessed: Apr. 07, 2023. [Online]. Available: https://www.researchgate.net/profile/Narcis-Mitu-2/publication/46524168_Will_Eastern_European_Countries_Join_the_Single_European_Currency_Rapidly/links/0c9605316d71977586000000/Will-Eastern-European-Countries-Join-the-Single-European-Currency-Rapidly.pdf#page=33
[83] H. Nakamura and N. Abe, “Evaluation of the hybrid model of public bicycle-sharing operation and private bicycle parking management,” *Transp Policy (Oxf)*, vol. 35, pp. 31–41, Sep. 2014, doi: 10.1016/J.TRANPOL.2014.05.009.
[84] T. Suramaythangkoor and Z. Li, “Energy policy tools for agricultural residues utilization for heat and power generation: A case study of sugarcane trash in Thailand,” *Renewable and Sustainable Energy Reviews*, vol. 16, no. 6, pp. 4343–4351, Aug. 2012, doi: 10.1016/J.RSER.2012.02.033.
[85] D.-A. Ciupăgeanu and G. Lăzăroiu, “Carbon Dioxide Emissions Reduction by Renewable Energy Employment in Romania”.
[86] L. Abdallah and T. El-Shennawy, “Reducing carbon dioxide emissions from electricity sector using smart electric grid applications,” *Journal of Engineering (United Kingdom)*, vol. 2013. Hindawi Limited, 2013. doi: 10.1155/2013/845051.
[87] O. Mohiuddin, S. Asumadu-Sarkodie, and M. Obaidullah, “The relationship between carbon dioxide emissions, energy consumption, and GDP: A recent evidence from Pakistan,” *Cogent Eng*, vol. 3, no. 1, 2016, doi: 10.1080/23311916.2016.1210491.

[88] C. Sovannara, “A REVIEW ON ENVIRONMENTAL IMPACT OF WIND ENERGY,” *Proceeding Forum in Research*, p. 2016.

[89] H. Yousefi, A. Abbaspour, and H. Seraj, “Worldwide Development of Wind Energy and CO2 Emission Reduction,” *Environmental Energy and Economic Research*, vol. 3, no. 1, pp. 1–9, 2019, doi: 10.22097/eeer.2019.164295.1064.

[90] R. Saidur *et al.*, “Environmental impact of wind energy,” *Renewable and Sustainable Energy Reviews*, vol. 15, pp. 2423–2430, 2011, doi: 10.1016/j.rser.2011.02.024.

[91] C. Marimuthu and V. Kirubakaran, “Carbon pay back period for solar and wind energy project installed in India: A critical review,” *Renewable and Sustainable Energy Reviews*, vol. 23, pp. 80–90, Jul. 2013, doi: 10.1016/J.RSER.2013.02.045.

[92] L. Xu, J. Wang, Y. Ou, Y. Fu, and X. Bian, “A novel decision-making system for selecting offshore wind turbines with PCA and D numbers,” *Energy*, vol. 258, p. 124818, Nov. 2022, doi: 10.1016/J.ENERGY.2022.124818.

[93] M. of A. and C. Land Development Department, “climate classification The weather conditions that cause rain in Thailand and the seasons.” https://www.ldd.go.th/Web_UNCCD/Thai/document02.htm (accessed Oct. 09, 2022).

[94] L. M. Sheridan *et al.*, “Wind energy resource atlas of the United States,” *Wind Energy Science*, vol. 7, no. 2, pp. 659–676, Mar. 1987, doi: 10.5194/WES-7-659-2022.

[95] A. Kalmikov, “Wind Power Fundamentals”.

[96] F. Mahmuddin, “Analysis of wind energy potential with a mobile floating structure around Sulawesi and Maluku Islands of Indonesia,” *Proceedings of the International Conference on Offshore Mechanics and Arctic Engineering - OMAE*, vol. 9, 2015, doi: 10.1115/OMAE2015-41588.

[97] K. Böttzauw, *FINDING YOUR CHEAPEST WAY TO A LOW CARBON FUTURE The Danish Levelized Cost of Energy Calculator*. Copenhagen V Denmark, 2020. Accessed: Oct. 29, 2022. [Online]. Available: https://ens.dk/sites/ens.dk/files/Globalcooperation/vejledning_lcoe_calculator.pdf

[98] T. Badouard, D. Moreira De Oliveira, J. Yearwood, and P. Torres, “Final Report-Cost of Energy (LCOE) Study on energy costs, taxes and the impact of government interventions on investments in the energy sector,” Rotterdam, The Netherlands, 2020.

[99] "Levelised Cost of Electricity Calculator – Data Tools - IEA." https://www.iea.org/data-and-statistics/data-tools/levelised-cost-of-electricity-calculator (accessed Nov. 03, 2022).

[100] I. Renewable Energy Agency, "Renewable power generation costs in 2021," 2022. Accessed: Nov. 10, 2022. [Online]. Available: www.irena.org

[101] S. Sinsadok, "Thailand Utilities-Renewables New wind and solar capacity on the way", Accessed: Apr. 05, 2023. [Online]. Available: https://www.fnsyrus.com/uploads/research/20220913ThailandUtilities-Renewables-Newcapacityforwindandsolarcomingsoon.pdf

[102] Provincial Electricity Authority, *Regulations of the Energy Regulatory Commission - Provincial Electricity Authority*. 2022. Accessed: Nov. 10, 2022. [Online]. Available: https://www.pea.co.th/Portals/0/PEAContent/eee/aee_div/VSPP/docs/PEA_annouce%20for%20Biglot%201.pdf?ver=2022-10-03-170437-107

[103] *Regulations of the Energy Regulatory Commission on the Procurement of Electricity from Renewable Energy in the form of Feed-in Tariff (FiT) Year 2022 - 2030 for the Group without Fuel Cost*. 2022, pp. 3–16. Accessed: Nov. 11, 2022. [Online]. Available: https://www.erc.or.th/web-upload/200xf869baf82be74c18cc110e974eea8d5c/tinymce/22-6a9d5b8c16a9d9911e16927afadc1ad7/re/00%20%E0%B8%A3%E0%B8%B0%E0%B9%80%E0%B8%9A%E0%B8%B5%E0%B8%A2%E0%B8%9A%20%E0%B8%81%E0%B8%81%E0%B8%9E.%20RE%20Biglot%20%E0%B8%A5%E0%B8%87%E0%B8%A3%E0%B8%B2%E0%B8%8A%E0%B8%81%E0%B8%B4%E0%B8%88%E0%B8%88%E0%B8%B2.pdf

[104] "Thailand's 5 GW renewable PPA FiT scheme: 2022-2030 - WFW." https://www.wfw.com/articles/thailands-5-gw-renewable-ppa-fit-scheme-2022-2030/ (accessed Nov. 10, 2022).

[105] T. National Energy Policy Council, "Power purchase rate according to the resolution of the National Energy Policy Council In the meeting No. 3/2022 (No. 158) on May 6, 2022," Thailand, May 2022. Accessed: Nov. 11, 2022. [Online]. Available: https://www.erc.or.th/web-upload/200xf869baf82be74c18cc110e974eea8d5c/tinymce/22-6a9d5b8c16a9d9911e16927afadc1ad7/re/02-01%20%E0%B8%AD%E0%B8%B1%E0%B8%95%E0%B8%A3%E0%B8%B2%E0%B8%A3%E0%B8%B1%E0%B8%9A%E0%B8%8B%E0%B8%B7%E0%B9%89%E0%B8%AD%E0%B9%84%E0%B8%9F%E0%B8%9F%E0%B9%89%E0%B8%B2.pdf

[106] Bank of Thailand, "foreign exchange rate." https://www.bot.or.th/thai/_layouts/application/exchangerate/exchangerate.aspx (accessed Nov. 12, 2022).

[107] K. J. Kim, H. Lee, and Y. Koo, "Research on local acceptance cost of renewable energy in South Korea: A case study of photovoltaic and wind power projects," *Energy Policy*, vol. 144, p. 111684, Sep. 2020, doi: 10.1016/J.ENPOL.2020.111684.

[108] T. Cuong, T. T. Q. Chinh, Y. Zhang, and Y. Xie, "Economic Performance of Forest Plantations in Vietnam: Eucalyptus, Acacia mangium, and Manglietia conifera," *Forests 2020, Vol. 11, Page 284*, vol. 11, no. 3, p. 284, Feb. 2020, doi: 10.3390/F11030284.

[109] R. Saidur, N. A. Rahim, M. R. Islam, and K. H. Solangi, "Environmental impact of wind energy," *Renewable and Sustainable Energy Reviews*, vol. 15, no. 5. Elsevier Ltd, pp. 2423–2430, 2011. doi: 10.1016/j.rser.2011.02.024.

[110] H. Yousefi, A. Abbaspour, and H. Seraj, "Worldwide Development of Wind Energy and CO2 Emission Reduction," *Environmental Energy and Economic Research*, vol. 3, no. 1, pp. 1–9, 2019, doi: 10.22097/eeer.2019.164295.1064.

[111] S. Dale, "bp Statistical Review of World Energy 2022 | 71st edition," Jun. 2022. Accessed: Apr. 06, 2023. [Online]. Available: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2022-full-report.pdf

[112] "Global Wind Atlas." https://globalwindatlas.info/en/area/Thailand (accessed Nov. 22, 2022).

[113] "BOI : The Board of Investment of Thailand." https://www.boi.go.th/upload/content/City_Planning_Act.pdf (accessed Apr. 06, 2023).

[114] E. Adulyadej and Rex, "Environmental Quality Act B.E. 2535 (1992)," p. 2535, 1992.

[115] "Power Plant and Transmission System Engineering and Construction Business - Electricity Generating Authority of Thailand." https://www.egat.co.th/home/en/power-plant-and-transmission-system-engineering-and-construction-business/ (accessed Apr. 06, 2023).

[116] "Law Text Land Code Act 1954 (up to 2008 amendments) | Thai Law Texts (translations)." https://www.samuiforsale.com/law-texts/law-text-land-code-act-1954.html (accessed Apr. 06, 2023).

[117] “The Thailand Civil and Commercial Code | Thai Law Texts (translations).” https://www.samuiforsale.com/law-texts/thailand-civil-code-part-1.html (accessed Apr. 06, 2023).

[118] “INVESTMENT PROMOTION ACT B.E. 2520,” 1977. https://www.boi.go.th/english/download/boi_forms/proact_eng.pdf (accessed Apr. 06, 2023).

APPENDICES

Appendix A

Wind statistics at heights of 10, 60, 90, and 120 meters

Sector [°]	Variable	Mean	Min	at	Max	at
Chonburi Resource grid 10 m.						
All	Air density	1.146 kg/m³	1.077 kg/m³	(722180, 1467710)	1.154 kg/m³	(714680, 1473710)
All	Weibull-A	1.9 m/s	0.2 m/s	(718280, 1470710)	4.8 m/s	(719780, 1470710)
All	Weibull-k	1.07	0.78	(725480, 1467710)	1.17	(716180, 1466810)
All	Mean speed	1.88 m/s	0.20 m/s	(718280, 1470710)	4.72 m/s	(719780, 1470710)
All	Power density	23 W/m²	0 W/m²	(718280, 1470710)	291 W/m²	(719780, 1470710)
All	Elevation	47.9 m	-37.4 m	(714680, 1473710)	774.3 m	(722180, 1467710)
All	RIX	2.40%	0.00%	(726680, 1490810)	28.50%	(719780, 1470710)
All	Site roughness length	0.216 m	0.000 m	(725180, 1485710)	1.500 m	(726680, 1468010)
All	Turbulence intensity					
All	Flow inclination					
All	Delta-RIX	2.40%	0.00%	(726680, 1490810)	28.50%	(719780, 1470710)
0	Mean speed	1.03 m/s	0.02 m/s	(720080, 1472510)	3.19 m/s	(717680, 1470110)
30	Mean speed	2.09 m/s	0.01 m/s	(718580, 1470710)	5.08 m/s	(712880, 1465310)

Sector [°]	Variable	Mean	Min	at	Max	at
60	Mean speed	2.95 m/s	0.01 m/s	(718580, 1470710)	6.33 m/s	(719780, 1470710)
90	Mean speed	1.41 m/s	0.03 m/s	(725780, 1467410)	5.59 m/s	(719780, 1470410)
120	Mean speed	1.58 m/s	0.06 m/s	(723080, 1471610)	4.56 m/s	(719780, 1470710)
150	Mean speed	1.57 m/s	0.09 m/s	(725480, 1468310)	4.11 m/s	(720080, 1471310)
180	Mean speed	1.16 m/s	0.06 m/s	(723980, 1471310)	2.68 m/s	(718280, 1470110)
210	Mean speed	1.17 m/s	0.03 m/s	(718580, 1470710)	3.09 m/s	(718280, 1470110)
240	Mean speed	2.04 m/s	0.03 m/s	(718580, 1470710)	4.89 m/s	(719780, 1470710)
270	Mean speed	2.56 m/s	0.07 m/s	(725180, 1466810)	7.18 m/s	(719780, 1470710)
300	Mean speed	1.31 m/s	0.07 m/s	(725180, 1466810)	5.09 m/s	(720080, 1471310)
330	Mean speed	0.83 m/s	0.05 m/s	(721880, 1469810)	2.67 m/s	(723380, 1469510)
Chonburi Resource grid 60 m.						
All	Air density	1.141 kg/m³	1.073 kg/m³	(722180, 1467710)	1.149 kg/m³	(714680, 1473710)
All	Weibull-A	2.9 m/s	1.8 m/s	(720680, 1469810)	4.7 m/s	(719780, 1470710)
All	Weibull-k	1.22	0.96	(720680, 1469810)	1.37	(720080, 1465910)
All	Mean speed	2.68 m/s	1.67 m/s	(718280, 1471010)	4.41 m/s	(719780, 1470710)
All	Power density	44 W/m²	9 W/m²	(718280, 1471010)	184 W/m²	(719780, 1470710)
All	Elevation	47.9 m	-37.4 m	(714680, 1473710)	774.3 m	(722180, 1467710)
All	RIX	2.40%	0.00%	(726680, 1490810)	28.50%	(719780, 1470710)

Sector [°]	Variable	Mean	Min	at	Max	at
All	Site roughness length	0.216 m	0.000 m	(725180, 1485710)	1.500 m	(726680, 1468010)
All	Turbulence intensity					
All	Flow inclination					
All	Delta-RIX	2.40%	0.00%	(726680, 1490810)	28.50%	(719780, 1470710)
0	Mean speed	1.49 m/s	0.29 m/s	(725480, 1464410)	3.32 m/s	(717980, 1468310)
30	Mean speed	3.07 m/s	0.29 m/s	(725480, 1464410)	5.27 m/s	(721280, 1468310)
60	Mean speed	4.31 m/s	0.99 m/s	(720680, 1469810)	7.09 m/s	(719780, 1470710)
90	Mean speed	2.01 m/s	0.43 m/s	(720680, 1469810)	4.64 m/s	(723680, 1469510)
120	Mean speed	2.30 m/s	0.37 m/s	(720380, 1468910)	4.43 m/s	(723680, 1469510)
150	Mean speed	2.28 m/s	0.67 m/s	(720680, 1469510)	4.06 m/s	(717980, 1468310)
180	Mean speed	1.65 m/s	0.42 m/s	(725480, 1464410)	2.63 m/s	(712880, 1465310)
210	Mean speed	1.66 m/s	0.48 m/s	(725180, 1464410)	2.98 m/s	(718280, 1470110)
240	Mean speed	2.93 m/s	0.25 m/s	(720680, 1469510)	4.71 m/s	(722780, 1466510)
270	Mean speed	3.68 m/s	0.18 m/s	(720680, 1469810)	6.17 m/s	(719780, 1470710)
300	Mean speed	1.82 m/s	0.18 m/s	(720680, 1469810)	4.09 m/s	(713780, 1465910)
330	Mean speed	1.19 m/s	0.37 m/s	(720680, 1469810)	2.30 m/s	(717980, 1468310)

Sector [°]	Variable	Mean	Min	at	Max	at
Chonburi Resource grid 90 m.						
All	Air density	1.138 kg/m³	1.070 kg/m³	(722180, 1467710)	1.146 kg/m³	(714680, 1473710)
All	Weibull-A	3.1 m/s	2.2 m/s	(720680, 1469810)	4.9 m/s	(719780, 1470710)
All	Weibull-k	1.25	1.02	(720680, 1469510)	1.4	(720080, 1465910)
All	Mean speed	2.93 m/s	2.09 m/s	(718280, 1471010)	4.55 m/s	(719780, 1470710)
All	Power density	54 W/m²	17 W/m²	(720680, 1465310)	188 W/m²	(719780, 1470710)
All	Elevation	47.9 m	-37.4 m	(714680, 1473710)	774.3 m	(722180, 1467710)
All	RIX	2.40%	0.00%	(726680, 1490810)	28.50%	(719780, 1470710)
All	Site roughness length	0.216 m	0.000 m	(725180, 1485710)	1.500 m	(726680, 1468010)
All	Turbulence intensity					
All	Flow inclination					
All	Delta-RIX	2.40%	0.00%	(726680, 1490810)	28.50%	(719780, 1470710)
0	Mean speed	1.63 m/s	0.50 m/s	(720680, 1469510)	3.31 m/s	(717980, 1468310)
30	Mean speed	3.38 m/s	1.79 m/s	(725180, 1464410)	5.35 m/s	(721280, 1468310)
60	Mean speed	4.74 m/s	2.70 m/s	(720680, 1469810)	7.29 m/s	(719780, 1470710)
90	Mean speed	2.19 m/s	0.77 m/s	(720380, 1469210)	4.66 m/s	(723680, 1469510)

Sector [°]	Variable	Mean	Min	at	Max	at
120	Mean speed	2.53 m/s	0.77 m/s	(720380, 1469210)	4.40 m/s	(723680, 1469510)
150	Mean speed	2.50 m/s	0.90 m/s	(720380, 1469210)	4.07 m/s	(717980, 1468310)
180	Mean speed	1.79 m/s	0.74 m/s	(725480, 1464410)	2.71 m/s	(712880, 1465310)
210	Mean speed	1.80 m/s	1.03 m/s	(725480, 1464410)	3.07 m/s	(721280, 1468310)
240	Mean speed	3.20 m/s	1.85 m/s	(725180, 1471310)	4.98 m/s	(722780, 1466510)
270	Mean speed	4.01 m/s	0.37 m/s	(720380, 1469210)	6.38 m/s	(719780, 1470710)
300	Mean speed	1.98 m/s	0.37 m/s	(720380, 1469210)	3.99 m/s	(723680, 1469510)
330	Mean speed	1.30 m/s	0.48 m/s	(720680, 1469510)	2.33 m/s	(717980, 1468310)
Chonburi Resource grid 120 m.						
All	Air density	1.135 kg/m³	1.067 kg/m³	(722180, 1467710)	1.143 kg/m³	(714680, 1473710)
All	Weibull-A	3.4 m/s	2.5 m/s	(720680, 1469810)	5.0 m/s	(719780, 1470710)
All	Weibull-k	1.25	1.04	(720680, 1469510)	1.38	(716480, 1467110)
All	Mean speed	3.15 m/s	2.41 m/s	(725480, 1468310)	4.65 m/s	(719780, 1470710)
All	Power density	67 W/m²	26 W/m²	(720680, 1465310)	201 W/m²	(719780, 1470710)
All	Elevation	47.9 m	-37.4 m	(714680, 1473710)	774.3 m	(722180, 1467710)
All	RIX	2.40%	0.00%	(726680, 1490810)	28.50%	(719780, 1470710)
All	Site roughness length	0.216 m	0.000 m	(725180, 1485710)	1.500 m	(726680, 1468010)

Sector [°]	Variable	Mean	Min	at	Max	at
All	Turbulence intensity					
All	Flow inclination					
All	Delta-RIX	2.40%	0.00%	(726680, 1490810)	28.50%	(719780, 1470710)
0	Mean speed	1.76 m/s	0.74 m/s	(720680, 1469510)	3.37 m/s	(717980, 1468310)
30	Mean speed	3.64 m/s	2.41 m/s	(721280, 1465010)	5.54 m/s	(721280, 1468310)
60	Mean speed	5.12 m/s	3.31 m/s	(720680, 1465310)	7.43 m/s	(719780, 1470710)
90	Mean speed	2.36 m/s	1.28 m/s	(720380, 1469210)	4.69 m/s	(723680, 1469510)
120	Mean speed	2.73 m/s	1.08 m/s	(720380, 1469210)	4.42 m/s	(723680, 1469510)
150	Mean speed	2.69 m/s	1.17 m/s	(720380, 1469210)	4.12 m/s	(717980, 1468310)
180	Mean speed	1.92 m/s	1.00 m/s	(725480, 1464410)	2.71 m/s	(712880, 1465310)
210	Mean speed	1.93 m/s	1.27 m/s	(721280, 1465010)	3.13 m/s	(721280, 1468310)
240	Mean speed	3.42 m/s	2.28 m/s	(725180, 1471310)	5.18 m/s	(722780, 1466510)
270	Mean speed	4.29 m/s	1.60 m/s	(720380, 1469210)	6.58 m/s	(719780, 1470710)
300	Mean speed	2.11 m/s	0.56 m/s	(720380, 1469210)	3.92 m/s	(720080, 1471310)
330	Mean speed	1.39 m/s	0.61 m/s	(720680, 1469510)	2.32 m/s	(717980, 1468310)
Ko Sichang Resource grid 10 m.						
All	Air density	1.152 kg/m³	1.136 kg/m³	(708510, 1451630)	1.153 kg/m³	(709710, 1462130)

Sector [°]	Variable	Mean	Min	at	Max	at
All	Weibull-A	1.6 m/s	0.4 m/s	(695310, 1457030)	2.4 m/s	(704910, 1450430)
All	Weibull-k	1.37	0.94	(705810, 1453430)	1.5	(695610, 1454930)
All	Mean speed	1.48 m/s	0.41 m/s	(695310, 1457030)	2.32 m/s	(704910, 1450430)
All	Power density	6 W/m²	0 W/m²	(695310, 1457030)	32 W/m²	(704910, 1450430)
All	Elevation	4.1 m	0.0 m	(709710, 1462130)	175.5 m	(708510, 1451630)
All	RIX	0.40%	0.00%	(710010, 1469330)	7.80%	(708510, 1451630)
All	Site roughness length	0.066 m	0.000 m	(709710, 1462130)	1.500 m	(710010, 1457930)
All	Turbulence intensity					
All	Flow inclination					
All	Delta-RIX	-1.20%	-1.60%	(710010, 1469330)	6.20%	(708510, 1451630)
0	Mean speed	1.19 m/s	0.16 m/s	(706110, 1452830)	2.07 m/s	(704910, 1450430)
30	Mean speed	1.39 m/s	0.18 m/s	(695910, 1456430)	2.07 m/s	(695910, 1456730)
60	Mean speed	1.21 m/s	0.14 m/s	(705810, 1452530)	1.93 m/s	(695610, 1457030)
90	Mean speed	1.05 m/s	0.14 m/s	(705810, 1452530)	1.98 m/s	(695610, 1457030)
120	Mean speed	1.49 m/s	0.08 m/s	(708510, 1454330)	2.65 m/s	(703710, 1448630)
150	Mean speed	2.15 m/s	0.08 m/s	(708510, 1454330)	3.45 m/s	(704910, 1450430)

Sector [°]	Variable	Mean	Min	at	Max	at
180	Mean speed	1.19 m/s	0.10 m/s	(708510, 1454330)	2.45 m/s	(695610, 1453130)
210	Mean speed	0.59 m/s	0.09 m/s	(708810, 1453430)	1.15 m/s	(695610, 1455230)
240	Mean speed	0.42 m/s	0.07 m/s	(709110, 1455230)	0.71 m/s	(695610, 1457030)
270	Mean speed	0.46 m/s	0.11 m/s	(709110, 1454330)	0.74 m/s	(695610, 1457030)
300	Mean speed	0.62 m/s	0.10 m/s	(709110, 1454330)	1.10 m/s	(708810, 1454630)
330	Mean speed	0.89 m/s	0.12 m/s	(706710, 1452530)	1.48 m/s	(704910, 1450430)
Ko Sichang Resource grid 60 m.						
All	Air density	1.148 kg/m³	1.131 kg/m³	(708510, 1451630)	1.148 kg/m³	(709710, 1462130)
All	Weibull-A	2.1 m/s	1.5 m/s	(705810, 1453430)	3.1 m/s	(695610, 1456730)
All	Weibull-k	1.52	1.39	(705210, 1450430)	1.64	(703710, 1449230)
All	Mean speed	1.90 m/s	1.35 m/s	(705810, 1453430)	2.77 m/s	(695610, 1456730)
All	Power density	11 W/m²	4 W/m²	(706110, 1454030)	31 W/m²	(695610, 1456730)
All	Elevation	4.1 m	0.0 m	(709710, 1462130)	175.5 m	(708510, 1451630)
All	RIX	0.40%	0.00%	(710010, 1469330)	7.80%	(708510, 1451630)
All	Site roughness length	0.066 m	0.000 m	(709710, 1462130)	1.500 m	(710010, 1457930)
All	Turbulence intensity					

Sector [°]	Variable	Mean	Min	at	Max	at
All	Flow inclination					
All	Delta-RIX	-1.20%	-1.60%	(710010, 1469330)	6.20%	(708510, 1451630)
0	Mean speed	1.50 m/s	0.97 m/s	(708510, 1452230)	2.28 m/s	(704910, 1450430)
30	Mean speed	1.76 m/s	1.07 m/s	(705810, 1451330)	2.44 m/s	(695610, 1456730)
60	Mean speed	1.54 m/s	0.86 m/s	(705810, 1452230)	2.53 m/s	(695610, 1457030)
90	Mean speed	1.36 m/s	0.98 m/s	(705810, 1453130)	2.40 m/s	(695610, 1457030)
120	Mean speed	1.93 m/s	1.30 m/s	(705810, 1453430)	3.07 m/s	(695610, 1456730)
150	Mean speed	2.76 m/s	1.72 m/s	(706110, 1454030)	3.90 m/s	(695610, 1456730)
180	Mean speed	1.50 m/s	0.74 m/s	(708810, 1455530)	2.31 m/s	(695610, 1453130)
210	Mean speed	0.74 m/s	0.39 m/s	(709110, 1455530)	1.20 m/s	(695610, 1457030)
240	Mean speed	0.53 m/s	0.35 m/s	(709410, 1454930)	0.88 m/s	(695610, 1457030)
270	Mean speed	0.59 m/s	0.42 m/s	(709410, 1453730)	0.96 m/s	(695610, 1457030)
300	Mean speed	0.78 m/s	0.58 m/s	(709410, 1453730)	1.24 m/s	(695610, 1456730)
330	Mean speed	1.12 m/s	0.84 m/s	(695910, 1456430)	1.69 m/s	(695610, 1456730)
Ko Sichang Resource grid 90 m.						
All	Air density	1.145 kg/m³	1.129 kg/m³	(708510, 1451630)	1.145 kg/m³	(709710, 1462130)
All	Weibull-A	2.3 m/s	1.8 m/s	(706110, 1454030)	3.1 m/s	(695610, 1456730)

Sector [°]	Variable	Mean	Min	at	Max	at
All	Weibull-k	1.54	1.46	(702810, 1446530)	1.67	(708510, 1452830)
All	Mean speed	2.03 m/s	1.58 m/s	(706110, 1454030)	2.77 m/s	(695610, 1456730)
All	Power density	13 W/m²	5 W/m²	(706110, 1454030)	31 W/m²	(695610, 1456730)
All	Elevation	4.1 m	0.0 m	(709710, 1462130)	175.5 m	(708510, 1451630)
All	RIX	0.40%	0.00%	(710010, 1469330)	7.80%	(708510, 1451630)
All	Site roughness length	0.066 m	0.000 m	(709710, 1462130)	1.500 m	(710010, 1457930)
All	Turbulence intensity					
All	Flow inclination					
All	Delta-RIX	-1.20%	-1.60%	(710010, 1469330)	6.20%	(708510, 1451630)
0	Mean speed	1.59 m/s	1.20 m/s	(708510, 1452230)	2.21 m/s	(704910, 1450430)
30	Mean speed	1.87 m/s	1.30 m/s	(705810, 1451330)	2.42 m/s	(695610, 1456730)
60	Mean speed	1.64 m/s	1.04 m/s	(705810, 1452230)	2.49 m/s	(695610, 1457030)
90	Mean speed	1.46 m/s	1.20 m/s	(705810, 1453130)	2.33 m/s	(695610, 1457030)
120	Mean speed	2.07 m/s	1.63 m/s	(705810, 1453430)	3.04 m/s	(695610, 1456730)
150	Mean speed	2.95 m/s	2.09 m/s	(706110, 1454030)	3.96 m/s	(695610, 1456730)
180	Mean speed	1.59 m/s	0.90 m/s	(708510, 1456430)	2.35 m/s	(695310, 1457330)

Sector [°]	Variable	Mean	Min	at	Max	at
210	Mean speed	0.78 m/s	0.48 m/s	(709110, 1455530)	1.19 m/s	(695610, 1457030)
240	Mean speed	0.56 m/s	0.43 m/s	(709410, 1454930)	0.84 m/s	(695610, 1457030)
270	Mean speed	0.62 m/s	0.52 m/s	(709410, 1453730)	0.93 m/s	(695610, 1457030)
300	Mean speed	0.83 m/s	0.72 m/s	(709410, 1453730)	1.21 m/s	(708810, 1454630)
330	Mean speed	1.19 m/s	1.01 m/s	(695910, 1456430)	1.64 m/s	(695610, 1456730)
Ko Sichang Resource grid 120 m.						
All	Air density	1.142 kg/m³	1.126 kg/m³	(708510, 1451630)	1.142 kg/m³	(709710, 1462130)
All	Weibull-A	2.4 m/s	2.0 m/s	(706110, 1454030)	3.1 m/s	(695610, 1456730)
All	Weibull-k	1.54	1.47	(702810, 1446530)	1.66	(708510, 1452830)
All	Mean speed	2.14 m/s	1.76 m/s	(706110, 1454030)	2.78 m/s	(695610, 1456730)
All	Power density	15 W/m²	8 W/m²	(706110, 1454030)	31 W/m²	(695610, 1456730)
All	Elevation	4.1 m	0.0 m	(709710, 1462130)	175.5 m	(708510, 1451630)
All	RIX	0.40%	0.00%	(710010, 1469330)	7.80%	(708510, 1451630)
All	Site roughness length	0.066 m	0.000 m	(709710, 1462130)	1.500 m	(710010, 1457930)
All	Turbulence intensity					
All	Flow inclination					

Sector [°]	Variable	Mean	Min	at	Max	at
All	Delta-RIX	-1.20%	-1.60%	(710010, 1469330)	6.20%	(708510, 1451630)
0	Mean speed	1.67 m/s	1.39 m/s	(708510, 1452230)	2.19 m/s	(704910, 1450430)
30	Mean speed	1.97 m/s	1.48 m/s	(705810, 1451330)	2.43 m/s	(695610, 1456730)
60	Mean speed	1.73 m/s	1.19 m/s	(705810, 1452230)	2.46 m/s	(695610, 1457030)
90	Mean speed	1.54 m/s	1.34 m/s	(696210, 1456730)	2.28 m/s	(695610, 1457030)
120	Mean speed	2.20 m/s	1.87 m/s	(704310, 1450730)	3.02 m/s	(695610, 1456730)
150	Mean speed	3.12 m/s	2.39 m/s	(706110, 1454030)	4.00 m/s	(695610, 1456730)
180	Mean speed	1.66 m/s	1.01 m/s	(708510, 1456430)	2.37 m/s	(695310, 1457330)
210	Mean speed	0.82 m/s	0.55 m/s	(709110, 1455530)	1.17 m/s	(695610, 1457030)
240	Mean speed	0.58 m/s	0.49 m/s	(710010, 1455230)	0.82 m/s	(695610, 1457030)
270	Mean speed	0.65 m/s	0.57 m/s	(696210, 1456730)	0.91 m/s	(695610, 1457030)
300	Mean speed	0.87 m/s	0.78 m/s	(704310, 1450730)	1.20 m/s	(708810, 1454630)
330	Mean speed	1.24 m/s	1.11 m/s	(704310, 1450730)	1.62 m/s	(695610, 1456730)
Pattaya Resource grid 10 m.						
All	Air density	1.152 kg/m³	1.137 kg/m³	(692810, 1428760)	1.153 kg/m³	(709010, 1439560)
All	Weibull-A	1.6 m/s	0.9 m/s	(706310, 1433260)	2.8 m/s	(692810, 1428760)
All	Weibull-k	1.49	1.19	(702710, 1429360)	1.65	(692210, 1427860)
All	Mean speed	1.42 m/s	0.79 m/s	(706310, 1433260)	2.56 m/s	(692810, 1428760)

Sector [°]	Variable	Mean	Min	at	Max	at
All	Power density	5 W/m²	1 W/m²	(705710, 1433560)	28 W/m²	(692810, 1428760)
All	Elevation	12.4 m	0.0 m	(709010, 1439560)	174.0 m	(692810, 1428760)
All	RIX	0.10%	0.00%	(715010, 1442860)	6.50%	(692810, 1428760)
All	Site roughness length	0.072 m	0.000 m	(713810, 1417360)	1.500 m	(715010, 1429360)
All	Turbulence intensity					
All	Flow inclination					
All	Delta-RIX	-0.30%	-0.40%	(715010, 1442860)	6.10%	(692810, 1428760)
0	Mean speed	1.02 m/s	0.32 m/s	(692510, 1428160)	1.57 m/s	(693110, 1429360)
30	Mean speed	1.43 m/s	0.50 m/s	(692510, 1428160)	2.01 m/s	(711710, 1424860)
60	Mean speed	1.84 m/s	0.48 m/s	(702710, 1429360)	3.56 m/s	(692810, 1428760)
90	Mean speed	1.83 m/s	0.40 m/s	(692510, 1429060)	3.88 m/s	(692810, 1428760)
120	Mean speed	1.70 m/s	0.40 m/s	(692510, 1429060)	3.00 m/s	(692810, 1429060)
150	Mean speed	1.33 m/s	0.47 m/s	(701810, 1429660)	2.23 m/s	(693110, 1429360)
180	Mean speed	1.24 m/s	0.49 m/s	(692810, 1428160)	1.68 m/s	(692810, 1426960)
210	Mean speed	1.21 m/s	0.40 m/s	(702710, 1429360)	1.93 m/s	(692810, 1428760)
240	Mean speed	1.20 m/s	0.27 m/s	(702710, 1429360)	2.36 m/s	(692810, 1428760)

Sector [°]	Variable	Mean	Min	at	Max	at
270	Mean speed	1.29 m/s	0.32 m/s	(692510, 1429060)	2.74 m/s	(692810, 1428760)
300	Mean speed	1.51 m/s	0.32 m/s	(692510, 1429060)	2.71 m/s	(693710, 1430260)
330	Mean speed	1.58 m/s	0.43 m/s	(692510, 1429060)	2.76 m/s	(693110, 1429360)
Pattaya Resource grid 60 m.						
All	Air density	1.147 kg/m³	1.132 kg/m³	(692810, 1428760)	1.148 kg/m³	(709010, 1439560)
All	Weibull-A	2.1 m/s	1.8 m/s	(713810, 1418860)	3.2 m/s	(692810, 1428760)
All	Weibull-k	171.00%	154.00%	(693110, 1429360)	182.00%	(707810, 1442860)
All	Mean speed	1.88 m/s	1.58 m/s	(713810, 1417360)	2.87 m/s	(692810, 1428760)
All	Power density	9 W/m²	5 W/m²	(714110, 1417660)	32 W/m²	(692810, 1428760)
All	Elevation	12.4 m	0.0 m	(709010, 1439560)	174.0 m	(692810, 1428760)
All	RIX	0.10%	0.00%	(715010, 1442860)	6.50%	(692810, 1428760)
All	Site roughness length	0.072 m	0.000 m	(713810, 1417360)	1.500 m	(715010, 1429360)
All	Turbulence intensity					
All	Flow inclination					
All	Delta-RIX	-0.30%	-0.40%	(715010, 1442860)	6.10%	(692810, 1428760)
0	Mean speed	1.33 m/s	1.01 m/s	(705710, 1431460)	1.91 m/s	(692510, 1429060)

Sector [°]	Variable	Mean	Min	at	Max	at
30	Mean speed	1.91 m/s	1.58 m/s	(704210, 1430560)	2.63 m/s	(692510, 1429060)
60	Mean speed	2.46 m/s	1.74 m/s	(702710, 1429360)	3.97 m/s	(692810, 1428760)
90	Mean speed	2.44 m/s	1.77 m/s	(704210, 1434160)	4.18 m/s	(692810, 1428760)
120	Mean speed	2.28 m/s	1.56 m/s	(704210, 1434460)	3.58 m/s	(692810, 1429060)
150	Mean speed	1.78 m/s	1.24 m/s	(704510, 1434760)	2.59 m/s	(693110, 1429360)
180	Mean speed	1.66 m/s	1.19 m/s	(705410, 1435060)	2.13 m/s	(692810, 1428760)
210	Mean speed	1.60 m/s	1.21 m/s	(706910, 1435060)	2.28 m/s	(692810, 1428760)
240	Mean speed	1.59 m/s	1.24 m/s	(708410, 1431760)	2.49 m/s	(692810, 1428760)
270	Mean speed	1.71 m/s	1.38 m/s	(708710, 1431760)	2.81 m/s	(692810, 1428760)
300	Mean speed	2.00 m/s	1.60 m/s	(707810, 1431460)	3.03 m/s	(692810, 1428760)
330	Mean speed	2.08 m/s	1.63 m/s	(707210, 1430860)	2.85 m/s	(693110, 1429360)
Pattaya Resource grid 90 m.						
All	Air density	1.144 kg/m³	1.129 kg/m³	(692810, 1428760)	1.146 kg/m³	(709010, 1439560)
All	Weibull-A	2.3 m/s	2.0 m/s	(713810, 1418860)	3.2 m/s	(692810, 1428760)
All	Weibull-k	1.75	1.6	(693110, 1429360)	1.85	(707810, 1442860)
All	Mean speed	2.02 m/s	1.77 m/s	(713810, 1418860)	2.84 m/s	(692810, 1428760)
All	Power density	11 W/m²	7 W/m²	(714110, 1417660)	30 W/m²	(692810, 1428760)
All	Elevation	12.4 m	0.0 m	(709010, 1439560)	174.0 m	(692810, 1428760)

Sector [°]	Variable	Mean	Min	at	Max	at
All	RIX	0.10%	0.00%	(715010, 1442860)	6.50%	(692810, 1428760)
All	Site roughness length	0.072 m	0.000 m	(713810, 1417360)	1.500 m	(715010, 1429360)
All	Turbulence intensity					
All	Flow inclination					
All	Delta-RIX	-0.30%	-0.40%	(715010, 1442860)	6.10%	(692810, 1428760)
0	Mean speed	1.43 m/s	1.15 m/s	(712610, 1416760)	1.98 m/s	(692510, 1429060)
30	Mean speed	2.06 m/s	1.83 m/s	(704210, 1430560)	2.61 m/s	(692510, 1429060)
60	Mean speed	2.65 m/s	2.07 m/s	(702710, 1429360)	3.88 m/s	(692810, 1428760)
90	Mean speed	2.63 m/s	2.07 m/s	(704210, 1434160)	4.07 m/s	(692810, 1428760)
120	Mean speed	2.46 m/s	1.84 m/s	(704210, 1434460)	3.57 m/s	(692810, 1429060)
150	Mean speed	1.92 m/s	1.46 m/s	(704510, 1434760)	2.60 m/s	(692810, 1429060)
180	Mean speed	1.79 m/s	1.40 m/s	(705410, 1435060)	2.27 m/s	(692810, 1428760)
210	Mean speed	1.72 m/s	1.40 m/s	(715010, 1416160)	2.29 m/s	(692510, 1429060)
240	Mean speed	1.70 m/s	1.44 m/s	(708710, 1432060)	2.43 m/s	(692810, 1428760)
270	Mean speed	1.84 m/s	1.59 m/s	(709310, 1430860)	2.71 m/s	(692810, 1428760)
300	Mean speed	2.15 m/s	1.83 m/s	(710510, 1426060)	2.98 m/s	(692810, 1428760)

Sector [°]	Variable	Mean	Min	at	Max	at
330	Mean speed	2.23 m/s	1.90 m/s	(713210, 1437760)	2.84 m/s	(692810, 1428760)
Pattaya Resource grid 120 m.						
All	Air density	1.141 kg/m³	1.126 kg/m³	(692810, 1428760)	1.143 kg/m³	(709010, 1439560)
All	Weibull-A	2.4 m/s	2.2 m/s	(713810, 1418860)	3.2 m/s	(692810, 1428760)
All	Weibull-k	1.74	1.61	(693110, 1429360)	1.83	(711110, 1441960)
All	Mean speed	2.15 m/s	1.94 m/s	(713810, 1418860)	2.83 m/s	(692810, 1428760)
All	Power density	13 W/m²	9 W/m²	(714110, 1417660)	30 W/m²	(692810, 1428760)
All	Elevation	12.4 m	0.0 m	(709010, 1439560)	174.0 m	(692810, 1428760)
All	RIX	0.10%	0.00%	(715010, 1442860)	6.50%	(692810, 1428760)
All	Site roughness length	0.072 m	0.000 m	(713810, 1417360)	1.500 m	(715010, 1429360)
All	Turbulence intensity					
All	Flow inclination					
All	Delta-RIX	-0.30%	-0.40%	(715010, 1442860)	6.10%	(692810, 1428760)
0	Mean speed	1.51 m/s	1.26 m/s	(712610, 1416760)	2.02 m/s	(692510, 1429060)
30	Mean speed	2.19 m/s	2.00 m/s	(692510, 1429660)	2.62 m/s	(692510, 1429060)
60	Mean speed	2.82 m/s	2.35 m/s	(703010, 1429360)	3.86 m/s	(692810, 1428760)

Sector [°]	Variable	Mean	Min	at	Max	at
90	Mean speed	2.80 m/s	2.34 m/s	(704210, 1434160)	4.02 m/s	(692810, 1428760)
120	Mean speed	2.62 m/s	2.08 m/s	(704210, 1434460)	3.61 m/s	(692810, 1428760)
150	Mean speed	2.05 m/s	1.65 m/s	(704810, 1435060)	2.65 m/s	(692810, 1429060)
180	Mean speed	1.90 m/s	1.58 m/s	(705410, 1435060)	2.32 m/s	(692810, 1428760)
210	Mean speed	1.82 m/s	1.54 m/s	(715010, 1416160)	2.31 m/s	(692510, 1429060)
240	Mean speed	1.80 m/s	1.59 m/s	(710210, 1432960)	2.40 m/s	(692810, 1428760)
270	Mean speed	1.94 m/s	1.76 m/s	(714110, 1432060)	2.66 m/s	(692810, 1428760)
300	Mean speed	2.27 m/s	2.03 m/s	(710510, 1426060)	2.97 m/s	(692810, 1428760)
330	Mean speed	2.36 m/s	2.07 m/s	(715010, 1439260)	2.87 m/s	(692810, 1428760)

Appendix B

Rates of Exchange of Commercial Banks [106]

Bank of Thailand

FM_FX_001_S3 : **Rates of Exchange of Commercial Banks in Bangkok Metropolis** (2002-present)

(Unit: Baht / 1 Unit of Foreign Currency)

Last Updated : 22 Nov 2022 18:01

Retrieved date : 23 Nov 2022 00:51

		2021	2020	2019
1	REFERENCE RATE : US DOLLAR (USD)	31.9807	31.2955	31.0470
2	USA : DOLLAR (USD)			
3	BUYING SIGHT	31.7120	31.0333	30.7867
4	BUYING TRANSFER	31.8057	31.1255	30.8769
5	SELLING	32.1484	31.4618	31.2183
6	MID RATE	31.9771	31.2937	31.0476
7	UNITED KINGDOM : POUND STERING (GBP)			
8	BUYING SIGHT	43.3860	39.5631	39.0805
9	BUYING TRANSFER	43.5451	39.7101	39.2255
10	SELLING	44.4418	40.5713	40.0792
11	MID RATE	43.9935	40.1407	39.6524
12	EURO ZONE : EURO (EUR)			
13	BUYING SIGHT	37.3153	35.2009	34.2909
14	BUYING TRANSFER	37.4288	35.3093	34.4013
15	SELLING	38.1957	36.0445	35.1083
16	MID RATE	37.8123	35.6769	34.7548
17	JAPAN : YEN (100 YEN) (JPY)			
18	BUYING SIGHT	28.6735	28.8452	28.0024
19	BUYING TRANSFER	28.7720	28.9470	28.1079
20	SELLING	29.5188	29.7045	28.8533
21	MID RATE	29.1454	29.3258	28.4806
22	HONG KONG : DOLLAR (HKD)			
23	BUYING SIGHT	4.0549	3.9787	3.9085
24	BUYING TRANSFER	4.0720	3.9957	3.9250

Bank of Thailand

FM_FX_001_S3 : **Rates of Exchange of Commercial Banks in Bangkok Metropolis**

(2002-present)

(Unit: Baht / 1 Unit of Foreign Currency)

Last Updated : 22 Nov 2022 18:01

Retrieved date : 23 Nov 2022 00:51

		2021	2020	2019
25	SELLING	4.1591	4.0780	4.0019
26	MID RATE	4.1156	4.0369	3.9635
27	MALAYSIA : RINGGIT (MYR)			
28	BUYING SIGHT	7.5740	7.3004	7.3440
29	BUYING TRANSFER	7.6123	7.3429	7.3904
30	SELLING	7.8250	7.5529	7.6052
31	MID RATE	7.7186	7.4479	7.4978
32	SINGAPORE : DOLLAR (SGD)			
33	BUYING SIGHT	23.4346	22.3334	22.4178
34	BUYING TRANSFER	23.5133	22.4116	22.4963
35	SELLING	24.0963	22.9644	23.0358
36	MID RATE	23.8048	22.6881	22.7661
37	BRUNEI : DOLLAR (BND)			
38	BUYING SIGHT	23.3328	22.2119	22.2808
39	BUYING TRANSFER	23.4251	22.3211	22.4218
40	SELLING	24.1917	23.0482	23.1107
41	MID RATE	23.8084	22.6847	22.7663
42	PHILIPPINES : PESO (PHP)			
43	BUYING SIGHT	0.6306	0.6151	0.5849
44	BUYING TRANSFER	0.6357	0.6195	0.5886
45	SELLING	0.6623	0.6437	0.6120
46	MID RATE	0.6490	0.6316	0.6003
47	INDONESIA : RUPIAH (1,000 RUPIAH) (IDR)			
48	BUYING SIGHT	2.0807	1.9951	2.0373
49	BUYING TRANSFER	2.1406	2.0560	2.0965
50	SELLING	2.3450	2.2680	2.3202
51	MID RATE	2.2428	2.1620	2.2084
52	INDIA : RUPEE (INR)			

Bank of Thailand

FM_FX_001_S3 : **Rates of Exchange of Commercial Banks in Bangkok Metropolis**

(2002-present)

(Unit: Baht / 1 Unit of Foreign Currency)

Last Updated : 22 Nov 2022 18:01

Retrieved date : 23 Nov 2022 00:51

		2021	2020	2019
53	BUYING SIGHT	0.3929	0.3741	0.3933
54	BUYING TRANSFER	0.4093	0.3944	0.4123
55	SELLING	0.4559	0.4514	0.4731
56	MID RATE	0.4326	0.4229	0.4427
57	SWITZERLAND : FRANC (CHF)			
58	BUYING SIGHT	34.5141	32.8915	30.8108
59	BUYING TRANSFER	34.6257	32.9961	30.9084
60	SELLING	35.3549	33.6842	31.5582
61	MID RATE	34.9903	33.3402	31.2334
62	AUSTRALIA : DOLLAR (AUD)			
63	BUYING SIGHT	23.5218	21.1003	21.1156
64	BUYING TRANSFER	23.5958	21.1709	21.1875
65	SELLING	24.4231	21.9754	21.9597
66	MID RATE	24.0095	21.5732	21.5736
67	NEW ZEALAND : DOLLAR (NZD)			
68	BUYING SIGHT	22.2181	19.9394	20.0801
69	BUYING TRANSFER	22.2925	20.0128	20.1583
70	SELLING	22.9227	20.6178	20.7612
71	MID RATE	22.6077	20.3153	20.4598
72	PAKISTAN : RUPEE (PKR)			
73	BUYING SIGHT			
74	BUYING TRANSFER 1/	0.1953	0.1924	0.2061
75	SELLING	0.1974	0.1945	0.2084
76	MID RATE	0.1964	0.1935	0.2073
77	CANADA : DOLLAR (CAD)			
78	BUYING SIGHT	25.1328	22.9798	23.0427
79	BUYING TRANSFER	25.2147	23.0613	23.1273
80	SELLING	25.8029	23.5916	23.6464
81	MID RATE	25.5088	23.3265	23.3869

Bank of Thailand

FM_FX_001_S3 : **Rates of Exchange of Commercial Banks in Bangkok Metropolis**

(2002-present)

(Unit: Baht / 1 Unit of Foreign Currency)

Last Updated : 22 Nov 2022 18:01

Retrieved date : 23 Nov 2022 00:51

		2021	2020	2019
82	SWEDEN : KRONA (SEK)			
83	BUYING SIGHT	3.6676	3.3495	3.2319
84	BUYING TRANSFER	3.6859	3.3668	3.2488
85	SELLING	3.7691	3.4409	3.3224
86	MID RATE	3.7275	3.4039	3.2856
87	DENMARK : KRONE (DKK)			
88	BUYING SIGHT	5.0156	4.7222	4.5904
89	BUYING TRANSFER	5.0340	4.7401	4.6085
90	SELLING	5.1386	4.8354	4.7041
91	MID RATE	5.0863	4.7878	4.6563
92	NORWAY : KRONE (NOK)			
93	BUYING SIGHT	3.6608	3.2745	3.4774
94	BUYING TRANSFER	3.6749	3.2888	3.4915
95	SELLING	3.7639	3.3687	3.5725
96	MID RATE	3.7194	3.3288	3.5320
97	CHINA : YUAN RENMINBI (CNY)			
98	BUYING SIGHT	4.8614	4.4415	4.4070
99	BUYING TRANSFER	4.8958	4.4730	4.4373
100	SELLING	5.0373	4.6039	4.5524
101	MID RATE	4.9665	4.5385	4.4949
102	MEXICO : PESO (MXN)			
103	BUYING	1.5691	1.4572	1.6041
104	SELLING	1.5860	1.4729	1.6219
105	MID RATE	1.5776	1.4651	1.6131
106	SOUTH AFRICA : RAND (ZAR)			
107	BUYING	2.1550	1.9003	2.1395
108	SELLING	2.1782	1.9209	2.1631
109	MID RATE	2.1666	1.9106	2.1514
110	MYANMAR : KYAT (MMK)			

Bank of Thailand

FM_FX_001_S3 : **Rates of Exchange of Commercial Banks in Bangkok Metropolis**

(2002-present)

(Unit: Baht / 1 Unit of Foreign Currency)

Last Updated : 22 Nov 2022 18:01

Retrieved date : 23 Nov 2022 00:51

		2021	2020	2019
111	BUYING	0.0199	0.0226	0.0203
112	SELLING	0.0201	0.0229	0.0205
113	MID RATE	0.0200	0.0228	0.0204
114	SOUTH KOREA : WON (KRW)			
115	BUYING	0.0278	0.0264	0.0265
116	SELLING	0.0281	0.0267	0.0268
117	MID RATE	0.0280	0.0266	0.0267
118	TAIWAN : DOLLAR (TWD)			
119	BUYING	1.1388	1.0565	0.9991
120	SELLING	1.1511	1.0679	1.0102
121	MID RATE	1.1450	1.0622	1.0047
122	KUWAIT : DINAR (KWD)			
123	BUYING	105.4165	101.4511	101.6085
124	SELLING	106.5523	102.5475	102.7318
125	MID RATE	105.9844	101.9993	102.1702
126	SAUDI ARABIA : RIYAL (SAR)			
127	BUYING	8.4796	8.2942	8.2326
128	SELLING	8.5710	8.3838	8.3236
129	MID RATE	8.5253	8.3390	8.2781
130	UNITED ARAB EMIRATES : DIRHAM (AED)			
131	BUYING	8.6590	8.4739	8.4062
132	SELLING	8.7523	8.5654	8.4991
133	MID RATE	8.7056	8.5196	8.4527
134	BANGLADESH : TAKA (BDT)			
135	BUYING	0.3740	0.3668	0.3660
136	SELLING	0.3781	0.3708	0.3700
137	MID RATE	0.3761	0.3688	0.3680
138	CZECH REPUBLIC : KORUNA (CZK)			

Bank of Thailand

FM_FX_001_S3 : **Rates of Exchange of Commercial Banks in Bangkok Metropolis** (2002-present)

(Unit: Baht / 1 Unit of Foreign Currency)

Last Updated : 22 Nov 2022 18:01

Retrieved date : 23 Nov 2022 00:51

		2021	2020	2019
139	BUYING	1.4676	1.3420	1.3470
140	SELLING	1.4834	1.3565	1.3619
141	MID RATE	1.4755	1.3493	1.3544
142	CAMBODIA : RIEL (100 RIEL)(KHR)			
143	BUYING	0.7817	0.7630	0.7611
144	SELLING	0.7901	0.7713	0.7695
145	MID RATE	0.7860	0.7672	0.7653
146	KENYA : SHILLING (KES)			
147	BUYING	0.2901	0.2927	0.3028
148	SELLING	0.2932	0.2958	0.3062
149	MID RATE	0.2917	0.2943	0.3045
150	LAO PEOPLE'S DEMOCRATIC REPUBLIC : KIP (100 KIP)(LAK)			
151	BUYING	0.3271	0.3436	0.3545
152	SELLING	0.3306	0.3473	0.3584
153	MID RATE	0.3289	0.3455	0.3565
154	RUSSIAN FEDERATION : RUBLE (RUB)			
155	BUYING	0.4318	0.4328	0.4772
156	SELLING	0.4364	0.4375	0.4825
157	MID RATE	0.4341	0.4351	0.4799
158	VIET NAM : DONG (100 DONG)(VND)			
159	BUYING	0.1387	0.1339	0.1329
160	SELLING	0.1402	0.1354	0.1344
161	MID RATE	0.1395	0.1347	0.1337
162	EGYPT : EGYPTIAN POUND (EGP)			
163	BUYING	2.0261	1.9683	1.8360
164	SELLING	2.0479	1.9896	1.8563

Bank of Thailand

FM_FX_001_S3 : **Rates of Exchange of Commercial Banks in Bangkok Metropolis** (2002-present)

(Unit: Baht / 1 Unit of Foreign Currency)

Last Updated : 22 Nov 2022 18:01

Retrieved date : 23 Nov 2022 00:51

		2021	2020	2019
165	MID RATE	2.0371	1.9790	1.8462
166	POLAND : ZLOTY (PLN)			
167	BUYING	8.2434	7.9897	8.0461
168	SELLING	8.3323	8.0761	8.1350
169	MID RATE	8.2879	8.0329	8.0906
170	SRI LANKA : SRI LANKA RUPEE (LKR)			
171	BUYING	0.1603	0.1679	0.1728
172	SELLING	0.1621	0.1697	0.1747
173	MID RATE	0.1612	0.1688	0.1738
174	IRAQ : IRAQI DINAR (IQD)			
175	BUYING	0.0218	0.0259	0.0259
176	SELLING	0.0221	0.0262	0.0262
177	MID RATE	0.0220	0.0261	0.0261
178	BAHRAIN : BAHRAIN DINAR (BHD)			
179	BUYING	84.3735	82.5191	81.9021
180	SELLING	85.2827	83.4107	82.8075
181	MID RATE	84.8281	82.9649	82.3548
182	OMAN : RIAL OMANI (OMR)			
183	BUYING	82.6122	80.8404	80.2002
184	SELLING	83.5024	81.7139	81.0868
185	MID RATE	83.0574	81.2772	80.6435
186	JORDAN : JORDANIAN DINAR (JOD)			
187	BUYING	44.8607	43.9011	43.5496
188	SELLING	45.3441	44.3755	44.0310
189	MID RATE	45.1025	44.1384	43.7903
190	QATAR : QATARI RIAL (QAR)			
191	BUYING	8.7022	8.5280	8.4759
192	SELLING	8.7960	8.6201	8.5696

Bank of Thailand

FM_FX_001_S3 : **Rates of Exchange of Commercial Banks in Bangkok Metropolis**

(2002-present)

(Unit: Baht / 1 Unit of Foreign Currency)

Last Updated : 22 Nov 2022 18:01

Retrieved date : 23 Nov 2022 00:51

		2021	2020	2019
193	MID RATE	8.7491	8.5741	8.5228
194	MALDIVES : RUFIYAA (MVR)			
195	BUYING	2.0574	2.0131	1.9972
196	SELLING	2.0796	2.0349	2.0193
197	MID RATE	2.0685	2.0240	2.0083
198	NEPAL : NEPALESE RUPEE (NPR)			
199	BUYING	0.2689	0.2625	0.2741
200	SELLING	0.2718	0.2653	0.2771
201	MID RATE	0.2704	0.2640	0.2757
202	PAPUA NEW GUINEA : KINA (PGK)			
203	BUYING	9.0494	8.9709	9.1147
204	SELLING	9.1469	9.0679	9.2155
205	MID RATE	9.0981	9.0194	9.1651
206	ISRAEL : NEW ISRAELI SHEKEL (ILS)			
207	BUYING	9.8495	9.0468	8.6608
208	SELLING	9.9556	9.1445	8.7565
209	MID RATE	9.9026	9.0957	8.7087
210	HUNGARY : FORINT (HUF)			
211	BUYING	0.1050	0.1011	0.1064
212	SELLING	0.1062	0.1022	0.1076
213	MID RATE	0.1056	0.1017	0.1070

Source:

Bank of Thailand

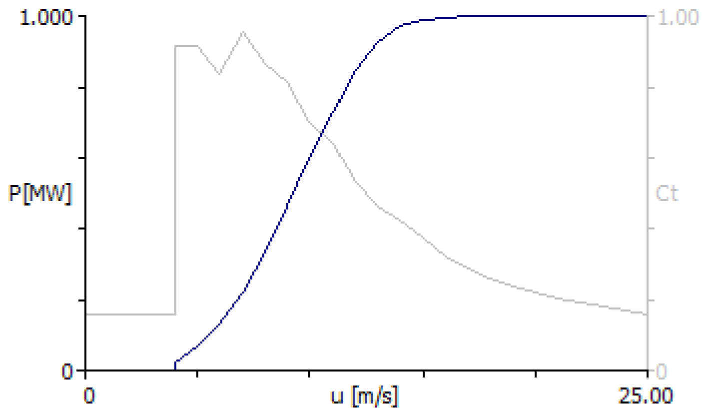
Remark:

1/ Since Nov 16, 2015 the data regarding Buying Transfer Rate of PKR has been changed to Buying Rate using Foreign Exchange Rates (THOMSON REUTERS) with Bangkok Market Crossing.

Appendix C

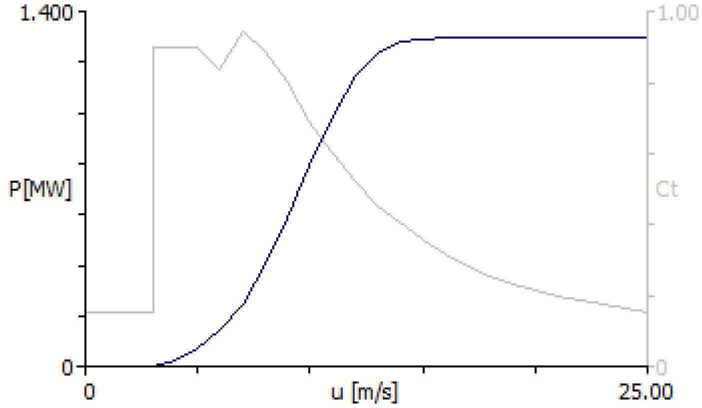
WAsP samples Wind turbine generators.

Bonus 1 MW



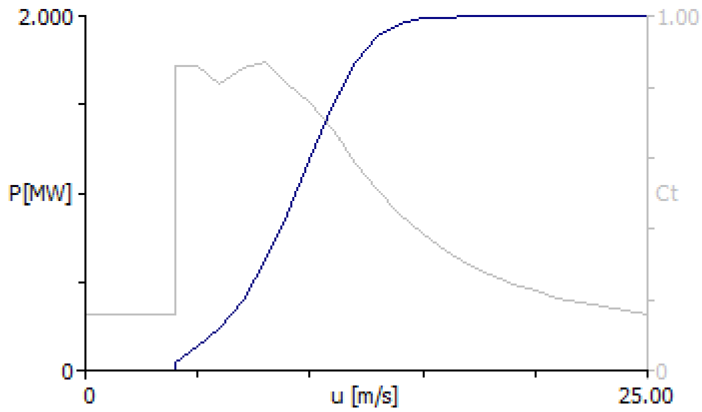
Manufacturer	Bonus Energy A/S
Web link	Undefined
Rotor diameter	54.2 m
Rated power (estimated)	1.000 MW
Control system (inferred)	Pitch
Default height	50.0 m
Comments	Address: Borupvej 16|Address: DK-7330 Brande, Denmark|Phone: +45 99 42 22 22|Fax: +45 97 18 30 86|E-mail: bonus@bonus.dk
Low speed cut-out	4.0 m/s
Low speed cut-in	4.0 m/s
Low speed limit	4.0 m/s
High speed cut-in	25.0 m/s
High speed cut-out	25.0 m/s
High speed limit	25.0 m/s

Bonus 1.3 MW



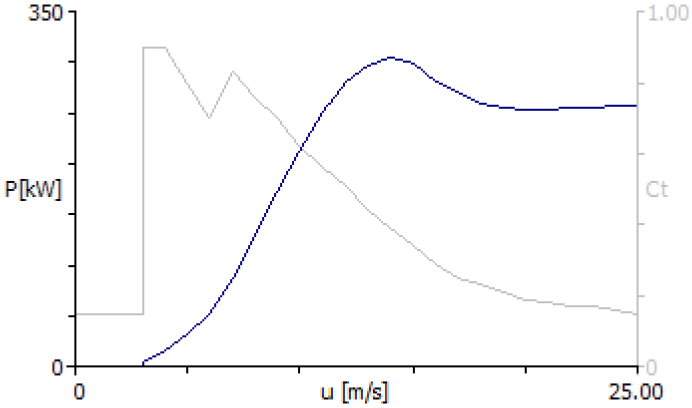
Manufacturer	Bonus Energy A/S
Web link	Undefined
Rotor diameter	62.0 m
Rated power (estimated)	1.300 MW
Control system (inferred)	Pitch
Default height	60.0 m
Comments	Address: Borupvej 16|Address: DK-7330 Brande, Denmark|Phone: +45 99 42 22 22|Fax: +45 97 18 30 86|E-mail: bonus@bonus.dk
Low speed cut-out	3.0 m/s
Low speed cut-in	3.0 m/s
Low speed limit	3.0 m/s
High speed cut-in	25.0 m/s
High speed cut-out	25.0 m/s
High speed limit	25.0 m/s

Bonus 2 MW



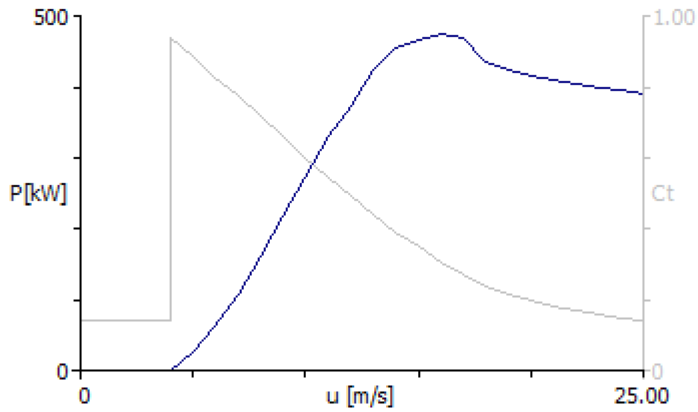
Manufacturer	Bonus Energy A/S
Web link	Undefined
Rotor diameter	76.0 m
Rated power (estimated)	2.000 MW
Control system (inferred)	Pitch
Default height	60.0 m
Comments	Address: Borupvej 16|Address: DK-7330 Brande, Denmark|Phone: +45 99 42 22 22|Fax: +45 97 18 30 86|E-mail: bonus@bonus.dk
Low speed cut-out	4.0 m/s
Low speed cut-in	4.0 m/s
Low speed limit	4.0 m/s
High speed cut-in	25.0 m/s
High speed cut-out	25.0 m/s
High speed limit	25.0 m/s

Bonus 300 kW Mk III



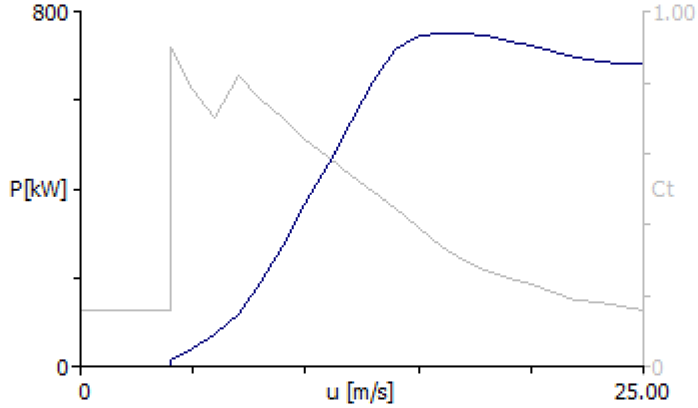
Manufacturer	Bonus Energy A/S
Web link	Undefined
Rotor diameter	33.4 m
Rated power	Undefined
Control system	Undefined
Default height	30.0 m
Comments	Address: Borupvej 16|Address: DK-7330 Brande, Denmark|Phone: +45 99 42 22 22|Fax: +45 97 18 30 86|E-mail: bonus@bonus.dk
Low speed cut-out	3.0 m/s
Low speed cut-in	3.0 m/s
Low speed limit	3.0 m/s
High speed cut-in	25.0 m/s
High speed cut-out	25.0 m/s
High speed limit	25.0 m/s

Bonus 450 kW MkIII



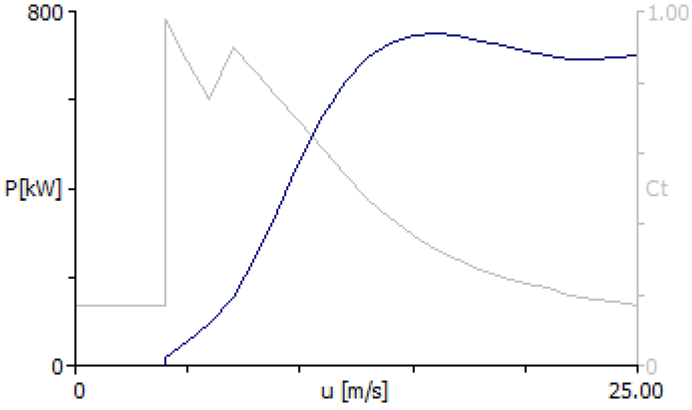
Manufacturer	Bonus Energy A/S
Web link	Undefined
Rotor diameter	37.0 m
Rated power	Undefined
Control system	Undefined
Default height	35.0 m
Comments	Address: Borupvej 16|Address: DK-7330 Brande, Denmark|Phone: +45 99 42 22 22|Fax: +45 97 18 30 86|E-mail: bonus@bonus.dk
Low speed cut-out	4.0 m/s
Low speed cut-in	4.0 m/s
Low speed limit	4.0 m/s
High speed cut-in	25.0 m/s
High speed cut-out	25.0 m/s
High speed limit	25.0 m/s

NEG-Micon 750/44 (750 kW)



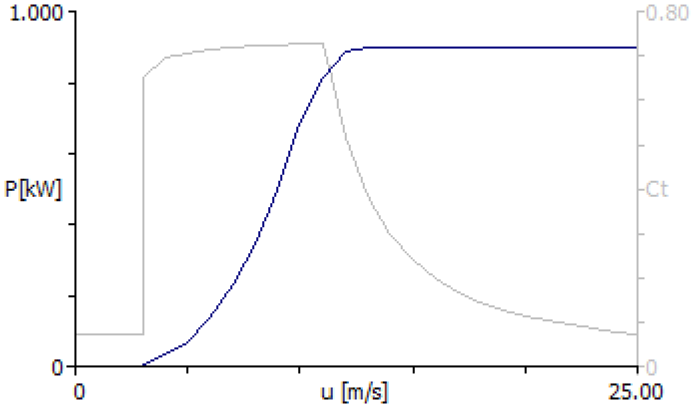
Manufacturer	NEG-Micon A/S
Web link	Undefined
Rotor diameter	44.0 m
Rated power (estimated)	760 kW
Control system (inferred)	Stall
Default height	50.0 m
Comments	Address: Alsvej 21|Address: DK-8900 Randers, Denmark|Phone: +45 87 10 50 00|Fax: +45 87 10 50 01|E-mail: mail@neg-micon.dk
Low speed cut-out	4.0 m/s
Low speed cut-in	4.0 m/s
Low speed limit	4.0 m/s
High speed cut-in	25.0 m/s
High speed cut-out	25.0 m/s
High speed limit	25.0 m/s

NEG-Micon 750/48 (750 kW)



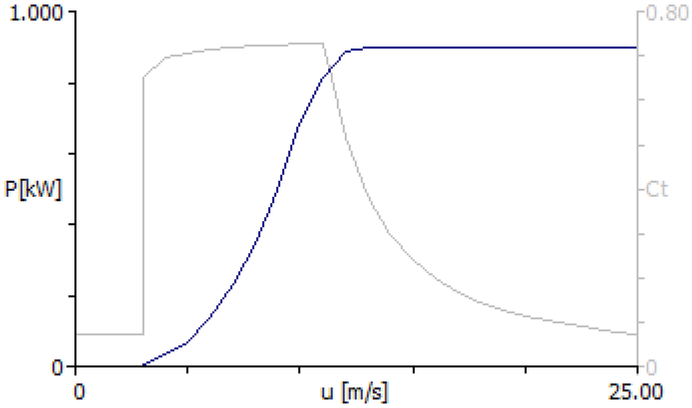
Manufacturer	NEG-Micon A/S
Web link	Undefined
Rotor diameter	48.2 m
Rated power (estimated)	760 kW
Control system (inferred)	Stall
Default height	50.0 m
Comments	Address: Alsvej 21|Address: DK-8900 Randers, Denmark|Phone: +45 87 10 50 00|Fax: +45 87 10 50 01|E-mail: mail@neg-micon.dk
Low speed cut-out	4.0 m/s
Low speed cut-in	4.0 m/s
Low speed limit	4.0 m/s
High speed cut-in	25.0 m/s
High speed cut-out	25.0 m/s
High speed limit	25.0 m/s

PowerWind 56 59.0 m



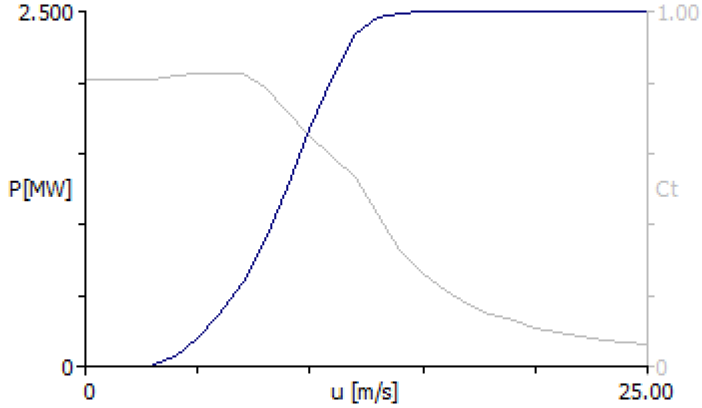
Manufacturer	PowerWind GmbH
Web link	www.powerwind-energy.com
Rotor diameter	56.0 m
Rated power (estimated)	900 kW
Control system (inferred)	Pitch
Default height	59.0 m
Comments	-
Low speed cut-out	3.0 m/s
Low speed cut-in	3.0 m/s
Low speed limit	3.0 m/s
High speed cut-in	25.0 m/s
High speed cut-out	25.0 m/s
High speed limit	25.0 m/s

PowerWind 56 71.0 m



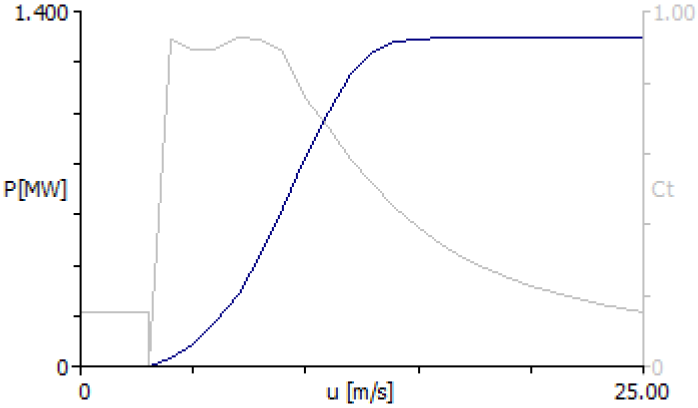
Manufacturer	PowerWind GmbH
Web link	www.powerwind-energy.com
Rotor diameter	56.0 m
Rated power (estimated)	900 kW
Control system (inferred)	Pitch
Default height	71.0 m
Comments	-
Low speed cut-out	3.0 m/s
Low speed cut-in	3.0 m/s
Low speed limit	3.0 m/s
High speed cut-in	25.0 m/s
High speed cut-out	25.0 m/s
High speed limit	25.0 m/s

PowerWind 90



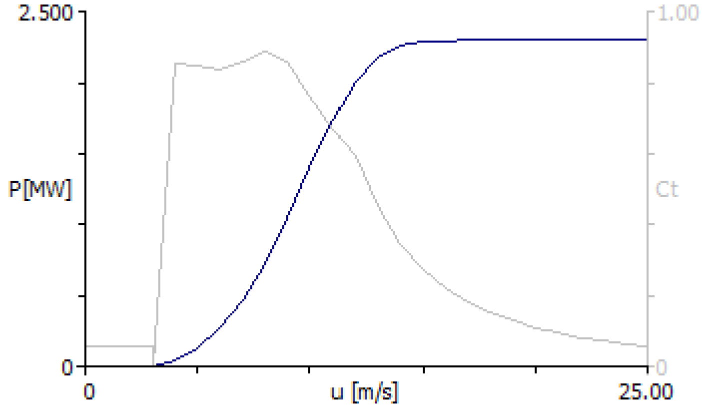
Manufacturer	PowerWind GmbH
Web link	www.powerwind-energy.com
Rotor diameter	90.0 m
Rated power (estimated)	2.500 MW
Control system (inferred)	Pitch
Default height	98.0 m
Comments	-
Low speed cut-out	3.0 m/s
Low speed cut-in	3.0 m/s
Low speed limit	3.0 m/s
High speed cut-in	25.0 m/s
High speed cut-out	25.0 m/s
High speed limit	25.0 m/s

SWT-1.3-62



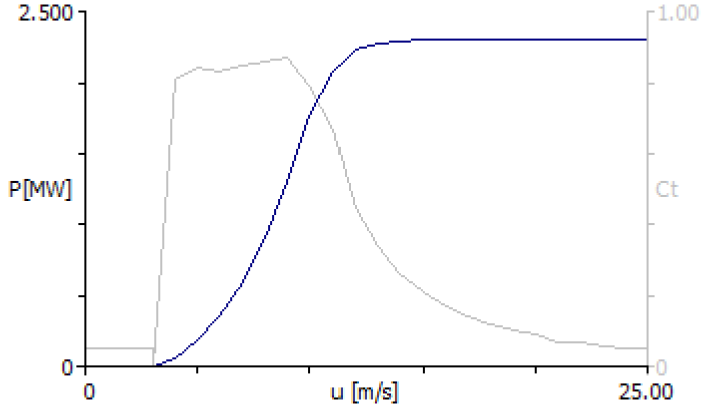
Manufacturer	Siemens Wind Power A/S
Web link	http://www.powergeneration.siemens.com/
Rotor diameter	62.0 m
Rated power (estimated)	1.300 MW
Control system (inferred)	Pitch
Default height	60.0 m
Comments	Address: Borupvej 16, DK-7330 Brande, Denmark|Phone: +45 99 42 22 22|Fax: +45 99 99 22 22|Mail: bsn@siemens.com
Low speed cut-out	3.0 m/s
Low speed cut-in	3.0 m/s
Low speed limit	3.0 m/s
High speed cut-in	25.0 m/s
High speed cut-out	25.0 m/s
High speed limit	25.0 m/s

SWT-2.3-82 VS



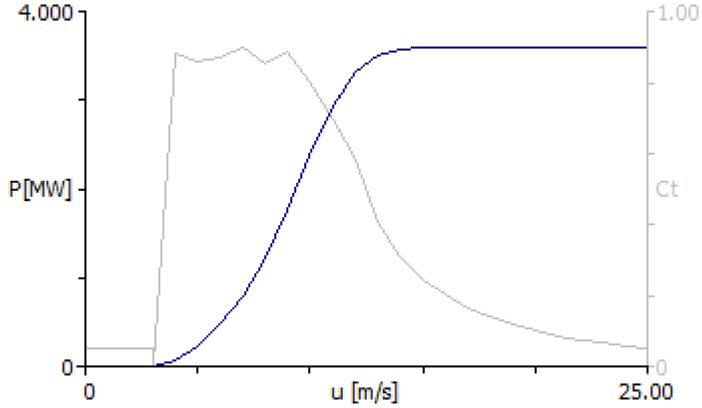
Manufacturer	Siemens Wind Power A/S
Web link	http://www.powergeneration.siemens.com/
Rotor diameter	82.4 m
Rated power (estimated)	2.300 MW
Control system (inferred)	Pitch
Default height	80.0 m
Comments	Address: Borupvej 16, DK-7330 Brande, Denmark|Phone: +45 99 42 22 22|Fax: +45 99 99 22 22|Mail: bsn@siemens.com
Low speed cut-out	3.0 m/s
Low speed cut-in	3.0 m/s
Low speed limit	3.0 m/s
High speed cut-in	25.0 m/s
High speed cut-out	25.0 m/s
High speed limit	25.0 m/s

SWT-2.3-93



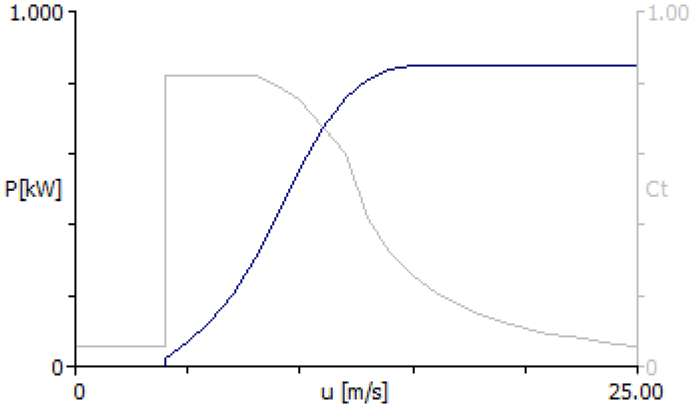
Manufacturer	Siemens Wind Power A/S
Web link	http://www.powergeneration.siemens.com/
Rotor diameter	93.0 m
Rated power (estimated)	2.300 MW
Control system (inferred)	Pitch
Default height	80.0 m
Comments	Address: Borupvej 16, DK-7330 Brande, Denmark|Phone: +45 99 42 22 22|Fax: +45 99 99 22 22|Mail: bsn@siemens.com
Low speed cut-out	3.0 m/s
Low speed cut-in	3.0 m/s
Low speed limit	3.0 m/s
High speed cut-in	25.0 m/s
High speed cut-out	25.0 m/s
High speed limit	25.0 m/s

SWT-3.6-107



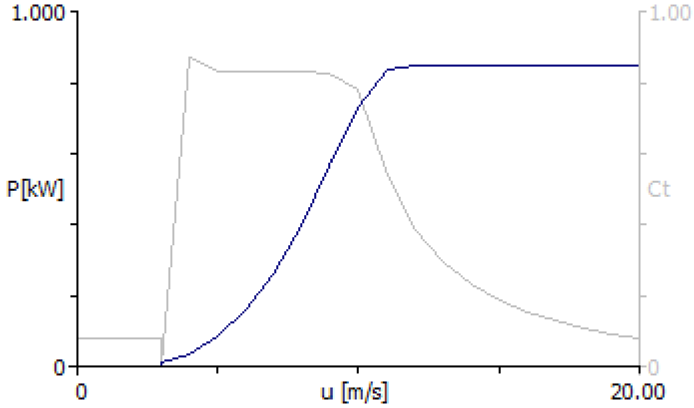
Manufacturer	Siemens Wind Power A/S
Web link	http://www.powergeneration.siemens.com/
Rotor diameter	107.0 m
Rated power (estimated)	3.600 MW
Control system (inferred)	Pitch
Default height	80.0 m
Comments	Address: Borupvej 16, DK-7330 Brande, Denmark|Phone: +45 99 42 22 22|Fax: +45 99 99 22 22|Mail: bsn@siemens.com
Low speed cut-out	3.0 m/s
Low speed cut-in	3.0 m/s
Low speed limit	3.0 m/s
High speed cut-in	25.0 m/s
High speed cut-out	25.0 m/s
High speed limit	25.0 m/s

Vestas V52-850 kW



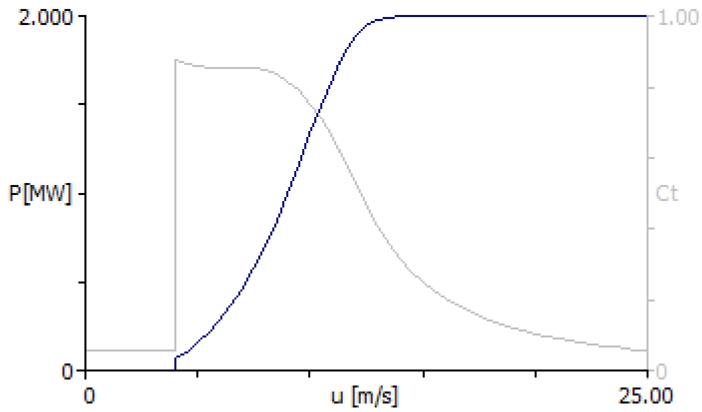
Manufacturer	Vestas Wind Systems A/S
Web link	www.vestas.com
Rotor diameter	52.0 m
Rated power (estimated)	860 kW
Control system (inferred)	Pitch
Default height	55.0 m
Comments	Address: Hedeager 44, 8200 Aarhus N, Denmark|Phone: +45 97 30 00 00|Fax: +45 97 30 00 01|E-mail: vestas@vestas.com
Low speed cut-out	4.0 m/s
Low speed cut-in	4.0 m/s
Low speed limit	4.0 m/s
High speed cut-in	25.0 m/s
High speed cut-out	25.0 m/s
High speed limit	25.0 m/s

Vestas V60-850 kW



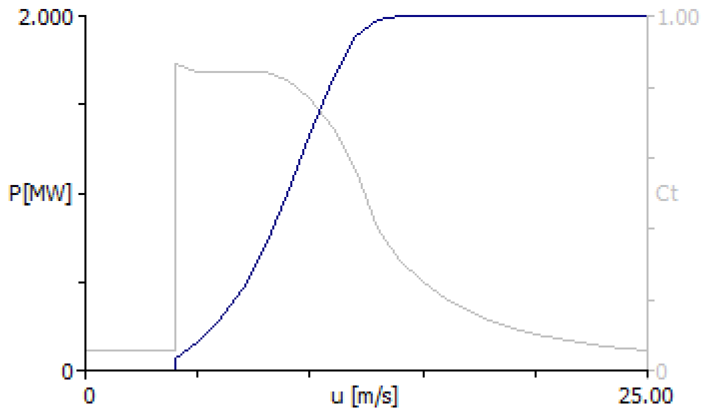
Manufacturer	Vestas Wind Systems A/S
Web link	www.vestas.com
Rotor diameter	60.0 m
Rated power (estimated)	860 kW
Control system (inferred)	Pitch
Default height	60.0 m
Comments	Address: Hedeager 44, 8200 Aarhus N, Denmark|Phone: +45 97 30 00 00|Fax: +45 97 30 00 01|E-mail: vestas@vestas.com
Low speed cut-out	3.0 m/s
Low speed cut-in	3.0 m/s
Low speed limit	3.0 m/s
High speed cut-in	20.0 m/s
High speed cut-out	20.0 m/s
High speed limit	20.0 m/s

V80-2.0 MW 50 Hz VCS



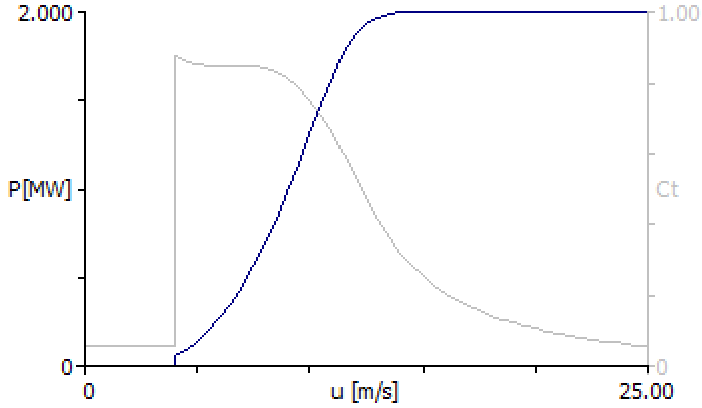
Manufacturer	Vestas Wind Systems A/S
Web link	www.vestas.com
Rotor diameter	80.0 m
Rated power (estimated)	2.000 MW
Control system (inferred)	Pitch
Default height	67.0 m
Comments	Address: Hedeager 44, 8200 Aarhus N, Denmark|Phone: +45 97 30 00 00|Fax: +45 97 30 00 01|E-mail: vestas@vestas.com
Low speed cut-out	4.0 m/s
Low speed cut-in	4.0 m/s
Low speed limit	4.0 m/s
High speed cut-in	25.0 m/s
High speed cut-out	25.0 m/s
High speed limit	25.0 m/s

V80-2.0 MW 60 Hz VCS



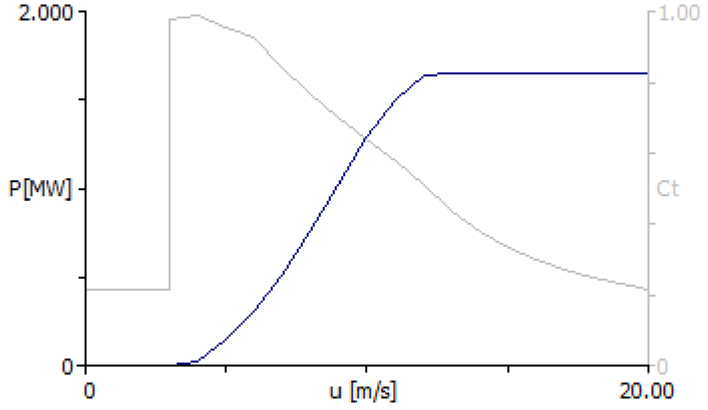
Manufacturer	Vestas Wind Systems A/S
Web link	www.vestas.com
Rotor diameter	80.0 m
Rated power (estimated)	2.000 MW
Control system (inferred)	Pitch
Default height	67.0 m
Comments	Address: Hedeager 44, 8200 Aarhus N, Denmark|Phone: +45 97 30 00 00|Fax: +45 97 30 00 01|E-mail: vestas@vestas.com
Low speed cut-out	4.0 m/s
Low speed cut-in	4.0 m/s
Low speed limit	4.0 m/s
High speed cut-in	25.0 m/s
High speed cut-out	25.0 m/s
High speed limit	25.0 m/s

Vestas V80-2.0 MW GridStreamer™



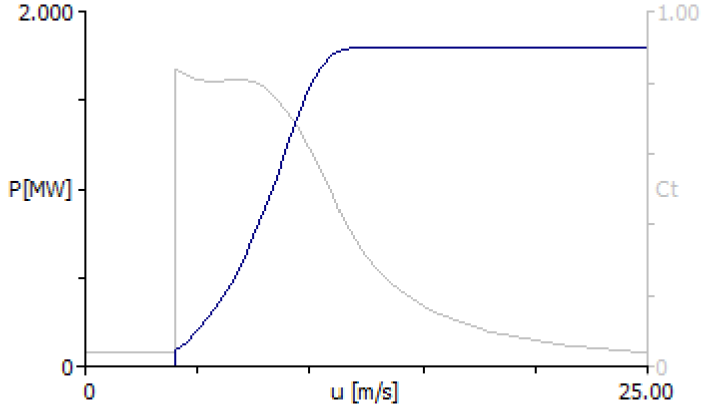
Manufacturer	Vestas Wind Systems A/S
Web link	www.vestas.com
Rotor diameter	80.0 m
Rated power (estimated)	2.000 MW
Control system (inferred)	Pitch
Default height	80.0 m
Comments	Address: Hedeager 44, 8200 Aarhus N, Denmark|Phone: +45 97 30 00 00|Fax: +45 97 30 00 01|E-mail: vestas@vestas.com
Low speed cut-out	4.0 m/s
Low speed cut-in	4.0 m/s
Low speed limit	4.0 m/s
High speed cut-in	25.0 m/s
High speed cut-out	25.0 m/s
High speed limit	25.0 m/s

Vestas V82 (1650 kW)



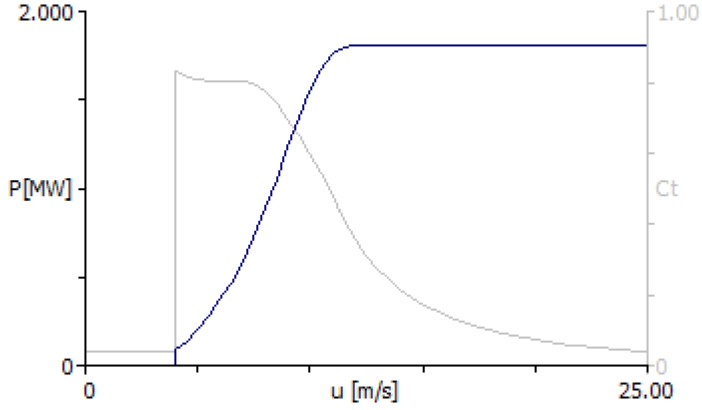
Manufacturer	Vestas Wind Systems A/S
Web link	www.vestas.com
Rotor diameter	82.0 m
Rated power (estimated)	1.650 MW
Control system (inferred)	Pitch
Default height	70.0 m
Comments	Address: Hedeager 44, 8200 Aarhus N, Denmark|Phone: +45 97 30 00 00|Fax: +45 97 30 00 01|Fax: +45 97 30 00 01|E-mail: vestas@vestas.com
Low speed cut-out	3.0 m/s
Low speed cut-in	3.0 m/s
Low speed limit	3.0 m/s
High speed cut-in	20.0 m/s
High speed cut-out	20.0 m/s
High speed limit	20.0 m/s

V90-1.8 MW 50 Hz VCS



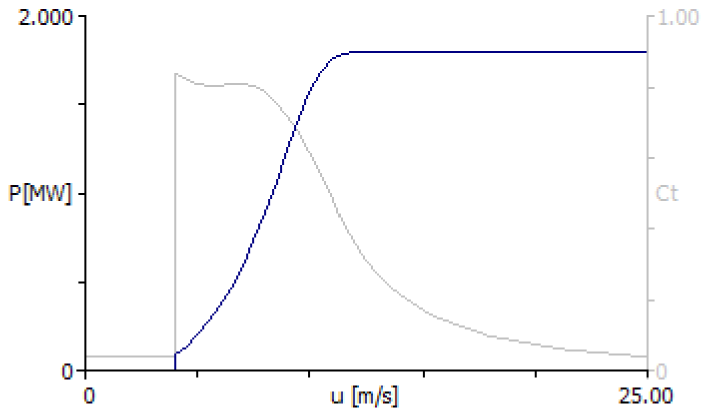
Manufacturer	Vestas Wind Systems A/S
Web link	www.vestas.com
Rotor diameter	90.0 m
Rated power (estimated)	1.800 MW
Control system (inferred)	Pitch
Default height	80.0 m
Comments	Address: Hedeager 44, 8200 Aarhus N, Denmark|Phone: +45 97 30 00 00|Fax: +45 97 30 00 01|E-mail: vestas@vestas.com
Low speed cut-out	4.0 m/s
Low speed cut-in	4.0 m/s
Low speed limit	4.0 m/s
High speed cut-in	25.0 m/s
High speed cut-out	25.0 m/s
High speed limit	25.0 m/s

V90-1.8 MW VCUS



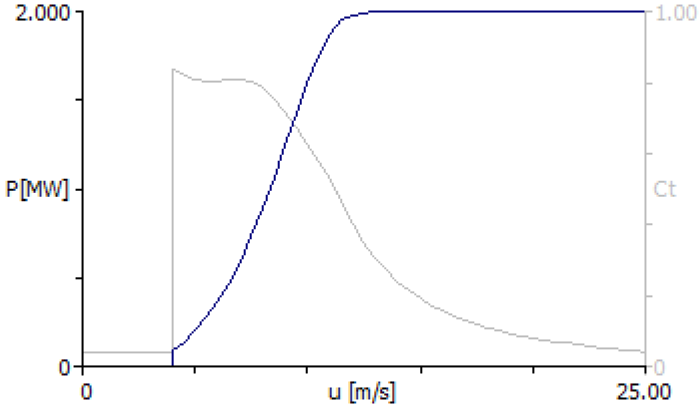
Manufacturer	Vestas Wind Systems A/S
Web link	www.vestas.com
Rotor diameter	90.0 m
Rated power (estimated)	1.825 MW
Control system (inferred)	Pitch
Default height	80.0 m
Comments	Address: Hedeager 44, 8200 Aarhus N, Denmark|Phone: +45 97 30 00 00|Fax: +45 97 30 00 01|E-mail: vestas@vestas.com
Low speed cut-out	4.0 m/s
Low speed cut-in	4.0 m/s
Low speed limit	4.0 m/s
High speed cut-in	25.0 m/s
High speed cut-out	25.0 m/s
High speed limit	25.0 m/s

V90-1.8 MW GridStreamer



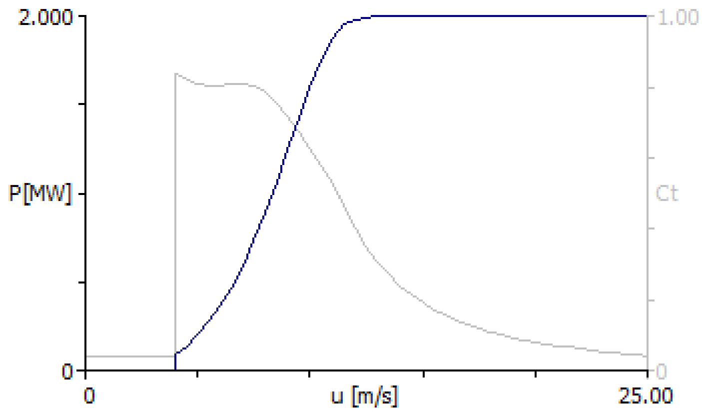
Manufacturer	Vestas Wind Systems A/S
Web link	www.vestas.com
Rotor diameter	90.0 m
Rated power (estimated)	1.800 MW
Control system (inferred)	Pitch
Default height	80.0 m
Comments	Address: Hedeager 44, 8200 Aarhus N, Denmark|Phone: +45 97 30 00 00|Fax: +45 97 30 00 01|E-mail: vestas@vestas.com
Low speed cut-out	4.0 m/s
Low speed cut-in	4.0 m/s
Low speed limit	4.0 m/s
High speed cut-in	25.0 m/s
High speed cut-out	25.0 m/s
High speed limit	25.0 m/s

V90-2.0 MW 50 Hz VCS



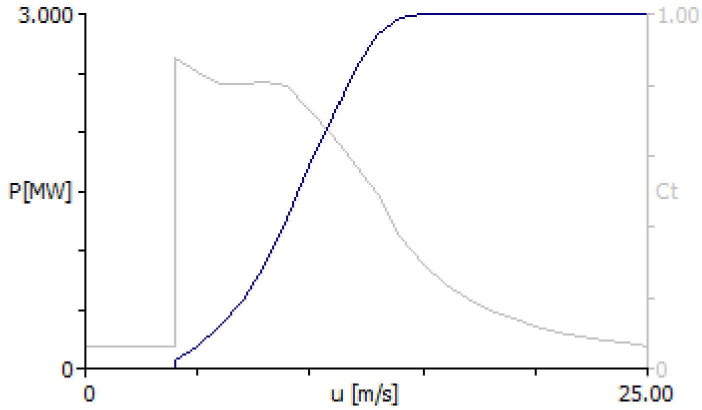
Manufacturer	Vestas Wind Systems A/S
Web link	www.vestas.com
Rotor diameter	90.0 m
Rated power (estimated)	2.000 MW
Control system (inferred)	Pitch
Default height	80.0 m
Comments	Address: Hedeager 44, 8200 Aarhus N, Denmark|Phone: +45 97 30 00 00|Fax: +45 97 30 00 01|E-mail: vestas@vestas.com
Low speed cut-out	4.0 m/s
Low speed cut-in	4.0 m/s
Low speed limit	4.0 m/s
High speed cut-in	25.0 m/s
High speed cut-out	25.0 m/s
High speed limit	25.0 m/s

V90-2.0 MW GridStreamer



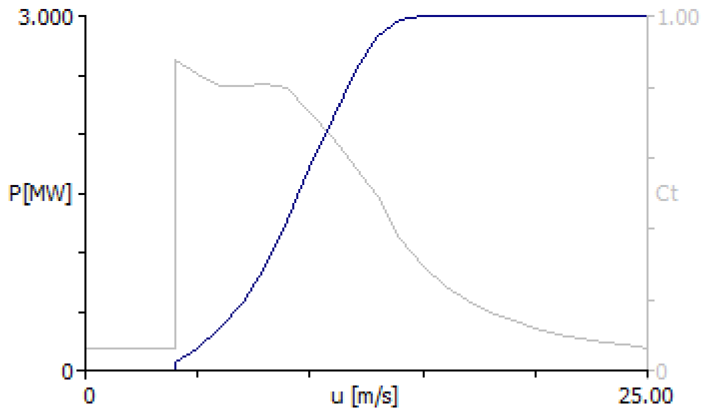
Manufacturer	Vestas Wind Systems A/S
Web link	www.vestas.com
Rotor diameter	90.0 m
Rated power (estimated)	2.000 MW
Control system (inferred)	Pitch
Default height	80.0 m
Comments	Address: Hedeager 44, 8200 Aarhus N, Denmark|Phone: +45 97 30 00 00|Fax: +45 97 30 00 01|E-mail: vestas@vestas.com
Low speed cut-out	4.0 m/s
Low speed cut-in	4.0 m/s
Low speed limit	4.0 m/s
High speed cut-in	25.0 m/s
High speed cut-out	25.0 m/s
High speed limit	25.0 m/s

V90-3.0 MW VCRS 60 Hz



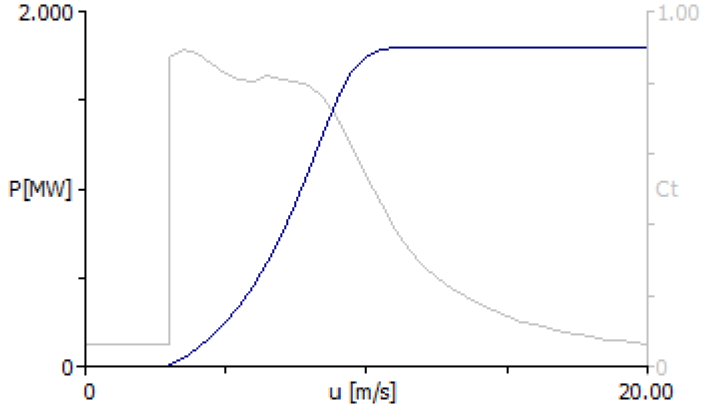
Manufacturer	Vestas Wind Systems A/S
Web link	www.vestas.com
Rotor diameter	90.0 m
Rated power (estimated)	3.000 MW
Control system (inferred)	Pitch
Default height	80.0 m
Comments	Address: Hedeager 44, 8200 Aarhus N, Denmark|Phone: +45 97 30 00 00|Fax: +45 97 30 00 01|E-mail: vestas@vestas.com
Low speed cut-out	4.0 m/s
Low speed cut-in	4.0 m/s
Low speed limit	4.0 m/s
High speed cut-in	25.0 m/s
High speed cut-out	25.0 m/s
High speed limit	25.0 m/s

V90-3.0 MW VCS 50 Hz



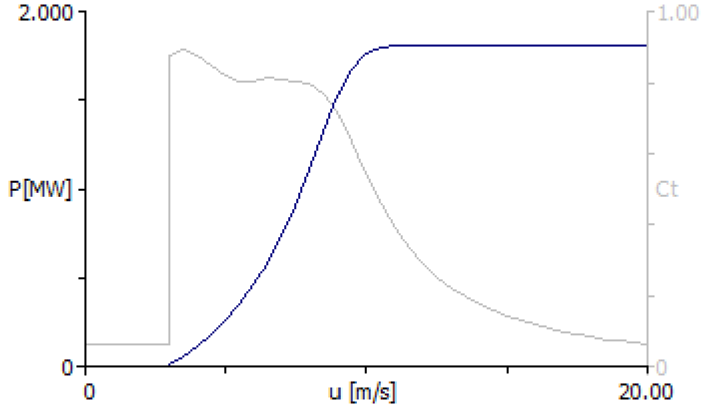
Manufacturer	Vestas Wind Systems A/S
Web link	www.vestas.com
Rotor diameter	90.0 m
Rated power (estimated)	3.000 MW
Control system (inferred)	Pitch
Default height	80.0 m
Comments	Address: Hedeager 44, 8200 Aarhus N, Denmark|Phone: +45 97 30 00 00|Fax: +45 97 30 00 01|E-mail: vestas@vestas.com
Low speed cut-out	4.0 m/s
Low speed cut-in	4.0 m/s
Low speed limit	4.0 m/s
High speed cut-in	25.0 m/s
High speed cut-out	25.0 m/s
High speed limit	25.0 m/s

V100-1.8 MW 50 Hz VCS



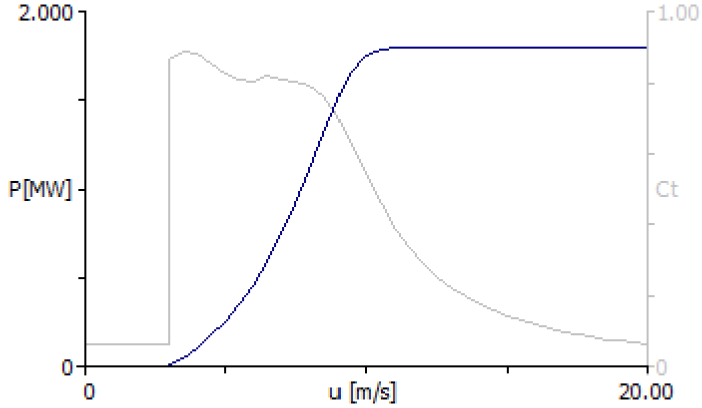
Manufacturer	Vestas Wind Systems A/S
Web link	www.vestas.com
Rotor diameter	100.0 m
Rated power (estimated)	1.800 MW
Control system (inferred)	Pitch
Default height	80.0 m
Comments	Address: Hedeager 44, 8200 Aarhus N, Denmark|Phone: +45 97 30 00 00|Fax: +45 97 30 00 01|E-mail: vestas@vestas.com
Low speed cut-out	3.0 m/s
Low speed cut-in	3.0 m/s
Low speed limit	3.0 m/s
High speed cut-in	20.0 m/s
High speed cut-out	20.0 m/s
High speed limit	20.0 m/s

V100-1.8 MW 60 Hz VCS



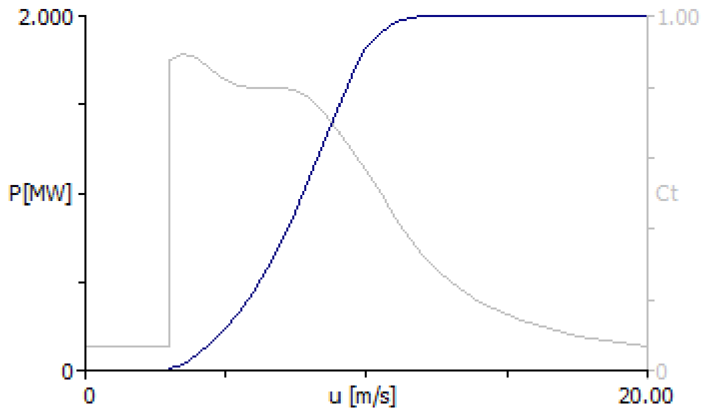
Manufacturer	Vestas Wind Systems A/S
Web link	www.vestas.com
Rotor diameter	100.0 m
Rated power (estimated)	1.825 MW
Control system (inferred)	Pitch
Default height	80.0 m
Comments	Address: Hedeager 44, 8200 Aarhus N, Denmark|Phone: +45 97 30 00 00|Fax: +45 97 30 00 01|E-mail: vestas@vestas.com
Low speed cut-out	3.0 m/s
Low speed cut-in	3.0 m/s
Low speed limit	3.0 m/s
High speed cut-in	20.0 m/s
High speed cut-out	20.0 m/s
High speed limit	20.0 m/s

V100-1.8 MW GridStreamer



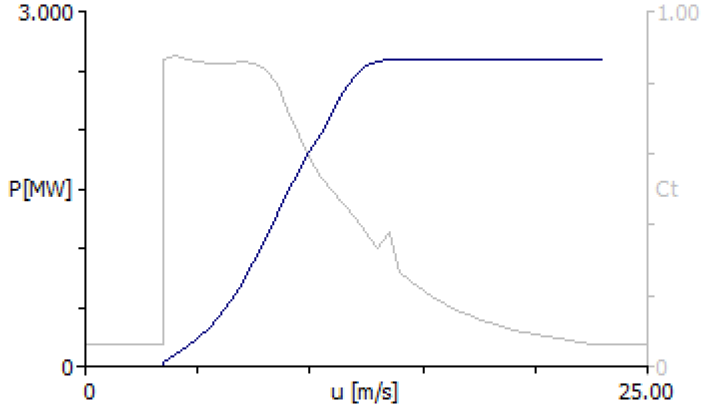
Manufacturer	Vestas Wind Systems A/S
Web link	www.vestas.com
Rotor diameter	100.0 m
Rated power (estimated)	1.800 MW
Control system (inferred)	Pitch
Default height	80.0 m
Comments	Address: Hedeager 44, 8200 Aarhus N, Denmark|Phone: +45 97 30 00 00|Fax: +45 97 30 00 01|E-mail: vestas@vestas.com
Low speed cut-out	3.0 m/s
Low speed cut-in	3.0 m/s
Low speed limit	3.0 m/s
High speed cut-in	20.0 m/s
High speed cut-out	20.0 m/s
High speed limit	20.0 m/s

V100-2.0 MW GridStreamer



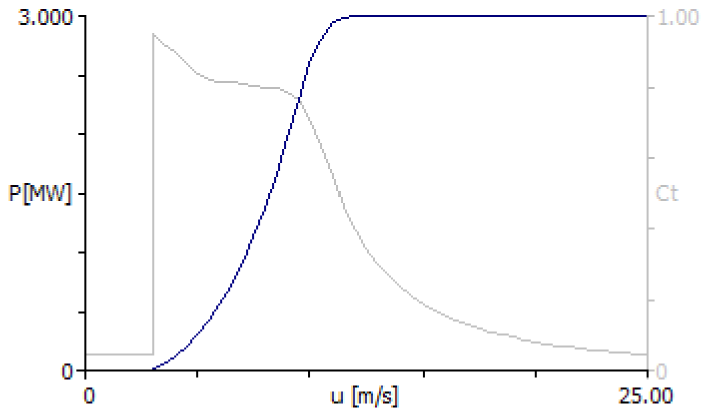
Manufacturer	Vestas Wind Systems A/S
Web link	www.vestas.com
Rotor diameter	100.0 m
Rated power (estimated)	2.000 MW
Control system (inferred)	Pitch
Default height	80.0 m
Comments	Address: Hedeager 44, 8200 Aarhus N, Denmark|Phone: +45 97 30 00 00|Fax: +45 97 30 00 01|E-mail: vestas@vestas.com
Low speed cut-out	3.0 m/s
Low speed cut-in	3.0 m/s
Low speed limit	3.0 m/s
High speed cut-in	20.0 m/s
High speed cut-out	20.0 m/s
High speed limit	20.0 m/s

V100-2.6 MW VCS 50 Hz



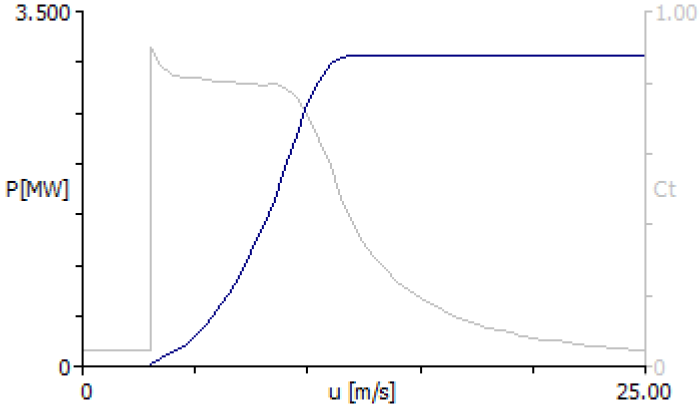
Manufacturer	Vestas Wind Systems A/S
Web link	www.vestas.com
Rotor diameter	100.0 m
Rated power (estimated)	2.600 MW
Control system (inferred)	Pitch
Default height	80.0 m
Comments	Address: Hedeager 44, 8200 Aarhus N, Denmark|Phone: +45 97 30 00 00|Fax: +45 97 30 00 01|E-mail: vestas@vestas.com
Low speed cut-out	3.5 m/s
Low speed cut-in	3.5 m/s
Low speed limit	3.5 m/s
High speed cut-in	23.0 m/s
High speed cut-out	23.0 m/s
High speed limit	23.0 m/s

V112-3.0 MW 50 Hz Offshore



Manufacturer	Vestas Wind Systems A/S
Web link	www.vestas.com
Rotor diameter	112.0 m
Rated power (estimated)	3.000 MW
Control system (inferred)	Pitch
Default height	84.0 m
Comments	Address: Hedeager 44, 8200 Aarhus N, Denmark|Phone: +45 97 30 00 00|Fax: +45 97 30 00 01|E-mail: vestas@vestas.com
Low speed cut-out	3.0 m/s
Low speed cut-in	3.0 m/s
Low speed limit	3.0 m/s
High speed cut-in	25.0 m/s
High speed cut-out	25.0 m/s
High speed limit	25.0 m/s

V112-3.0 MW



Manufacturer	Vestas Wind Systems A/S
Web link	www.vestas.com
Rotor diameter	112.0 m
Rated power (estimated)	3.100 MW
Control system (inferred)	Pitch
Default height	84.0 m
Comments	Address: Hedeager 44, 8200 Aarhus N, Denmark|Phone: +45 97 30 00 00|Fax: +45 97 30 00 01|E-mail: vestas@vestas.com
Low speed cut-out	3.0 m/s
Low speed cut-in	3.0 m/s
Low speed limit	3.0 m/s
High speed cut-in	25.0 m/s
High speed cut-out	25.0 m/s
High speed limit	25.0 m/s

Appendix D

Published paper (as a first author)

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 104, Issue 1 (2023) 169-184

SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879

Techno-Economic Assessment of Wind Energy in Urban Environments: A Case Study in Pattaya, Thailand

Chatchawich Chaihong[1], Juntakan Taweekun[1,2,*]

[1] Energy Technology Program, Faculty of Engineering, Prince of Songkla University, Hat Yai, 90110, Songkhla, Thailand
[2] Department of Mechanical and Mechatronics Engineering, Faculty of Engineering, Prince of Songkla University, Hat Yai, 90110, Songkhla, Thailand

ARTICLE INFO

Article history:
Received 3 December 2022
Received in revised form 18 February 2023
Accepted 25 February 2023
Available online 16 March 2023

Keywords:
Levelized Cost of Electricity (LCOE); Net Present Value (NPV); Benefit Cost ratio (BCR or B/C ratio); Payback Period (PBP); Internal Rate of Return (IRR); carbon dioxide (CO_2) emissions; WAsP; Thailand

ABSTRACT

The goal of reducing carbon dioxide (CO_2) emissions is a global collective challenge for the clean energy group, and it is reflected in Thailand's Renewable Energy Development Plan (AEDP) in 2018, which includes wind power as one of the six clean energy sectors. This study analysed the wind energy potential in Pattaya City, Bang Lamung District, Chonburi Province, in the Eastern Economic Corridor (EEC) Development Zone Plan, by utilizing data from weather stations and the Meteorological Department during the period of 2019-2021 at a height of 10 meters above the ground, comparing the areas of Pattaya Station, Chonburi Station, and Kao Si Chang Station. For the possibility of wind turbines with default heights ranging from 60 to 90 meters, three models are available: Bonus 1.3 MW, SWT-1.3-62, and SWT-2.3-82, as per the research results. The wind resources were found to be of Wind Power Class 1, with poor resource potential, and the prevailing wind direction in the study area was identified as northeast and west in Ko Sichang, southeast in Pattaya, and southwest and west in Chonburi. The Pattaya Station area was deemed unsuitable for wind farm establishment due to its low-wind power potential, as indicated by an economic analysis (public sector). It is not recommended for private or business sectors as it may not generate attractive returns or may result in losses. Based on the observations, the wind turbine with the highest AEP may not be the best choice for investment returns. This was demonstrated through an analysis of the SWT-2.3-82 VS wind turbine on Kaya Sira Hill, Koh Sichang, which had a CO_2 Emission Reduction capacity of 2,154.24 tons CO_2/GWh and an AEP of 3.366 GWh. Despite this, the LOCE of this model was not the lowest among the three models, and the LCOE and NPV of the SWT-1.3-62 were higher than the SWT-2.3-82 VS at all discount rate values. Moreover, the IRR of the SWT-1.3-62 were lower than the others, indicating that higher investments do not always lead to better returns.

* *Corresponding author.*
E-mail address: juntakan.t@psu.ac.th

https://doi.org/10.37934/arfmts.104.1.169184

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences
Volume 104, Issue 1 (2023) 169-184

1. Introduction

According to Thailand's Renewable Energy Development Plan (AEDP) 2018, the performance of renewable and alternative energy in terms of wind power has seen an expansion from 2016-2018, with sizes of 507.00, 627.80, and 1,102.82 MW, respectively [1]. The spatial base for this expansion covers more than 513,115 square kilometers (km^2) in over 23 provinces located near the sea [2,3]. As a result, Thailand has different topographies in each region, Previous research has surveyed the wind energy source area at an altitude of 120 meters above ground level (AGL) and found that the velocity ranged from 1.60-5.83 m/s, with the highest average annual power density of about 200 W/m^2 [4]. Simulation results from the Thongyai and Assawamartbunlue [5] showed that mountainous regions of the western, southern, and eastern regions of Thailand have higher wind energy resources than other regions, and the area located between 40-100 AGL in the east has the potential to generate electricity with an average wind speed of more than 6 m/s. Goudarzi *et al.,* [6] evaluated the technical and economic performance of more than 150 small wind turbines by Weibull probability density function and found that the average annual wind speed is about 3 m/s, which can produce electricity at 1990 kWh per year with a payback period of 13 years. Pawintanathon *et al.,* [7] analyzed wind energy potential in Roi Et, Buriram, Si Sa Ket, Surin, and Ubon Ratchathani at an altitude of 60 and 80 meters, using the Wind Atlas Analysis and Application Program (WAsP) [8]. The results showed that Roi Et had an annual energy production (AEP) of 18.932 GWh and 56.322 GWh at 60 and 80 meters, respectively, while the other provinces had AEPs ranging from 8.508 GWh to 45.737 GWh. Chand and Starcher [9] found that a 50 kW wind turbine system and a 42 kW PV system calculated PV WATTS, the annual energy production will be 228,531 kWh and 81,581 kWh, respectively, and the payback period of the wind is about 13 years. Bortolini *et al.,* [10] estimated the levelized energy cost (LCOE) of 10 MW and 25 MW wind farms at 4.01 c€/kWh and 5.76 c€/kWh, respectively, and assessed decision variables such as the number of wind turbines, distance to the main grid, and site perimeter conditions. Zakaria *et al.,* [11] found that the overall emission intensity for all power plants studied was approximately 0.54 tCO_2/MWh. Waewsak *et al.,* [12] conducted a high-resolution mapping of wind resources at 80, 100, 120, and 140 meters above ground level and found that wind potential at a wind speed of 120 m AGL above 8.0 m/s can produce electricity of 690 GWh/year and avoid greenhouse gas emissions of 1.2 million tones CO_2eq./year.

In this study, the scope was divided into the Eastern Economic Corridor (EEC) Development Zone Plan, which is a special local administrative organization area that includes Pattaya City, Bang Lamung District, Chonburi Province, as specified in the plan [13,14]. The research aimed to evaluate the feasibility of wind turbine farm construction in the area, specifically managing wind farm projects at heights between 60-90 meters above the ground using the WAsP tool. Wind speed data were collected from the Meteorological Department's weather station in Chonburi Province, Thailand, every 10 minutes at a height of 10 meters above the ground, during a 3-year period from January 1, 2019 to December 31, 2021, through supervision and a data collection system [15]. Wind data were compiled as periodic stratified data and analyzed using economic tools for a detailed joint analysis, including LCOE, NPV, PBP, IRR, BCR, and CO_2e reduction calculations, in order to evaluate the economic feasibility and potential environmental impact of a wind farm project [16]. Previous studies have used only some of these tools. Therefore, the results of this study can provide important insights into the feasibility of wind farm projects in urban areas and contribute to the development of sustainable energy policies in Thailand.

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences
Volume 104, Issue 1 (2023) 169-184

2. Methodology
2.1 Wind Data Collection

This research study focuses on evaluating the potential of wind energy resources in Thailand. The scope of the study was divided into regions according to the Meteorological Department and the area was selected from the weather station meteorology in Chonburi province, Thailand by collecting wind speed data [15]. This data was collected every 10 minutes at a height of 10 meters above the ground during the 3-year period from January 1, 2019, to December 31, 2021. The wind data was collected through supervision and the data collection system over a period of time as shown in Table 1 [16].

Table 1
Location of stations, including geographic positions and zones

Station area	Lat-Lon-Height		UTM/USNG		
	Latitude	Longitude	Northing (m) or Y co-ordinate	Easting (m) or X co-ordinate	Zone
Chonburi	N13° 21′ 20.00160″	E100° 58′ 55.89840″	1477313.912	714680.218	47
Ko Sichang	N13° 09′ 46.00080″	E100° 48′ 10.10160″	1455837.043	695399.636	47
Pattaya	N12° 55′ 23.00160″	E100° 51′ 56.19960″	1429363.948	702403.949	47

2.2 Wind Atlas Analysis and Application Program (WAsP)

The Wind Atlas Analysis and Application Program (WAsP) is a linear numerical model that is widely used in the wind energy industry as a standard for wind farm assessments [17]. It is based on actual data on turbine power generation and has been validated for both unresolved and user-defined changes in wind speeds at hub heights across all sites [16]. The uncorrected forecast produced the lowest deviation for annual net production (-1.2%) [17].

2.3 Data and Size of Wind Turbines

In order to analyze the opportunities and feasibility of the area, wind turbines with High-speed limit cut and Low speed limit cut were used, with a wide range to support high fluctuating wind power, and rotor diameters of 60-90 meters and default heights of 60-90 meters. From the collected wind data and spatial data, it was found that there are 3 models of wind turbines as shown in Table 2.

Table 2
Wind turbine model information

No.	Turbines	Rotor diameter (m)	Rated power (estimated) (MW)	Default height (m)	Low speed limit cut (m/s)	High speed limit cut (m/s)
1	Bonus 1.3 MW	62.00	1.3000	60.00	3.00	25.00
2	SWT-1.3-62	62.00	1.3000	60.00	3.00	25.00
3	SWT-2.3-82 VS	82.40	2.3000	80.00	3.00	25.00

2.4 Analysis of Meteorological Data

To assess the potential for wind energy production, data was analyzed using the WAsP software to estimate wind speed at heights of 60 and 90 meters above ground level, as well as the monthly average. The distribution of wind direction was also estimated to analyze the wind power production

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences
Volume 104, Issue 1 (2023) 169-184

of each selected type of wind turbine and to create a wind map. To improve the accuracy of the predictions, the terrain effect was "removed" first. The results, including topography, roughness, and obstruction, were extracted from the estimated wind conditions using a linear flow model based on the topographical map of the surrounding area [8]. The Weibull distribution, wind direction or wind rose histogram, gust factor, wind power quantity, and potential energy production were calculated for each turbine size [18,19].

2.4.1 Frequency distribution

A feasibility assessment of setting up wind farms for energy production requires careful consideration of the highly volatile nature of wind, which can vary by time of day, day of the year, and year over year [20,21]. In this process, it is crucial to characterize the wind speed data, and describe wind speed frequency [20,22]. The most commonly used evaluation technique to estimate the distribution of wind energy density, is the Weibull distribution [23-25]. Eq. (1) and Eq. (2) demonstrate how the shape of the Weibull distribution can be expressed [26-30]

$$f(V) = \frac{k}{c}\left(\frac{V}{c}\right)^{k-1} exp\left[-\left(\frac{V}{c}\right)^{k}\right], k > 0, v > 0, c > 1 \tag{1}$$

$$f(V) = 1 - exp\left[-\left(\frac{V}{c}\right)^{k}\right] \tag{2}$$

In these equations, f(V) is the probability of observing the wind speed, V is the wind speed (m/s), k is the contour parameter, and c is the level parameter (m/s).

2.4.2 Wind direction or wind rose histogram

Accurate characterization of average wind direction is critical in determining the feasibility of wind farms for energy production. This information helps determine the optimal placement of wind turbines within a wind farm as well as the direction in which they should face to maximize energy output. An analysis of average wind direction can be conducted using the frequency distribution method of wind direction data. The wind direction is expressed as the wind direction angle value, as shown in Eq. (3), which is calculated using the mean wind direction over time (degree angle), the total number of hours (N) (hour), the number of hours (n_i) (hour), and the mid-range value of the wind direction (d_i) (angle) [30]

$$WD_m = \frac{1}{N}\sum_{i=1}^{\infty} n_i d_i \tag{3}$$

2.5 Economic Analysis of Site Area and Decision-Making Criteria for Investment

The decision to establish a new electrical system powered by renewable energy sources is becoming increasingly necessary due to the non-polluting and renewable nature of these systems [31]. However, transitioning to these technologies presents several challenges, including (i) high initial costs, (ii) operating costs, and (iii) increased operational and investment risks. Moreover, political instability, existing innovation policy tools, and carbon policies can also impact the potential value of a project and the criteria used to evaluate it [32].

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences
Volume 104, Issue 1 (2023) 169-184

To measure the economic value of different investments, it is crucial to consider not only the initial investment but also the annual cash inflows and outflows associated with the 25-year project life. Additional economic issues that need to be considered include the index used to solve these problems, which consists of [33].

2.5.1 Levelized Cost of Energy (LCOE)

The LCOE is a metric proposed by the International Renewable Energy Agency (IRENA) [34] and is widely used in global government policies for evaluating the cost of new renewable energy technologies. It estimates the economic value of the average total cost of building and operating a power generation system over its lifetime, relative to the total power generated by the system over its lifetime [35]. This metric is considered significant for assessing the economic feasibility of renewable energy projects [31,32]. The LCOE is typically expressed in units of \$/MWh and is calculated using Eq. (4) and Eq. (5), where I_t is the capital expenditure in year t, M_t is an operating expense, and maintenance in year t, F_t is the fuel cost in year t, E_t is the electrical energy generated in year t, r is the discount rate, and n is the expected service life of the system or power station [36]. The LCOE can also be used to examine the production cost ratio of wind power plants and to calculate the proportion of the Levelized cost of energy (LCOE). It assumes discount rates of 7%, 5.4%, and 5% to determine costs.

$$LCOE = \frac{sum\ of\ costs\ over\ lifetime}{sum\ of\ eletrical\ energy\ produced\ over\ lifetime} \quad (4)$$

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t M_t F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \quad (5)$$

2.5.2 Net Present Value (NPV)

Net Present Value (NPV) is a widely used measure for determining the financial viability of a plan over the analysis period by calculating the difference between the present value of benefits (PVB) and the present value of costs (PVC) [37]. It is commonly used to evaluate the net value of all benefits. To calculate the NPV, data on the annual return from electricity sales (B_A), annual costs (C_A), initial investment cost (C_I), discount interest rate (I), duration or economic life of the project (n), and percentage of annual operation and maintenance costs (m) are required. Eq. (6) represents the NPV, which is calculated by using the assumption of discount rates of 7%, 5.4%, and 5% to determine the ratio.

$$NPV = B_A \left[\frac{(1+I)^n - 1}{I(1+I)^n}\right] - \left\{C_I \left[1 + m\left(\frac{(1+I)^n - 1}{I(1+I)^n}\right)\right]\right\} \quad (6)$$

2.5.3 Cost-benefit ratio or rate of return on expenses (BCR or B/C ratio)

The benefit-cost ratio (BCR) is a metric used to compare the present value of all benefits to the present value of all costs, including the initial investment, even if the investment has been made or only available in the first year of operation [33]. Using only the net present value (NPV) may not provide a complete picture when comparing two projects with different initial investment levels. Projects with high capital investments may have a higher chance of showing a positive NPV than projects with lower capital requirements. In such cases, the cost-benefit ratio (BCR) is a better tool

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences
Volume 104, Issue 1 (2023) 169-184

for economic decision-making. The BCR can be calculated using Eq. (7), taking into account factors such as the annual return on electricity sales(B_A), annual operation and maintenance costs (C_A), total investment cost (C_I), discount interest rate (I), period or economic life of the project (n), and percentage of annual operation and maintenance costs (m). To ensure the accuracy of the calculation, the assumption of discount rates of 7%, 5.4%, and 5% can be used.

$$BCR = \frac{B_A\left[\frac{(1+I)^n-1}{I(1+I)^n}\right]}{C_I\left[1+m\left(\frac{(1+I)^n-1}{I(1+I)^n}\right)\right]} \quad (7)$$

2.5.4 Payback Period (PBP)

The payback period (PBP) is a widely used metric to evaluate the feasibility of investments, indicating the amount of time needed for the investment to be recouped [38]. A shorter PBP generally indicates a better investment. However, PBP has limitations, as it does not account for changes in operating costs over time or the time value of money [39]. Moreover, PBP does not require making assumptions about discounts or interest rates. The project's economic viability is compromised when the PBP is too long, indicating an unacceptably high payback period, and when the PBP value criterion for availability is higher than the capacity project profit [40]. The initial investment and annual operating cash flow income (annual savings) can be used to calculate project profit using Eq. (8).

$$PBP = \frac{Initial\ investment\ (USD)}{Annual\ saving\ (USD)/years} = \text{years} \quad (8)$$

2.5.5 Internal rate of return (IRR)

The internal rate of return (IRR) is a crucial criterion for evaluating the economic viability of a project. It represents the discount rate at which the accumulated present value of all costs is equal to the benefits, or the point at which the net present value (NPV) of the project is zero [33]. In other words, IRR is the discount rate at which the present value of total benefits (PVB) is equivalent to the present value of total costs (PVC) [41]. The IRR reflects the maximum interest rate that the investment can achieve, and the discounted NPV of the project at IRR is zero. The payback period (PBP) where IRR is the life span of the project, with variables such as the annual return on electricity sales (B_A), operation fee and annual maintenance (C_A), total investment cost (C_I), discount interest rate (IRR), duration or economic life of the project (n), and the percentage of annual operation and maintenance costs (m) being the determining factors.

$$B_A\left[\frac{(1+IRR)^n-1}{IRR(1+IRR)^n}\right] = C_I\left[1+m\left(\frac{(1+IRR)^n-1}{IRR(1+IRR)^n}\right)\right] \quad (9)$$

2.6 Impact of Wind Energy on Carbon Dioxide (CO_2) Emissions Reduction

Reducing carbon dioxide (CO_2) emissions is one of the best practices for achieving constrained use objectives on the environment, emphasizing the mitigation of global warming through energy policy [42]. Approximately 40% of global CO_2 emissions are emitted from electricity generation through the burning of fossil fuels to generate the heat used to power steam turbines [43]. There is therefore a global effort to mitigate climate change and its impacts through multidisciplinary

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences
Volume 104, Issue 1 (2023) 169-184

research that raises global debate and awareness for national policies and planning on climate change in each country [44]. The process of evaluating and analysing the equivalent carbon emissions details has an average value of CO_2 emissions per unit of 640 g CO_2/kWh according to Eq. (10), where Activity Data is the amount of energy (e.g., kWh) and Emission Factor is the average unit emissions for a given period (g CO_2/kWh) [45-48].

$$Emission\ or\ CO_{2,emission} = ActivityData \times EmissionFactor \tag{10}$$

3. Results

This section describes in detail the wind resource assessment in a wind farm setup simulation. For elevations of 60 m and 90 m, the averages per plant indicate probabilities on a Levelized cost of electricity (LCOE), net present value (NPV), benefit-cost ratio (BCR), payback period (PBP), and internal rate of return (IRR) basis, as well as carbon dioxide equivalent (CO_2e) emissions.

3.1 Frequency Distribution

Based on simulations in WAsP and calculations obtained from the Weibull histogram (Figure 1 to 3) for the Chonburi station, the average velocity is 1.23 m/s with a power density of 6 W/m². For the Ko Sichang station, the average velocity is 1.09 m/s with a power density of 2 W/m², and for the third station, the average velocity is 1.42 m/s with a power density of 5 W/m².

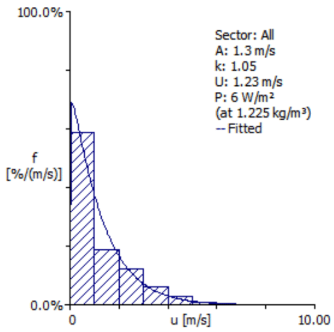


Fig. 1. Weibull histogram Chonburi station area

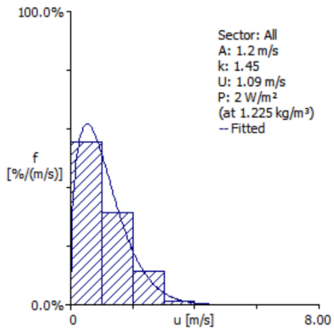


Fig. 2. Weibull histogram Ko Sichang station area

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences
Volume 104, Issue 1 (2023) 169-184

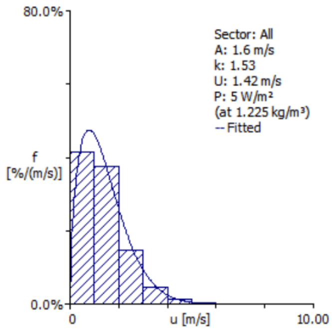


Fig. 3. Weibull histogram Pattaya station area

3.2 Wind Direction

The simulations in WAsP and the calculations in the wind rose diagram (Figure 4 to 6) show strong winds blowing from the northeast and west at the Chonburi station, strong winds blowing from the southeast at the Ko Sichang station, and strong winds blowing from the west and southwest at the Pattaya station.

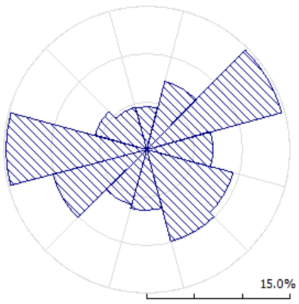


Fig. 4. Wind Direction and Wind rose histogram Chonburi station area

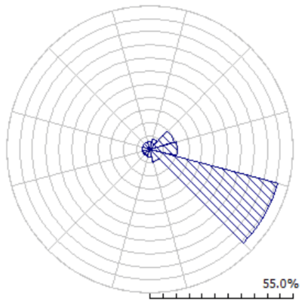


Fig. 5. Wind Direction and Wind rose histogram Ko Sichang station area

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences
Volume 104, Issue 1 (2023) 169-184

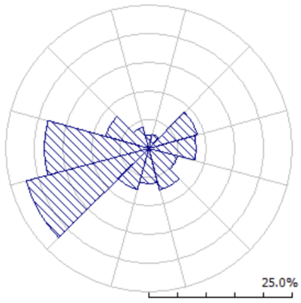


Fig. 6. Wind Direction and Wind rose histogram Pattaya station area

3.3 Economic Analysis of Site Area and Decision-Making Criteria for Investment

The data for this research were collected over a period of 3 years from January 1, 2019, to December 31, 2021, as previously mentioned. The focus of this study is on the economics of wind power in Thailand and the criteria used for investment decisions. In particular, we will examine the economic analysis from a public sector perspective, as presented in Table 3 [49].

Table 3
Cost elements in the calculation of the Levelized cost of energy

	Economic analysis (public sector)	Financial analysis (private sector)
Viewpoint	Overall society	Investor / Developer
Decision criteria	Positive net present value	Payback or internal rate of return
Timeframe	Life cycle (technical life)	Often shorter term
Discount rate	Reflects social preferences and other factors	Reflects costs of borrowing, desired returns (normally higher than the economic discount rate)
Energy prices (benefits)	Social values reflect willingness to pay; alternative uses	Prevailing market prices
Costs	Overall costs to society	Private, prevailing market prices
Taxes and subsidies	Ignored	Considered
Social infrastructure (e.g., roads)	Considered	Ignored, if not part of investment
External impacts	Analyzed as much as possible	Ignored

The data were collected additional decision criteria, such as the Payback Period and Internal Rate of Return, were included to support investment decisions. The results are presented as the average per wind turbine tower using the 6-pole model and based on calculation data. The base parameters used were Net AEP (GWh) and Capacity factor (%), derived from WAsP and shown in Table 4 and Table 5. The Discount rate was obtained and the average was found to be 5.40%, with the median at 5.00%, while the total average from IEA, 2022 is at 7.00% [49-51]. The lifetime of wind power plants was found to be 25 years from Danish Energy Agency [49], and Badouard *et al.,* [50]. Additionally, the Total Installed cost for 2021 was found to be 1,412 USD/kW and the O&M cost for onshore wind was 33 USD/kW, as per Renewable Power Generation Costs in 2021 [52].

This research focuses on wind energy and utilizes the Feed-In Tariff (FiT) structure for renewable energy projects in Thailand, as per Sinsadok [53]. The current exchange rate is 31.4395 THB/USD, and the FiT for wind farms is set at 0.0986 USD/kWh [54]. This tariff will be used to estimate income and

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences
Volume 104, Issue 1 (2023) 169-184

address economic issues such as the Levelized Energy Cost (LCOE), Net Present Value (NPV), Cost-Benefit Ratio or Benefit-Cost Ratio (BCR or B/C ratio), Payback Period (PBP), and Internal Rate of Return (IRR).

Table 4
Unit information for reading in Table 5 to Table 7

Note: The calculation results are stored in the form	
• Average Net AEP (Unit: MWh)	• PBP (Unit: Year)
• LCOE (Unit: USD)	○ PBP[a] is PBP without O&M
• NPV (Unit: USD)	○ PBP[b] is PBP with O&M
• BCR (Unit: -)	• IRR (Unit: %)

Table 5
Economic analysis of wind power area Chonburi

Area		Chonburi					
Wind farm		cluster Ban Bueng	cluster Nong Khang Khok	cluster Ban Bueng	cluster Nong Khang Khok	cluster Ban Bueng	cluster Nong Khang Khok
wind turbine models		Bonus 1.3 MW	Bonus 1.3 MW	SWT-1.3-62	SWT-1.3-62	SWT-2.3-82 VS	SWT-2.3-82 VS
Average Net AEP		1,010.00	1,111.00	1,044.00	1,160.00	1,791.00	2,055.00
LCOE	5.0%	162.42	147.65	157.13	141.41	162.05	141.23
(USD)	5.4%	166.79	151.63	161.36	145.23	166.42	145.04
	7.0%	184.82	168.02	178.80	160.92	184.40	160.71
NPV	5.0%	-1,036,007.21	-895,584.91	-988,736.34	-827,459.24	-1,827,267.61	-1,460,223.18
(USD)	5.4%	-1,067,103.25	-932,141.95	-1,021,670.73	-866,665.68	-1,882,504.11	-1,529,733.98
	7.0%	-1,174,456.41	-1,058,348.18	-1,135,370.48	-1,002,018.45	-2,073,197.65	-1,769,706.83
BCR	5.0%	-1.36	-1.72	-1.47	-1.95	-1.36	-1.96
	5.4%	-1.26	-1.59	-1.37	-1.79	-1.27	-1.80
	7.0%	-0.99	-1.21	-1.06	-1.33	-0.99	-1.33
PBP	PBP[a]	18.42	16.75	17.82	16.04	18.38	16.02
(Year)	PBP[b]	32.36	27.52	30.55	25.66	32.23	25.61
IRR (%)		2.50%	3.35%	2.79%	3.75%	2.52%	3.76%

Table 6
Economic analysis of wind power area Ko Sichang

Area		Ko Sichang					
Wind farm		cluster Khao Kaya Sira Hill	cluster Hat Tham Phang	cluster Khao Kaya Sira Hill	cluster Hat Tham Phang	cluster Khao Kaya Sira Hill	cluster Hat Tham Phang
wind turbine models		Bonus 1.3 MW	Bonus 1.3 MW	SWT-1.3-62	SWT-1.3-62	SWT-2.3-82 VS	SWT-2.3-82 VS
Average Net AEP		2,077.00	1,507.00	2,231.00	1,615.00	3,366.00	2,750.00
LCOE	5.0%	78.98	108.85	73.53	101.57	86.22	105.54
(USD)	5.4%	81.11	111.79	75.51	104.31	88.55	108.38
	7.0%	89.87	123.87	83.67	115.58	98.12	120.09
NPV	5.0%	447,464.02	-345,018.27	661,573.27	-194,863.73	362,486.09	-493,950.91
(USD)	5.4%	358,676.03	-402,986.75	564,458.60	-258,671.70	222,090.41	-601,039.89
	7.0%	52,152.32	-603,111.95	229,188.63	-478,956.62	-262,599.01	-970,744.25
BCR	5.0%	6.45	-6.07	4.69	-11.52	12.91	-7.74
	5.4%	7.74	-5.00	5.28	-8.34	20.25	-6.11
	7.0%	45.78	-2.87	11.19	-3.88	-14.74	-3.26
PBP	PBP[a]	8.96	12.35	8.34	11.52	9.78	11.97
(Year)	PBP[b]	11.33	17.36	10.36	15.77	12.68	16.62
IRR (%)		10.17%	6.37%	11.13%	7.13%	6.70%	9.05%

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences
Volume 104, Issue 1 (2023) 169-184

Table 7
Economic analysis of wind power area Pattaya

Area		Pattaya					
Wind farm		cluster Phra Tamnak Mountain	cluster Ko Lan	cluster Phra Tamnak Mountain	cluster Ko Lan	cluster Phra Tamnak Mountain	cluster Ko Lan
wind turbine models		Bonus 1.3 MW	Bonus 1.3 MW	SWT-1.3-62	SWT-1.3-62	SWT-2.3-82 VS	SWT-2.3-82 VS
Average Net AEP		34.52	151.05	42.09	184.37	66.67	260.12
LCOE	5.0%	4,752.56	1,085.99	3,897.26	889.71	4,353.27	1,115.73
(USD)	5.4%	4,880.72	1,115.28	4,002.35	913.70	4,470.66	1,145.81
	7.0%	5,408.18	1,235.81	4,434.88	1,012.45	4,953.80	1,269.64
NPV	5.0%	-2,392,241.94	-2,230,222.41	-2,381,710.27	-2,183,891.40	-4,224,640.55	-3,955,679.01
(USD)	5.4%	-2,370,594.23	-2,214,875.61	-2,360,472.13	-2,170,346.40	-4,186,643.60	-3,928,141.93
	7.0%	-2,295,859.59	-2,161,893.69	-2,287,151.48	-2,123,584.87	-4,055,466.33	-3,833,075.39
BCR	5.0%	-0.02	-0.09	-0.02	-0.12	-0.02	-0.09
	5.4%	-0.02	-0.09	-0.02	-0.11	-0.02	-0.09
	7.0%	-0.02	-0.08	-0.02	-0.10	-0.02	-0.08
PBP	PBP[a]	539.11	123.19	442.09	100.92	493.81	126.56
(Year)	PBP[b]	-46.48	-65.56	-47.37	-74.28	-46.85	-64.64
IRR (%)		-16.46%	-9.76%	-15.63%	-8.73%	-16.10%	-9.89%

The present study aimed to calculate the Levelized Cost of Energy (LCOE) for a 25-year project involving three wind turbines located in the Pattaya, Chonburi, and Ko Sichang station areas. The LCOE was computed to assess the feasibility of wind power generation in the region. At a 5% discount rate, the LCOE in the Pattaya station area was 889.71 USD/MWh, while the Chonburi station area and Ko Sichang station had an LCOE of 141.23 USD/MWh and 73.53 USD/MWh, respectively. When the discount rate was increased to 5.4%, the LCOE in the Pattaya, Chonburi, and Ko Sichang station areas decreased to 913.70, 145.04, and 75.51 USD/MWh, respectively. A further increase in the discount rate to 7% resulted in a decrease of the LCOE in the Pattaya, Chonburi, and Ko Sichang station areas to 1,012.45, 160.71, and 83.67 USD/MWh, respectively. Comparing the LCOE values obtained in this study with the averages reported by IRENA and Lazard's report revealed that the LCOE in the study area was significantly higher. According to International Energy Agency [52], the average LCOE for onshore wind in 2021 was 33 USD/MWh, while Lazard's [55] report indicated an average range of 26-50 USD/MWh. This result suggests that the LCOE in the study area is still far from the average for currently developed technology, indicating an inconsistency with the area's potential.

Net Present Value (NPV). The results indicated that only the Ko Sichang station area on the Khao Kaya Sira Hill cluster for the Bonus 1.3 MW and SWT-1.3-62 wind turbines had a positive NPV at discount rates of 5.0%, 5.4%, and 7.0%. The SWT-2.3-82 wind turbine model had a positive NPV only at discount rates of 5.0% and 5.4%. In contrast, the NPV was negative for all discount rates in the Chonburi and Pattaya station areas, with the Pattaya station area having the highest negative value of -4,224,640.55 (5%).

To further support the results, the Benefit Cost ratio (BCR) was also computed. The BCR values indicated both positive and negative values, with the negative values in the Pattaya station area being less negative than those in the Chonburi station area. Based on the BCR values, the economic viability of the areas was ranked as follows: Ko Sichang Station Area, Pattaya Station Area, and Chonburi Station Area.

In summary, the analysis of the NPV and BCR demonstrated that only the Khao Kaya Sira Hill cluster in the Ko Sichang station area showed positive potential for wind energy generation. However, the potential varied according to the discount rate, and the SWT-2.3-82 wind turbine

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences
Volume 104, Issue 1 (2023) 169-184

generator had very negative NPV and BCR values at a discount rate of 7%. Furthermore, the Pattaya station area had a relatively high cost, and if the cost could be managed below the cost of education, the BCR could be positive.

The study investigated the payback period (PBP) in the study area and a comparable area, and found significant differences. The SWT-1.3-62 wind turbine generation in the Ko Sichang station (cluster Khao Kaya Sira Hill) area had the shortest PBP, at 8.34 years without O&M and 10.36 years with O&M. This was the only area with the potential to achieve payback within a project period of 25 years. On the other hand, the Pattaya station area had a PBP without O&M that could not be paid back within the specified period, and the value for PBP with O&M resulted in a negative value, indicating that payback cannot be achieved. Similarly, for the Chonburi station area, PBP without O&M could be achieved within the specified period, but PBP with O&M could not be achieved.

The internal rate of return (IRR) is a crucial metric for assessing project feasibility. To determine the IRR, this study used average discount rates of 5.0%, 5.4%, and 7.0% as simulations of possible IRR rates in the project. The results showed that only the Ko Sichang station area had positive values, with an average of 8.43%. Among all three stations, SWT-1.3-62 (cluster Hat Tham Phang, Ko Sichang), Bonus 1.3 MW wind turbines (cluster Khao Kaya Sira Hill, Ko Sichang), and SWT-1.3-62 (cluster Khao Kaya Sira Hill, Ko Sichang) had IRRs of 7.13%, 10.17%, and 8.35%, respectively, which were higher than the IEA Central case at 7% [51]. These results were based on the scenario of the purchase value of the system at the feed-in-tariff (FiT) equal to 3.1014 Baht/unit [56,57].

In contrast, the Pattaya Station area had negative IRRs for both cluster Ko Lan and cluster Phra Tamnak Mountain, with the highest negative value of -16.10% for the SWT-2.3-82 VS wind turbine (cluster Phra Tamnak Mountain) and the lowest negative value of -8.73% (cluster Ko Lan). These results indicate that investing in wind turbine projects in these areas may not be financially feasible. It is worth noting that the IRRs are affected by the cost of the project and the revenue generated from the energy sales, and any change in these factors can impact the IRR.

3.4 Impact of Wind Energy on Carbon Dioxide (CO_2) Emissions Reduction

In general, wind power is known to not produce direct air pollution, and the potential for reducing CO_2 emissions varies depending on the energy distribution of each region [58,59]. In this study, the average CO_2 emission per unit was assessed and analyzed, with a value of 640 g CO_2/kWh [45-48]. The findings indicated that all areas could contribute to reducing CO_2 emissions, depending on the amount of power produced in each area. Among the Pattaya Station area clusters, the SWT-2.3-82 VS wind turbine (cluster Ko Lan) had the highest potential for CO_2 emissions reduction at 166.48 tons CO_2/GWh. However, the Ko Sichang station area, specifically the SWT-2.3-82 VS (cluster Khao Kaya Sira Hill), showed the highest value for reduction among all three areas, with a CO_2 emissions reduction of 2,154.24 tons CO_2/GWh. Furthermore, this area is the only one with a positive NPV, BCR, and IRR.

4. Conclusions

The establishment of a wind farm involves considering both external and internal high-impact factors. External factors include wind resources, seasonality, and government policies, while internal factors comprise wind resource assessments, the potential of the area, cost management, and funding sources. This research assesses wind energy resources using WAsP software for the study site in Chonburi Province, Thailand, with data from three stations. The analysis reveals that wind direction prevails in the northeast and west in the Ko Sichang station area, southeast in the Pattaya

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences
Volume 104, Issue 1 (2023) 169-184

station area, and southwest and west according to the WASP software analysis and yield maps of wind energy resources. However, wind resources in the study area have a low potential for setting up wind farms. Mountain peaks and ridges have slightly higher potential than the plains, which are in level 1 wind energy with poor resource potential. Additionally, the average wind speed decreases from May to October, but it increases from November to April due to the northeast monsoon bringing strong winds from the South China Sea to the Gulf of Thailand and the coastal areas of south-eastern Thailand.

Economic studies indicate that wind turbines with the maximum annual energy production (AEP) are not always the most economical choice. For example, the SWT-2.3-82 VS wind turbine (cluster Khao Kaya Sira Hill, Ko Sichang) had an AEP of 3.366 GWh, resulting in a potential reduction in CO_2 emissions of 2,154.24 metric tons CO_2/GWh. However, the scaled cost of electricity (LCOE) of this turbine was not the lowest of the three comparable areas, and the most economical LCOE was on the SWT-1.3-62 turbine. The net present value (NPV) of the SWT-1.3-62 turbine was also the highest of the three discount rates (5.0%, 5.4%, and 7.0%). Benefit ratios, cost-to-cost (BCR), and payback period (PBP) also supported the SWT-1.3-62 wind turbines. The internal rate of return (IRR) for SWT-2.3-82 VS wind turbines is lower than for SWT-1.3-62 wind turbines, although negative values were not shown, for example in the Chonburi and Pattaya station areas.

The results suggest that investment in wind farms with high-speed limit cuts and low-speed limit cuts has the widest range. The rotor diameter and initial height range between 60 and 90 meters is not recommended for businesses or the private sector in the Pattaya station area due to the low potential to generate sufficiently attractive returns or may suffer a loss. The economic feasibility of setting up wind farms in this area, and consequently lower potential CO_2 emission reductions compared to other areas, led to this conclusion.

Acknowledgement
The authors would like to extend their gratitude to the Energy Technology Program at the Faculty of Engineering at Prince of Songkla University, Hat Yai, Songkhla 90112, Thailand for their support. They would also like to acknowledge the invaluable assistance provided by the Thai Meteorological Department (TMD) for sharing valuable wind data.

References

[1] Ministry of Energy (TH), Department of Alternative Energy Development and Efficiency. "THAILAND: Alternative Energy Development Plan 2018-2037 (AEDP 2018-2037)." *Ministry of Energy (TH), Bangkok*.

[2] Department of Land Development (TH). "Some information of Thailand." *Department of Land Development (TH)*.

[3] Aquatic Resources Research Institute (ARRI) (TH). "Maritime Province." *Aquatic Resources Research Institute (ARRI) (TH)*.

[4] Chancham, Chana, Jompob Waewsak, Tanate Chaichana, M. Landry, and Y. Gagnon. "Assessment of onshore wind energy potential using regional atmospheric modeling system (RAMS) for Thailand." *Energy Procedia* 52 (2014): 487-496. https://doi.org/10.1016/j.egypro.2014.07.102

[5] Thongyai, Naruwit, and Kriengkrai Assawamartbunlue. "Wind atlas of Chanthaburi and Trat provinces, Thailand." *Energy Procedia* 141 (2017): 389-393. https://doi.org/10.1016/j.egypro.2017.11.048

[6] Goudarzi, Navid, Kasra Mohammadi, Alexandra St Pé, Ruben Delgado, and Weidong Zhu. "Wind resource assessment and economic viability of conventional and unconventional small wind turbines: A case study of Maryland." *Energies* 13, no. 22 (2020): 5874. https://doi.org/10.3390/en13225874

[7] Pawintanathon, Natthapat, Somchai Saeung, and Juntakan Taweekun. "Techno-Economic Analysis of Wind Energy Potential in North-Eastern of Thailand." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 93, no. 1 (2022): 25-49. https://doi.org/10.37934/arfmts.93.1.2549

[8] Dörenkämper, Martin, Bjarke T. Olsen, Björn Witha, Andrea N. Hahmann, Neil N. Davis, Jordi Barcons, Yasemin Ezber et al. "The making of the new european wind atlas-part 2: Production and evaluation." *Geoscientific Model Development* 13, no. 10 (2020): 5079-5102. https://doi.org/10.5194/gmd-13-5079-2020

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences
Volume 104, Issue 1 (2023) 169-184

[9] Chang, Byungik, and Ken Starcher. "Evaluation of wind and solar energy investments in Texas." *Renewable Energy* 132 (2019): 1348-1359. https://doi.org/10.1016/j.renene.2018.09.037

[10] Bortolini, Marco, Maurizio Faccio, Emilio Ferrari, Mauro Gamberi, and Mojtaba Nedaei. "Techno-Economic Design of Wind Farms: A Methodology and Multi-Scenario Application." *Procedia Manufacturing* 39 (2019): 1270-1278. https://doi.org/10.1016/j.promfg.2020.01.342

[11] Zakaria, Sazalina, Radin Diana R. Ahmad, Ahmad Rosly Abbas, and Mohd Faizal Mohideen Batcha. "Greenhouse Gas Emission Intensity Assessment for Power Plants in Peninsular Malaysia." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 88, no. 2 (2021): 14-26. https://doi.org/10.37934/arfmts.88.2.1426

[12] Waewsak, Jompob, Chana Chancham, Somphol Chiwamongkhonkarn, and Yves Gagnon. "Wind resource assessment of the southernmost region of Thailand using atmospheric and computational fluid dynamics wind flow modeling." *Energies* 12, no. 10 (2019): 1899. https://doi.org/10.3390/en12101899

[13] Secretariat of the Cabinet (TH). "Pattaya City Administrative Act, 1978." *Secretariat of the Cabinet (TH)*.

[14] Secretariat of the Cabinet (TH). "Eastern Special Development Zone Act, 2018." *Secretariat of the Cabinet (TH)*.

[15] Thai Meteorological Department. "Daily Observation Report." *Thai Meteorological Department*.

[16] Ju, Beomcheol, Jihyun Jeong, and Kyungnam Ko. "Assessment of Wind Atlas Analysis and Application Program and computational fluid dynamics estimates for power production on a Jeju Island wind farm." *Wind Engineering* 40, no. 1 (2016): 59-68. https://doi.org/10.1177/0309524X15624346

[17] Sveinbjornsson, Stefan Kari. "Analysis of WAsP (Wind Atlas Analysis and Application Program) in complex topographical conditions using measured production from a large scale wind farm." *PhD diss., University of Washington*, 2013.

[18] Khan, Tariq, Ismail Kamdar, Watchara Saeheng, and Juntakan Taweekun. "Analysis of Wind Data Collected from 15 Stations in Thailand." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 94, no. 1 (2022): 19-27. https://doi.org/10.37934/arfmts.94.1.1927

[19] Tammelin, Bengt, Timo Vihma, Evgeny Atlaskin, Jake Badger, Carl Fortelius, Hilppa Gregow, Matti Horttanainen et al. "Production of the Finnish wind atlas." *Wind Energy* 16, no. 1 (2013): 19-35. https://doi.org/10.1002/we.517

[20] Azad, A. K., and M. M. Alam. "A statistical tools for clear energy: Weibull's distribution for potentiality analysis of wind energy." *International Journal of Advanced Renewable Energy Research* 1, no. 5 (2012): 240-247.

[21] Akpinar, E. Kavak, and S. Akpinar. "An assessment on seasonal analysis of wind energy characteristics and wind turbine characteristics." *Energy Conversion and Management* 46, no. 11-12 (2005): 1848-1867. https://doi.org/10.1016/j.enconman.2004.08.012

[22] Zhang, Shi, Giovanni Solari, Qingshan Yang, and Maria Pia Repetto. "Extreme wind speed distribution in a mixed wind climate." *Journal of Wind Engineering and Industrial Aerodynamics* 176 (2018): 239-253. https://doi.org/10.1016/j.jweia.2018.03.019

[23] Kidmo, D. K., R. Danwe, S. Y. Doka, and N. Djongyang. "Statistical analysis of wind speed distribution based on six Weibull Methods for wind power evaluation in Garoua, Cameroon." *Revue des Energies Renouvelables* 18, no. 1 (2015): 105-125.

[24] Arslan, Talha, Y. Murat Bulut, and Arzu Altın Yavuz. "Comparative study of numerical methods for determining Weibull parameters for wind energy potential." *Renewable and Sustainable Energy Reviews* 40 (2014): 820-825. https://doi.org/10.1016/j.rser.2014.08.009

[25] Al-Ttowi, Abobakr, Djamal Hissein Didane, Mohammad Kamil Abdullah, and Bukhari Manshoor. "Wind and solar resources assessment techniques for wind-solar map development in Jeddah, Saudi Arabia." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 96, no. 1 (2022): 11-24. https://doi.org/10.37934/arfmts.96.1.1124

[26] Sasujit, Kittikorn, and Nigran Homdoung. "Analysis of wind speed data and annual energy potential at Samoeng district in Thailand." *RMUTP Research Journal* 15, no. 2 (2022): 169-178.

[27] Shi, Huanyu, Zhibao Dong, Nan Xiao, and Qinni Huang. "Wind speed distributions used in wind energy assessment: a review." *Frontiers in Energy Research* 9 (2021): 790. https://doi.org/10.3389/fenrg.2021.769920

[28] Al Buhairi, Mahyoub H. "A statistical analysis of wind speed data and an assessment of wind energy potential in Taiz-Yemen." *Assiut University Bulletin for Environmental Researches* 9, no. 2 (2006): 21-33. https://doi.org/10.21608/auber.2006.150274

[29] Mondal, Mithun, Djamal Hissein Didane, Alhadj Hisseine Issaka Ali, and Bukhari Manshoor. "Technical assessment of wind energy potentials in Bangladesh." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 96, no. 2 (2022): 10-21. https://doi.org/10.37934/arfmts.96.2.1021

[30] Firdaus, Nofirman, Bambang Teguh Prasetyo, Hasnida Ab-Samat, Prayudi Prayudi, Hendri Hendri, Wahirom Wahirom, Heri Suyanto, and Rusjdi Halim. "Wind Energy Potential On A Highrise Building: A Preliminary Study." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 88, no. 3 (2021): 20-30. https://doi.org/10.37934/arfmts.88.3.2030

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences
Volume 104, Issue 1 (2023) 169-184

[31] Qiao, Huiting, Shangyong Wen, Liangzheng Wu, and Bing Zeng. "Research on wind power project investment risk evaluation based on fuzzy-gray clustering trigonometric function." *Energy Reports* 8 (2022): 1191-1199. https://doi.org/10.1016/j.egyr.2022.02.222

[32] Richstein, Jörn C., and Karsten Neuhoff. "Carbon contracts-for-difference: How to de-risk innovative investments for a low-carbon industry?." *iScience* 25, no. 8 (2022): 104700. https://doi.org/10.1016/j.isci.2022.104700

[33] Sathyajith, Mathew. *Wind energy: fundamentals, resource analysis and economics*. Springer Science & Business Media, 2006.

[34] Ragnarsson, Birgir Freyr, Gudmundur V. Oddsson, Runar Unnthorsson, and Birgir Hrafnkelsson. "Levelized cost of energy analysis of a wind power generation system at burfell in iceland." *Energies* 8, no. 9 (2015): 9464-9485. https://doi.org/10.3390/en8099464

[35] Aldersey-Williams, John, Ian D. Broadbent, and Peter A. Strachan. "Better estimates of LCOE from audited accounts-A new methodology with examples from United Kingdom offshore wind and CCGT." *Energy Policy* 128 (2019): 25-35. https://doi.org/10.1016/j.enpol.2018.12.044

[36] United Kingdom Department for Business. "Electricity Generation Costs." *National Archives UK*.

[37] Pani, Iskandar, Dinar Dwi Anugerah Putranto, and Putri Kusuma Wardhani. "Net present value (NPV) of the rehabilitated irrigation channels to increase agricultural production." *International Journal of Advanced Technology and Engineering Exploration* 8, no. 78 (2021): 576. https://doi.org/10.19101/IJATEE.2021.874034

[38] Khastagir, Anirban, and Niranjali Jayasuriya. "Investment evaluation of rainwater tanks." *Water Resources Management* 25 (2011): 3769-3784. https://doi.org/10.1007/s11269-011-9883-1

[39] Rosenquist, Greg, Katie Coughlin, Larry Dale, James McMahon, and Steve Meyers. "Life-cycle cost and payback period analysis for commercial unitary air conditioners." *University of California, Berkeley, CA* (2004). https://doi.org/10.2172/829989

[40] Yaniktepe, Bulent, Osman Kara, and Coskun Ozalp. "Technoeconomic evaluation for an installed small-scale photovoltaic power plant." *International Journal of Photoenergy* 2017 (2017). https://doi.org/10.1155/2017/3237543

[41] Shively, Gerald, and Marta Galopin. "An overview of benefit-cost analysis." *Iowa State University* (2013).

[42] Ciupăgeanu, Dana-Alexandra, Gheorghe Lăzăroiu, and Mihai Tîrşu. "Carbon dioxide emissions reduction by renewable energy employment in Romania." In *2017 International Conference on Electromechanical and Power Systems (SIELMEN)*, pp. 281-285. IEEE, 2017. https://doi.org/10.1109/SIELMEN.2017.8123333

[43] Abdallah, Lamiaa, and Tarek El-Shennawy. "Reducing carbon dioxide emissions from electricity sector using smart electric grid applications." *Journal of Engineering* 2013 (2013). https://doi.org/10.1155/2013/845051

[44] Mohiuddin, Obaidullah, Samuel Asumadu-Sarkodie, and Madina Obaidullah. "The relationship between carbon dioxide emissions, energy consumption, and GDP: A recent evidence from Pakistan." *Cogent Engineering* 3, no. 1 (2016): 1210491. https://doi.org/10.1080/23311916.2016.1210491

[45] Sovanara, Chan, Firdaus Firdaus, and Rusdianasari Rusdianasari. "A Review on environmental impact of wind energy." In *Proceeding Forum in Research, Science, and Technology (FIRST) 2016*. Politeknik Negeri Sriwijaya, 2016.

[46] Yousefi, Hossein, Atefeh Abbaspour, and HamidReza Seraj. "Worldwide development of wind energy and CO2 emission reduction." *Environmental Energy and Economic Research* 3, no. 1 (2019): 1-9.

[47] Saidur, Rahman, Nasrudin A. Rahim, Monirul Rafiqu Islam, and Khalid H. Solangi. "Environmental impact of wind energy." *Renewable and Sustainable Energy Reviews* 15, no. 5 (2011): 2423-2430. https://doi.org/10.1016/j.rser.2011.02.024

[48] Marimuthu, C., and V. Kirubakaran. "Carbon pay back period for solar and wind energy project installed in India: a critical review." *Renewable and Sustainable Energy Reviews* 23 (2013): 80-90. https://doi.org/10.1016/j.rser.2013.02.045

[49] Danish Energy Agency. "Finding Your Cheapest Way to a Low Carbon Future." *Danish Energy Agency*.

[50] Badouard, Thierry, Débora Moreira de Oliveira, Jessica Yearwood, Perla Torres, and Matthias Altmann. "Final Report Cost of Energy (LCOE) - Energy costs, taxes and the impact of government interventions on investments." *European Commission*, 2020.

[51] International Energy Agency. "Levelised Cost of Electricity Calculator." *IEA*.

[52] International Energy Agency. "Renewable power generation costs in 2021." *IEA*.

[53] Sinsadok, Suwat. "Thailand Utilities-Renewables New wind and solar capacity on the way." *Equities Research*.

[54] Bank of Thailand. "Foreign exchange rate." *Bank of Thailand*.

[55] Lazard. "Levelized Cost Of Energy, Levelized Cost Of Storage, and Levelized Cost Of Hydrogen." *Lazard*. October 28, 2021.

[56] Watson Farley & Williams. "Thailand's 5 GW renewable PPA FiT scheme: 2022-2030." *Watson Farley & Williams (WFW)*. October 12, 2022.

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences
Volume 104, Issue 1 (2023) 169-184

[57] Thailand National Energy Policy Council. "Power purchase rate according to the resolution of the National Energy Policy Council." *Thailand National Energy Policy Council*. May 6, 2022.

[58] Saidur, Rahman, Nasrudin A. Rahim, Monirul Rafiqu Islam, and Khalid H. Solangi. "Environmental impact of wind energy." *Renewable and Sustainable Energy Reviews* 15, no. 5 (2011): 2423-2430. https://doi.org/10.1016/j.rser.2011.02.024

[59] Yousefi, Hossein, Atefeh Abbaspour, and HamidReza Seraj. "Worldwide development of wind energy and co2 emission reduction." *Environmental Energy and Economic Research* 3, no. 1 (2019): 1-9.

VITAE

Name Mr. Chatchawich Chaihong

Student ID 6410120004

Educational Attainment

Degree	Name of Institution	Year of Graduation
Bachelor of Business Administration Degree in Business Information System	Prince of Songkla University	2020

Scholarship Awards during Enrollment

Engineering Graduate Scholarship Faculty of Engineering, Prince of Songkla University

PSU.GS. Financial Support for Thesis, Graduate School, Prince of Songkla University

List of Publication and Proceeding

Chaihong, Chatchawich, and Juntakan Taweekun. 2023. “Techno-Economic Assessment of Wind Energy in Urban Environments: A Case Study in Pattaya, Thailand”. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 104 (1):169-84. https://doi.org/10.37934/arfmts.104.1.169184.