

Innovation Lab

Femtec x Daimler Truck

Strategic analysis of decentralized energy supply

March – July 2023

Table of Contents

1	INTRODUCTION	7
1.1	Problem Statement	7
1.2	Participants	8
1.3	Acknowledgement	9
1.4	Report structure	9
2	SCENARIOS & CUSTOMER NEEDS	10
2.1	Scenarios	10
2.1.1	Base Scenario	10
2.1.2	Other Scenarios	12
2.2	Customer Needs	17
2.2.1	Interview with Markus Schiller	18
2.2.2	Interview with Julius Kaiser	21
2.2.3	Customer Needs & Values Evaluation	24
2.3	Customer Personas	24
2.4	Daimler Truck Needs	26
3	TOOL	28
3.1	Basic principles	28
3.2	How to work with EASy	29
3.2.1	Background: PVGIS	29
3.2.2	Input parameter	30
3.3	Comments on EASy	33
3.4	Output and results	34
3.5	Use cases for EASy	37
4	TECH	38
4.1	Harvest	38
4.1.1	Fuel cells	38
4.1.2	Wind Turbines	40
4.1.3	Photovoltaic Systems	44
4.2	Storage	45
4.2.1	Batteries	46
	Redox-flow-battery	46
	Lithium-Ion Battery	48
4.2.2	Other Battery types	50
	Saltwater	50
	Thermal batteries (NaS/ZEBRA)	50
	Lead acid	50
	Ni/Cd	50
	NiMHydride	50
4.3	Alternatives	50

4.3.1	Chemical	50
4.3.2	Mechanical	52
	Flywheel	52
	Pumped storage power plant	52
	Compressed Air Storage	53
4.3.3	Thermal	53
4.4	Battery calculation	54
4.5	Harvest-Storage System Combination	56
4.6	Conclusion	57
4.7	Outlook	58
4.7.1	Energy Harvest Systems	58
4.7.2	Energy Storage Systems	58
4.7.3	Second Life Batteries	60
4.7.4	Smart charging	62
4.7.5	Conclusion	64
5	REGULATIONS, MARKET & FINANCE	65
5.1	Tasks and Goals	65
5.2	Prospectus Daimler Truck	66
5.2.1	General Risks	66
5.2.2	Market	66
5.2.3	Strategic Partnerships	66
5.2.4	Financial information	67
5.3	Regulations overview	67
5.3.1	Standards	67
5.3.2	Economy	67
5.3.3	Regulations	68
	Charging Infrastructure	68
	PV in open spaces	68
	Wind	69
	Energy storage	70
5.4	Fundings and incentives in the EU	71
5.5	Classification of financial models	71
5.5.1	Leasing	72
5.5.2	Renting	73
5.5.3	White labeling	74
5.5.4	Contracting	74
5.5.5	Outsourcing	75
5.5.6	Pay-per-Use-Model (PpU)	75
5.6	Calculation and Analysis	78
5.6.1	Price sheet & financial overview	78
5.6.2	Utility analysis	80
5.6.3	CAPEX and OPEX calculation scenarios	81
5.6.4	Amortisation calculation (customer point of view)	82
5.6.5	Revenues (DTAG point of view)	84
	First revenue stream	84
	Second revenue stream	85

5.6.6	High cost factors – components	85
	Financial leasing for PV panels and converters	85
	Renting a battery	86
5.6.7	VAWT	87
5.7	Key partners	87
5.7.1	PV	87
5.7.2	Battery	88
5.7.3	Converter	89
5.7.4	Leasing/ Renting of PV modules	90
5.7.5	Possible investors	91
5.7.6	Possible Industrial Internet of Things (IIoT) providers	91
6	BUSINESS MODEL	92
6.1	Business Model Design	92
6.2	Customer	92
6.2.1	Customer Segments	92
6.2.2	Customer Relationships	93
6.3	Product	94
6.4	Finance	95
6.4.1	Cost structure and revenue stream for customer	95
	CAPEX Customer	96
	OPEX Customer	96
	Highest Cost factors for depot solution – for all scenarios	96
	Saving and Revenues Streams for the Customer	96
6.4.2	Financing solutions	96
	Renting/Leasing model	96
	Pay per use model	97
6.4.3	Cost Structure and Revenue Stream for DTAG	97
6.5	Business	97
6.5.1	Key partners	97
6.5.2	Key activities	98
6.5.3	Key resources	98
6.6	Sustainability	98
7	APPENDIX	99
	Output for Den Haag 13 charge cycles of eActros300	99
	Output for Den Haag 13 charge cycles of eActros600	101
	Output for Stockholm 13 charge cycles of eActros300	103
	Output for Stockholm 13 charge cycles of eActros600	105
	Output for Stuttgart 13 charge cycles of eActros300	107
	Output for Stuttgart 13 charge cycles of eActros600	109
	Output for Stuttgart 40 charge cycles of eActros300	111
	Output for Stuttgart 40 charge cycles of eActros600	113
	Output for Stuttgart 20 charge cycles of eActros300	115
	Output for Stuttgart 20 charge cycles of eActros600	117
	Output for Madrid 13 charge cycles of eActros300	119
	Output for Madrid 13 charge cycles of eActros600	121

Table of figures

Figure 1.1: Goal of our Innolab.....	8
Figure 2.1: Parameters for scenarios	10
Figure 2.2 Factors influencing the depot	11
Figure 2.3 Factors influencing the demand	11
Figure 2.4: Chosen parameters for the final base scenario.....	12
Figure 2.5: Base Scenario	12
Figure 2.6: Scenario 1.....	13
Figure 2.7: Scenario 2.....	13
Figure 2.8: Scenario 3.....	14
Figure 2.9: Scenario 4.....	14
Figure 2.10: Scenario 5.....	14
Figure 2.11: Scenario 6.....	15
Figure 2.12 First overview over customer needs	17
Figure 2.13: Final overview over condensed customer needs and values	18
Figure 2.14: Prioritized customer needs & values.....	24
Figure 2.15: Customer persona: Big Freight Forwarder & Early Adopter	25
Figure 2.16: Customer persona: Medium-sized Freight Forwarder & Early Majority.....	25
Figure 2.17: Customer persona: Small Freight Forwarder & Late Adopter.....	25
Figure 2.18 Goals and requirements for business model	26
Figure 2.19: Importance and interdependencies of DT needs	27
Figure 3.1 Radiation map of Europe by PVGIS.....	28
Figure 3.2 Wind speed map at 10m height by the Global Wind Atlas	29
Figure 3.3 Map of used satellite imaging systems by PVGIS	30
Figure 3.4 Input sheet for EASy	31
Figure 3.5: Explanation window for input cell "include wind turbines?"	31
Figure 3.6: Input sheet for EASy with possible input parameters.....	31
Figure 3.7: Output 1 - PV area varying with module tilt and orientation and battery data.....	34
Figure 3.8: Output 2 - Power output of PV panels at best position and with grid support.....	35
Figure 3.9: Output 3 - Power output of VAWTs and with grid support	35
Figure 3.10: Output 3 - Power output of HAWTS at the same location.....	36
Figure 3.11: Output 4 - Combined power output of VAWTs and PV panels with grid support ...	36
Figure 4.1: Overview over different energy harvesting technologies	38
Figure 4.2: Different types of fuel cells	39
Figure 4.3: Advantages and disadvantages of VAWTs	42
Figure 4.4: Example for a hybrid power system.....	43
Figure 4.5: Overview over storage technologies.....	46
Figure 4.6: Advantages and disadvantages of a redox flow battery	47
Figure 4.7: Data for different Lithium-Ion battery technologies.....	48
Figure 4.8: Comparison of Lithium Ion battery technologies	49
Figure 4.9: Advantages and disadvantages of a Lithium Ion Battery.....	49
Figure 4.10: Working principle of a fuel cell.....	51
Figure 4.11: Losses in chemical energy storage	51
Figure 4.12: Components needed for the whole system	56
Figure 4.13: Concept of second life of batteries	60
Figure 4.14: Input parameters and algorithm for Smart Charging.....	63
Figure 5.1: Leasing Financial Model.....	73
Figure 5.2: Business model PaaS with financing.....	76
Figure 5.3: Financing model for DTAG.....	77

<i>Figure 5.4: Period of amortization.....</i>	<i>83</i>
<i>Figure 6.1: Sustainable business model canvas</i>	<i>92</i>
<i>Figure 6.2: Customer segments and their main needs</i>	<i>93</i>
<i>Figure 6.3: Modular service offering by Daimler Truck.....</i>	<i>95</i>
<i>Figure 6.4: Technical solution infrastructure</i>	<i>95</i>

1 Introduction

This report is a result of the collaboration of 26 female students in partnership with Daimler Truck as part of the Innolab 2023.

The Innolab is organized by Femtec, an organization dedicated to empowering female STEM talents to reach their full potential. With a strong focus on targeted training, invaluable industry connections, and a robust network, Femtec supports and nurtures individuals who embody creativity, courage, and clear goals.

At Femtec we envision a workforce where diversity thrives, enabling a sustainable and socially equitable society. In this era of rapid technological advancement, we foster opportunities for collaboration and synergy, ensuring that the multifaceted perspectives we strive for are well-represented in the world of tomorrow. We believe that by working together, we can bring about positive change and create a more inclusive future.

One notable aspect of our organization is the Femtec Innovation Lab, a collaborative initiative undertaken during our second school phase. Over the course of four months, participating students engage in a real-life innovation project, with the project proposal being provided by a partner company affiliated with Femtec, here in our case Daimler Truck.

During our second school phase, a four-day kick-off event is organized, affording us the opportunity to interact directly with the partner company. This interaction enables us to comprehend the problem statement, make critical decisions regarding project structure and objectives, establish virtual meeting schedules, and determine the necessary tools for effective collaboration. Through the support of the Innovation Lab, we assume full responsibility for the project, enhancing our expertise in virtual collaboration within a complex environment, while also developing our ability to navigate ambiguity and exhibit leadership skills.

The Innovation Lab comprises three primary stakeholders: Daimler Truck as the partner company, which not only presents the problem statement but also assists in project framing and offers technical mentoring; a project and innovation management coach, in our case Klaus Kammermeier, responsible for overall coordination and consultancy with the partner company, as well as providing methodological guidance; and the Femtec participants, who work collaboratively with one another in executing the project.

1.1 Problem Statement

Our groupwork started with a kick-off event in Berlin. During this kick-off, our partner company, Daimler Truck, delves deeper into their specific problem statement and extends their full support to ensure our comprehensive understanding of the task at hand.

For instance, Daimler Truck presented an intriguing topic focused on their entry into the decentralized energy supply market. Emphasizing a holistic approach, eMobility Consulting encompasses various essential aspects, including technical considerations such as routes and charging infrastructure, financial aspects such as incentives and total cost of ownership, and operational factors such as operations, service, and IT systems. Daimler Truck also highlighted that the electrified depot of the future encompasses more than just trucks and charging infrastructure.

The goal of our Innolab is presented in the following *Figure 1.1*.

The goal of your inno lab is to holistically evaluate **how DTAG should enter the market** of decentralized energy supply

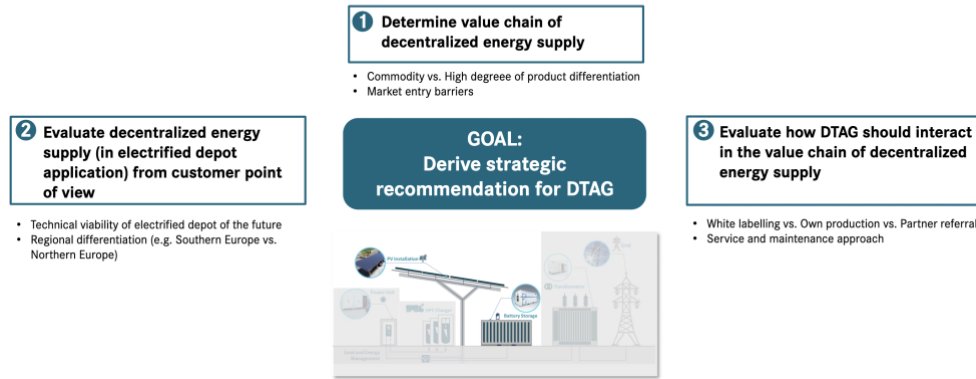


Figure 1.1: Goal of our Innolab

1.2 Participants

The 26 students working on this Innovation lab were the following:

Sandhya Elizabeth Anto	Information and Communication Engineering, TU Darmstadt
Ariadna Benimeli Borrás	Materials Science, University of Stuttgart
Julia Gierlach	Chemistry, Karlsruhe Institute of Technology
Anna Gutmann	Mechanical Engineering, Karlsruhe Institute of Technology
Céline Heimhofer	Environmental Engineering, ETH Zürich
Marie Hoyer	Molecular Bioengineering, TU Dresden
Arundhati Pawar	Management and Engineering, RWTH Aachen
Laura Pichler	Electrical Engineering, TU Munich
Johanna Pietzonka	Renewable Energy Systems, TU Dresden
Antonia Eva Schneider	Industrial Engineering, TU Dresden
Lena Schneider	Energy Engineering, University of Stuttgart
Jona Roshini Selvanathan	Electrical Engineering, University of Stuttgart
Shreyanka Shankarappa Geetha	Robotics Systems Engineering, RWTH Aachen
Goutami Sheshappanavar	Electrical Engineering, University of Stuttgart
Julia Spies	Chemical Engineering, Karlsruhe Institute of Technology
Emma Streng	Mechanical Engineering, TU Braunschweig
Mariam Talibe	Industrial and Mechanical Engineering, TU Darmstadt
Selin Tepe	Industrial Engineering, RWTH Aachen
Anna Jasmin Theobald	Mechanical and Process Engineering, TU Darmstadt
Anastasia Thiessen	Medical Engineering, University of Stuttgart
Henriette Vogel	Mechanical Engineering, TU Munich
Teresa von der Horst	Mechanical Engineering, TU Munich
Nora Weigel	Mechanical Engineering, TU Munich
Marie Windeck	Engineering Science, TU Berlin
Lisa Winkler	Renewable Energy Systems, TU Berlin
Viviane Wolfer	Biomedical Engineering, ETH Zürich

1.3 Acknowledgement

We would like to thank our great partners from Daimler Truck AG for giving us the chance with this exciting task proposal about energy systems for truck depots, especially Sharif Ghassemi and Dr. Florian Salah. They supported us in weekly meetings and always answered our questions or looked for somebody who could answer the questions. Thanks for everyone at Daimler Truck who took part in our journey and helped us on the way.

For the organisational part, we are happy to say big thanks to everyone who was involved, especially to Franca Pepe and Ariane Beckert. They coordinated our stays at Daimler Truck in Mannheim and Stuttgart and really helped us to get in touch with the company Daimler Truck. Without them, our experience would have been only half as great.

Furthermore, we would like to thank the Femtec side: of course, the whole organisation team behind the Femtec schools and Innolabs, but also thanks to our coach, Klaus Kammermeier, who was a part of our journey to get to know all the highs and lows of teamwork and leadership. He allowed us to have a great kick-off week in March in Berlin and continued to help out with meetings and advice.

Last but not least, one should always remember that this Innovation lab could not have happened without each and every student from different study backgrounds, universities and cultures. We learned a lot, for our career and for life and we should be thankful for each other, even if there were ups and downs. It was wonderful to see how everyone contributed bigger and smaller parts and made the Innolab to these eventful months.

Let's see what the future holds!

1.4 Report structure

We are providing this report to share all relevant information we gathered during this Innolab with Daimler Truck. During the Midterm and Endterm presentations we have already been able to show a lot of our work. But not everything could be shown during this time. That is why this report is available here.

The report is structured according to the different work areas of the team. At the very end is a clear business report that links a lot of information, especially from the Scenarios & Customer Needs team and the Regulations, Market and Finance team. The detailed information can be read in the individual specific chapters.

Individual files, such as invoices or program code, is passed separately to Daimler Truck.

2 Scenarios & Customer Needs

This section is divided into three parts, the scenarios, the customer needs, and the Daimler needs. The base scenario was established by defining the critical parameters, following an iterative brainstorming process, researching, and discussing. The other scenarios were created afterwards for a better variety. The other sections followed a similar approach to the customer needs resulting in interview questions for customers of interest.

2.1 Scenarios

Creating scenarios was the first step to classify different conditions which might affect the customer's needs as well as the technical possibilities and limits for the depot. At first, a set of parameters was specified which can be divided into parameters concerning the depot location and parameters concerning the customer demand. Based on further research a range was defined for each parameter.

The *Figure 2.1* presents all parameters with their range.

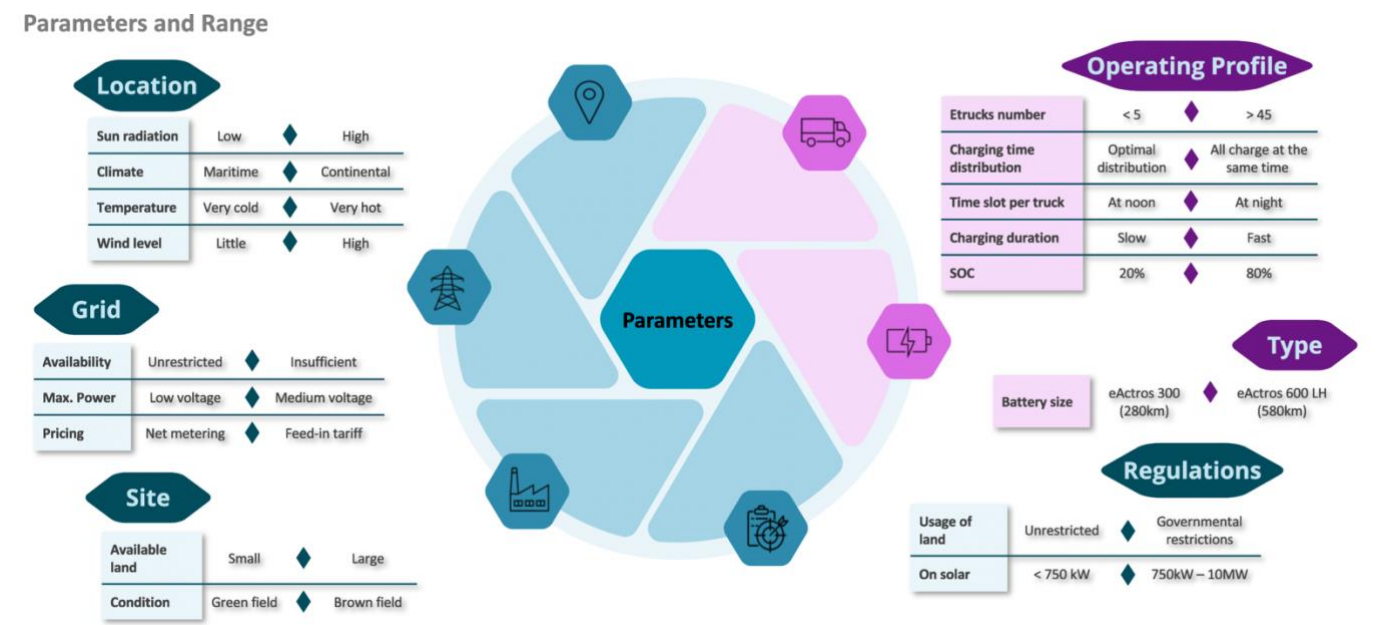


Figure 2.1: Parameters for scenarios

2.1.1 Base Scenario

The next step for the classification of different conditions was to create a base scenario which future scenarios can be compared to. The aim was to find the most likely parameter values in order to create a representable scenario for further comparison.

Influencing factors

When identifying the influencing factors for the depot, they were split into four categories:

- Location
- Grid
- Site
- Regulations

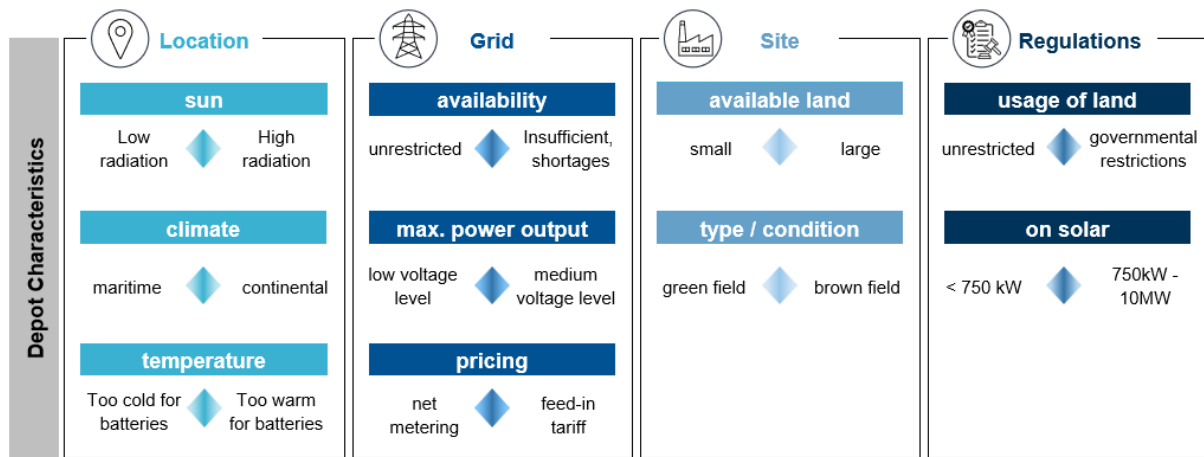


Figure 2.2 Factors influencing the depot

Similarly, the identified factors influencing the demand were split into two categories:

- Operating profile
- Type

Not all factors of the usage of trucks influence the charging. For example, when we look at distances travelled or the number of goods transported, this is important for efficient planning of the trucks, but when looking at the depot charging, the resulting parameter is only the amount of electricity needed (SOC – State of Charge when arriving and leaving) and the charging depending on their travel behaviour (day/night). It also does not make a difference what kind of truck we are looking at despite the battery type and size.

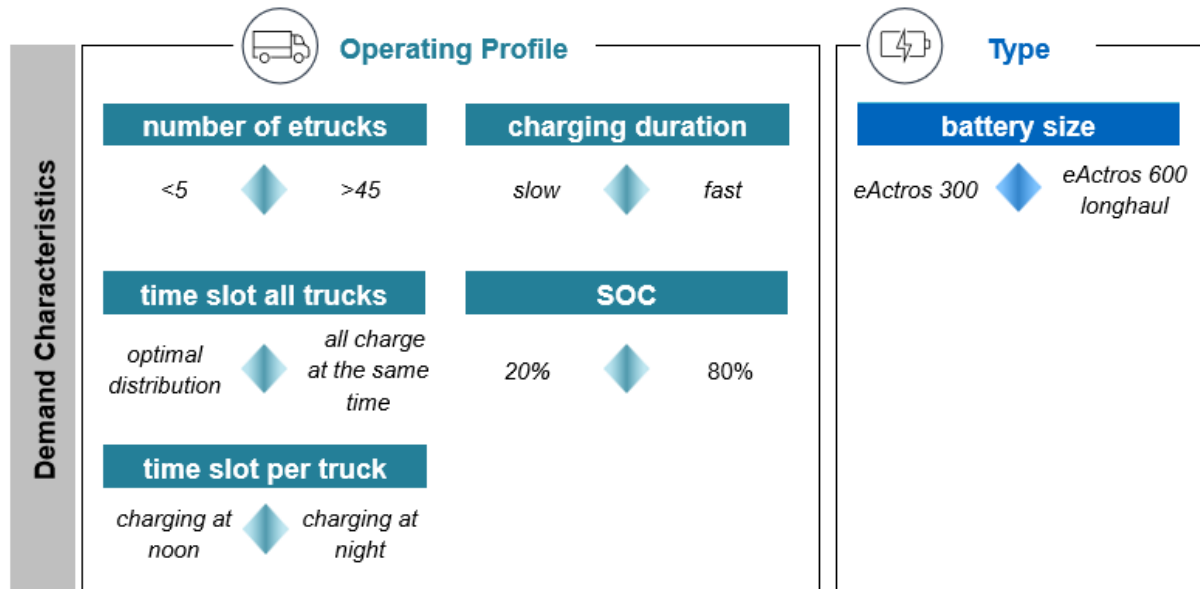


Figure 2.3 Factors influencing the demand

Defined base scenario

The parameters decided on for the final base scenario are listed below. This is the scenario the other groups started working with, and we continued to look at the individual customer needs and expectations of the solution.

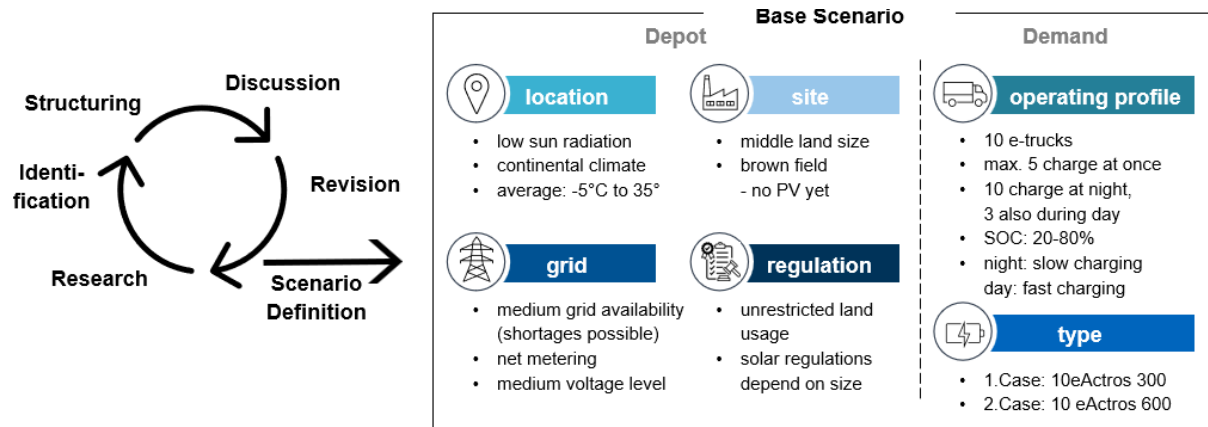


Figure 2.4: Chosen parameters for the final base scenario

The base scenario (scenario 0) is shown in the following:

Base Scenario

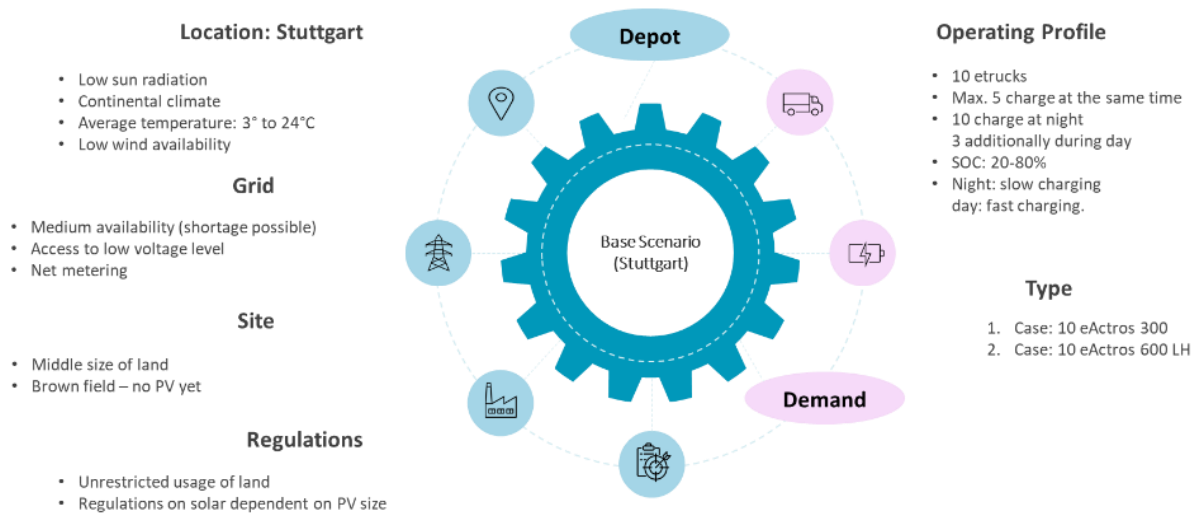


Figure 2.5: Base Scenario

2.1.2 Other Scenarios

The first scenarios cover the impact of different locations of the depot in Europe on the conditions.

For scenario 1 the location was chosen to be Den Haag in the Netherlands since the Netherlands was mentioned to be an important key market for Daimler Truck. The change of location affects the weather conditions, the grid conditions as well as the regulations on solar. The second case represents a scenario in the north of Europe which is typically less sunny, but is exposed to higher levels of wind.

Scenario 2 is therefore located in Stockholm, Sweden.

The third scenario is situated in Madrid, Spain. Thus, the depot in this scenario is exposed to a higher level of sun radiation. On top of the location variation, this scenario considers the possibility that a customer already has PV panels installed.

The next scenario (scenario 4) considers also a customer who already has PV installed. Instead of Spain this customer is located at the base scenario location Stuttgart with low sun radiation.

Scenario 5 focuses at a potential customer with a large fleet who is interested in 30 instead of 10 etrucks. This affects the depot size as well as the customer demand since a higher number of etrucks charging at the same time affects the dimension of the charging infrastructure and

storage. The enlarged number of trucks charging at the same time could also result from a more intense charging schedule.

This possibility is covered in the last scenario which focuses at the conditions in the case that the customer needs to charge more trucks at the same time.

The scenarios are summarized in the following graphics. The main variations to the base scenario are highlighted.

Scenario 1 – Different Location (Netherlands)

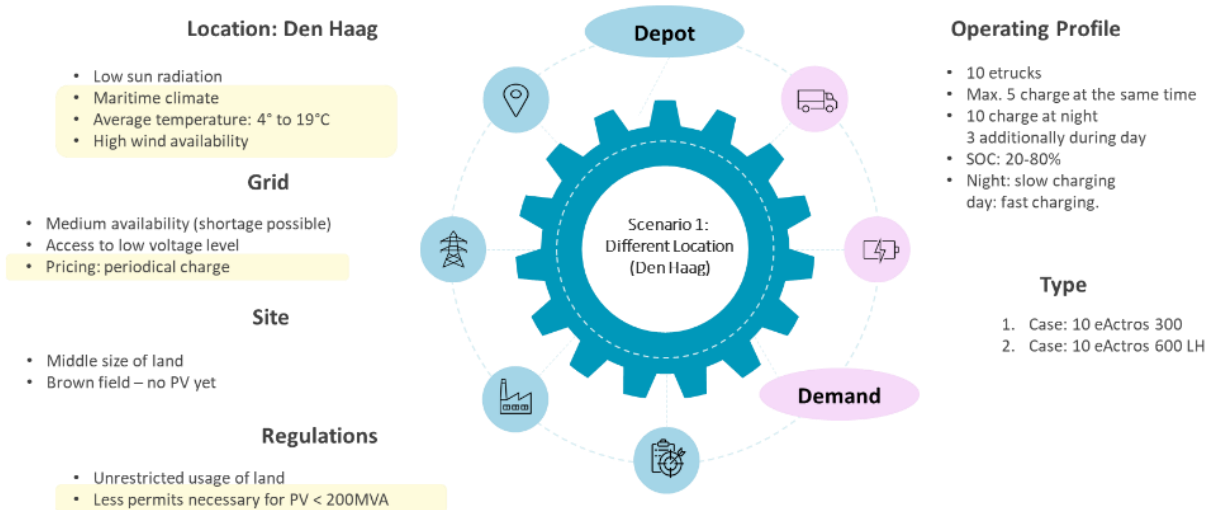


Figure 2.6: Scenario 1

Scenario 2 – Different Location (Sweden)

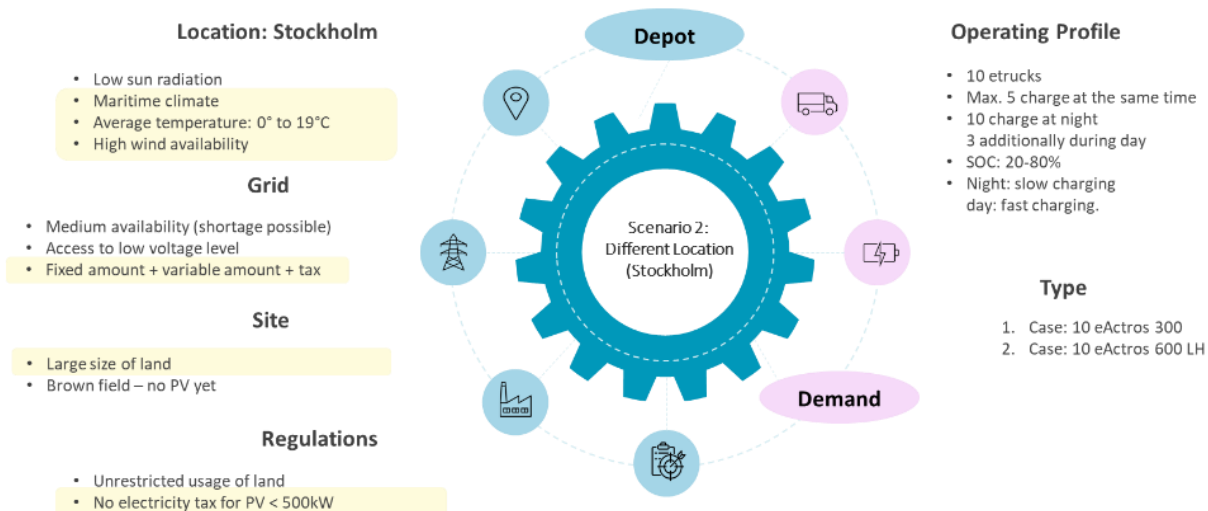


Figure 2.7: Scenario 2

Scenario 3 – Different PV Preconditions and Different Location (Spain)

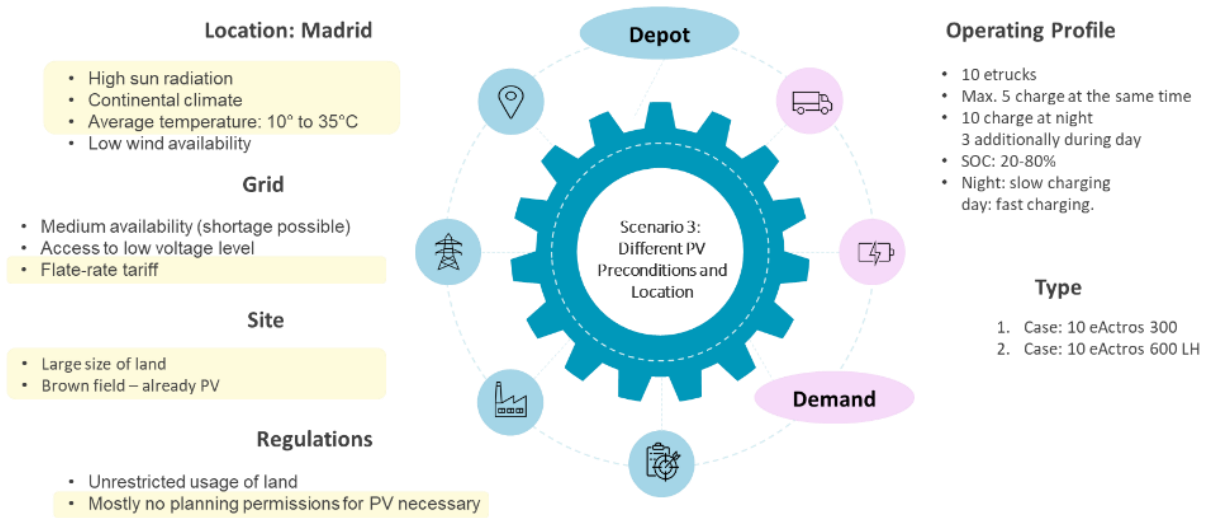


Figure 2.8: Scenario 3

Scenario 4 – Different PV Preconditions

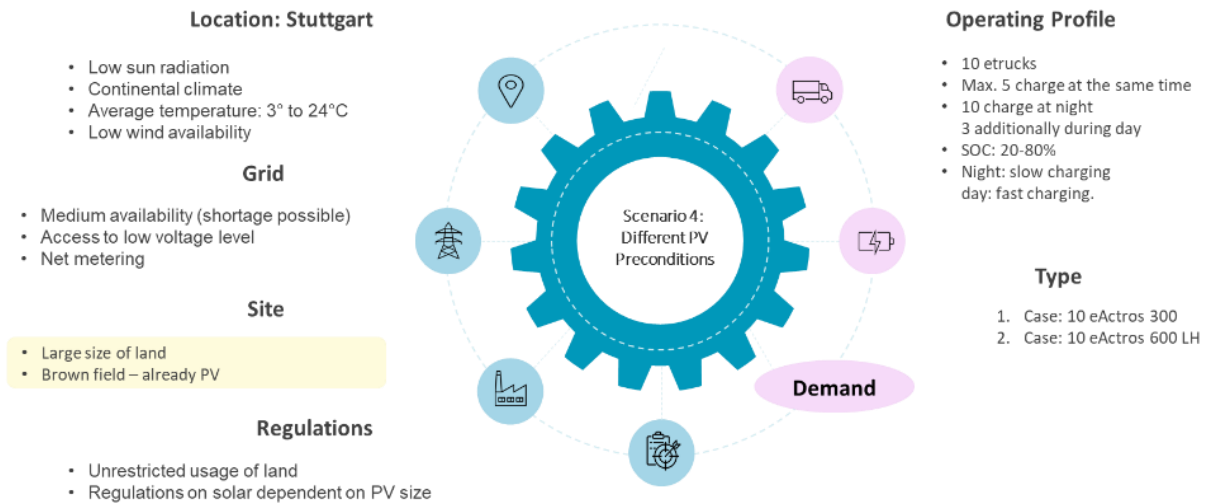


Figure 2.9: Scenario 4

Scenario 5 – Large Number of eTrucks

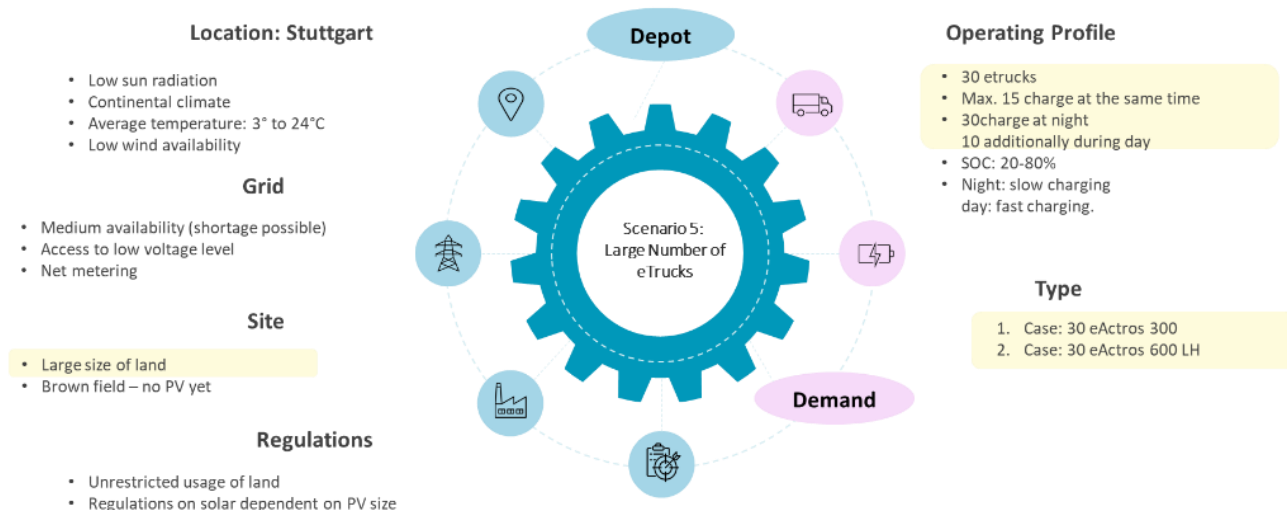


Figure 2.10: Scenario 5

Scenario 6 – High Number of Simultaneous Charging

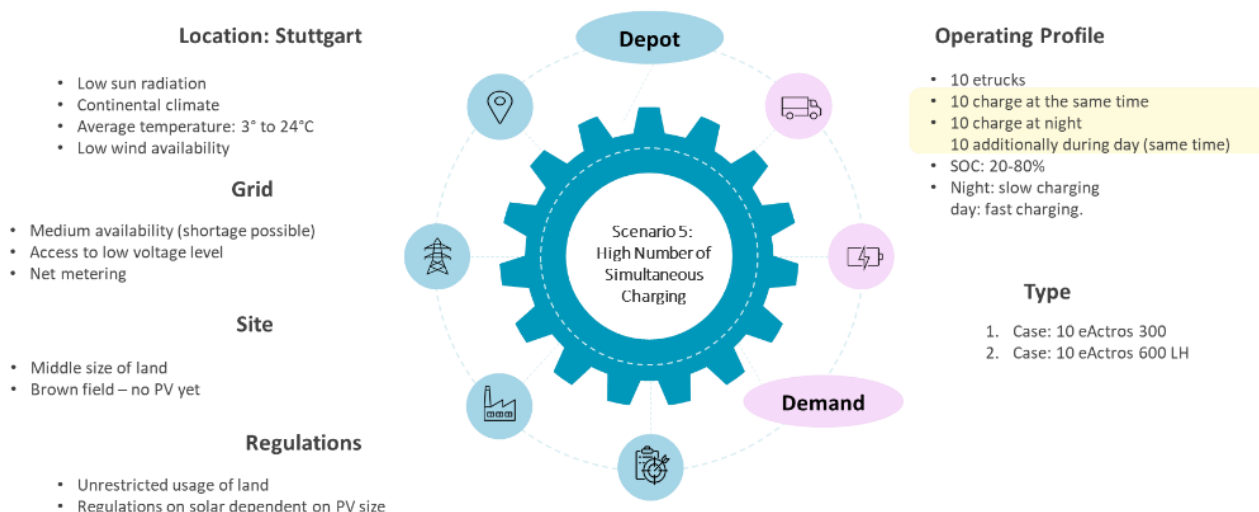


Figure 2.11: Scenario 6

Table 2.1 summarizes the scenarios and highlights the differences:

Table 2.1: Overview over scenarios

SCENARIOS		BASE SCENARIO	SCENARIO 1	SCENARIO 2	SCENARIO 3
			Different Location	Different Location	Different Location & Preconditions (already PV)
City		Stuttgart	Den Haag	Stockholm	Madrid
DEPOT CHARACTERISTICS					
Location	Sun radiation	Low	Low	Low	High
	Climate	Continental	Maritime	Maritime	Continental
	Average Temperature	3° to 24°C	4° to 19°C	0° to 19°C	10° to 35°C
	Wind availability	Low	High	High	Low
Grid	Availability	Unrestricted	Unrestricted	Unrestricted	Unrestricted
	Max. Power	Low voltage	Low voltage	Low voltage	Low voltage
	Pricing	Net metering	Pricing: periodical charge	Fixed amount + variable amount + tax	Flat-rate tariff
Site	Available land	Middle size	Middle size	Large size	Large size
	Condition	Brown field – no PV	Brown field – no PV	Brown field – no PV	Brown field – PV already
Regulations	Usage of land	Unrestricted	Unrestricted	Unrestricted	Unrestricted
	On solar	Dependent PV size	Less permits necessary for PV < 200MVA	No electricity tax for PV < 500kW	Mostly no planning permissions for PV necessary
DEMAND CHARACTERISTICS					
Operating Profile	Number of etrucks	10	10	10	10

	Charging time distribution	Max. 5 at same time	Max. 5 at same time	Max. 5 at same time	Max. 5 at same time
	Time slot per etruck	10 at night, 3 additionally during day	10 at night, 3 additionally during day	10 at night, 3 additionally during day	10 at night, 3 additionally during day
	Charging duration	Fast during day, slow at night	Fast during day, slow at night	Fast during day, slow at night	Fast during day, slow at night
	SOC	20-80%	20-80%	20-80%	20-80%
Type	Battery size	10 eActros 300 or 10 eActros 600 LH	10 eActros 300 or 10 eActros 600 LH	10 eActros 300 or 10 eActros 600 LH	10 eActros 300 or 10 eActros 600 LH
SCENARIOS		BASE SCENARIO	SCENARIO 4	SCENARIO 5	SCENARIO 6
			Different Preconditions	Large Number of eTrucks	High Number of Simultaneous Charging
City		Stuttgart	Stuttgart	Stuttgart	Stuttgart
DEPOT CHARACTERISTICS					
Location	Sun radiation	Low	Low	Low	Low
	Climate	Continental	Continental	Continental	Continental
	Average Temperature	3° to 24°C	3° to 24°C	3° to 24°C	3° to 24°C
	Wind availability	Low	Low	Low	Low
Grid	Availability	Unrestricted	Unrestricted	Unrestricted	Unrestricted
	Max. Power	Low voltage	Low voltage	Low voltage	Low voltage
	Pricing	Net metering	Net metering	Net metering	Net metering
Site	Available land	Middle size	Large size	Middle size	Middle size
	Condition	Brown field – no PV	Brown field – PV already	Brown field – no PV	Brown field – no PV
Regulations	Usage of land	Unrestricted	Unrestricted	Unrestricted	Unrestricted
	On solar	Dependent PV size	Dependent PV size	Dependent PV size	Dependent PV size
DEMAND CHARACTERISTICS					
Operating Profile	Number of etrucks	10	10	30	10
	Charging time distribution	Max. 5 at same time	Max. 5 at same time	Max. 15 at same time	Max. 10 at same time
	Time slot per etruck	10 at night, 3 additionally during day	10 at night, 3 additionally during day	30 at night, 10 additionally during day	10 at night, 10 additionally during day
	Charging duration	Fast during day, slow at night	Fast during day, slow at night	Fast during day, slow at night	Fast during day, slow at night
	SOC	20-80%	20-80%	20-80%	20-80%
Type	Battery size	10 eActros 300 or 10 eActros 600 LH	10 eActros 300 or 10 eActros 600 LH	30 eActros 300 or 30 eActros 600 LH	10 eActros 300 or 10 eActros 600 LH

2.2 Customer Needs

To develop a suitable strategy and identify the various influencing factors of the business model, the first step was to define and evaluate the customers' needs and values. Thus, we started already in Phase 1 to analyze the potential customer needs for an e-depot. Based on feedback and in combination with the learnings from phase 2, we decided on 10 customer needs and values. To come up with them and get deeper insights on the perspective of the customers and realization of an e-depot, we were able to conduct two interviews with experts from Daimler Truck.

The team analyzed the potential customer needs for an e-depot dividing the needs into 14 subcategories.

- The first two needs are related to financing and operating costs. The customer is interested in a short amortization period, a good Return on Investments, and low operating costs. For example, low operating costs could be realized with a charging management system that balances demand peaks.
- It is also essential that the infrastructure is 100% reliable and enables flexible charging operations.
- In addition, there could be a need for different business models. That means there should be multiple concepts of how the customer will invest in the e-depot. For example, a buying or a leasing model could be considered.
- For the customer, it is crucial that the system is adaptable, which means that the generated energy could be used for other purposes. Moreover, the system must be easily integrated and compatible with existing depots.
- Overall, the customer hopes for good efficiency and a few losses between the systems.
- Furthermore, the customer wants maintenance to ensure a durable and reliable system and safe operation. Additional services such as training or certificates are needed.
- The e-depot should be scalable. This means the system should be modular and easy to extend in the future.
- Moreover, it is vital that the system is user-friendly. For example, it should be easy to use and should allow transparency of charging data.
- Another essential customer need is sustainability. The system will help to reach the climate goals of the company and will decrease the dependency on fuels.
- The last customer need is the client relationship. By using e-trucks and e-depots, a trucking company will be a sustainability pioneer, which will increase its brand reputation.

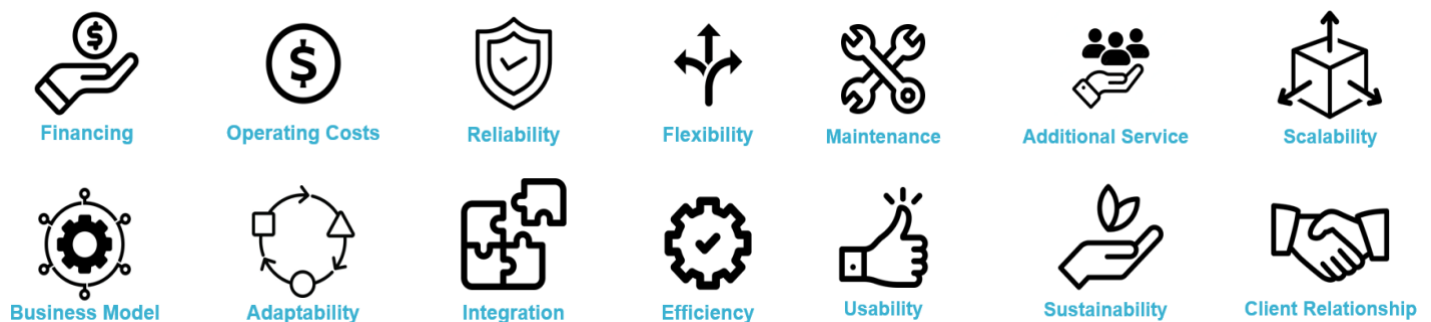


Figure 2.12 First overview over customer needs

After working on it and exchanging information with Sharif and Florian, we narrowed the customer needs and values from 14 to 10.

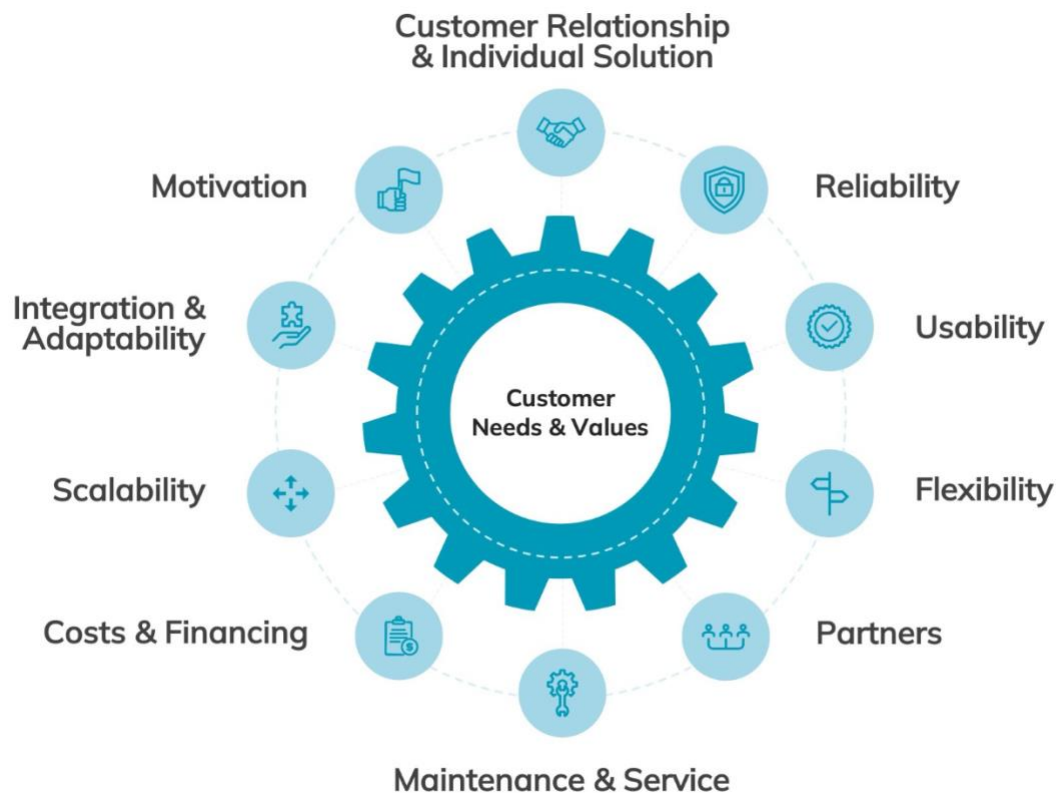


Figure 2.13: Final overview over condensed customer needs and values

2.2.1 Interview with Markus Schiller

Markus Schiller is a project manager at the Kompetenzzentrum für emissionsfreie Mobilität (KEM) in Mannheim. The KEM is part of Daimler Trucks strive for emission free mobility.

We talked to Markus to get to know a better understanding of how the KEM works and for potential customers and their values and needs.

Here is a short summary.

KEM Mannheim

- Grid / Energy Feed-in:
 - Feed-in possible (two other thirds of PV are fed in)
 - Making money by feed-in
- Scalability:
 - Prototype could be scaled up / expanded
 - Currently medium expansion stage of the battery system → can be expanded to more stacks within same container (no extra container needed)
 - Charging infrastructure (now: 1 charger) will be probably extended to at least 2 charging centres
- Reliability:
 - Reliability in KEM couldn't be tested yet
 - PV and storage not yet connected (certification from grid operator pending) → charger not yet used much
 - PV should be stable, battery too → charger most critical
 - Charger in Wörth for testing → a lot of issues
 - Charger did not work immediately when installed in KEM (waited 3 months)

- Currently no back-up charger
- Current Use / Status:
 - Challenges:
 - Expansion of grid / grid connection (except for producing location, only 1-2 charging columns)
 - Building application (3-9 months)
 - Certification
 - Goal:
 - Trying to introduce customers to e-mobility
 - Prototypes / pilot projects and vehicles → for testing, selected customers for test vehicles
 - Use:
 - At least two charging stations to simulate parallel charging planned (3 testing vehicles)
 - 1: internal vehicle (3 days of internal plant logistics + 2 days of being driven empty → 1x charging)
 - 2: vehicle from customer (1 week per month)
 - 3: test vehicle from customer (every day)

Integration

- PV is most often no “island solution” → used for different appliances → energy will be fed in main distribution to be used for different things (chargers, battery, production, etc.)
- Many customers have no production which is using up all the energy generated by PVs → currently feed-in, but could be used for e-trucks
- Certification with / through installation partner
- Different approach needed for layout (depending on requirements) → individual components → technology etc. is more standardized (approx. 70-80%)

Scalability

- Important to plan ahead for scaling up (expansion of the grid connection, traffos, laying of gauge pipes) → no need to “digging up” the depot again and again
- Many systems in basic development → compatibility important, systems are interdependent

Reliability

- Low reliability leads to high asset damages
 - One of the most important customer values if installation was done
 - in the truck business a lot is directly “connected” with a specific truck (mostly goods, especially important for refrigerated goods) → these can’t be easily switched
 - critical for time and goods
- Most often no extra charger for reliability
- High service level needed for high reliability (similar to truck itself)
- Charger most critical in reliability
 - Many products / chargers are tested before being used by the customer → different experience values
- Difficulties as soon as one of these complex components may not work

Maintenance and Service

- Repair:
 - 24/7 service hotline for chargers needed
 - Reaction times usually defined in service contract
 - Uptime = time until system is available again
 - Different uptimes and service level
 - 12 months guarantee for chargers (electronic systems)
- Preventive Maintenance:
 - 1x per year, can be planned ahead
 - Conducted by installation partner
 - Maintenance plan from the installation partner
- Often parallel for PV and Charger possible → depending on the companies executing the different sections (PV, storage, charger) → first contact is DTAG
- Additional Services / Trainings:
 - Trainings are essential
 - Partners are familiar with certain systems
 - Introduction / Training via installation partner

Trust and Customer's Perspective

- Many customers have no idea at all (greater understanding) → acceptance lower with more prior knowledge → disappointment
- much information important for customers → questions must be clarified (vehicle and charging infrastructure)
- some are "pioneers" others "wait and see" → enthusiastic about vehicle / e-truck, charging infrastructure important (many cannot imagine charging process at first)
- Large corporations / customers (Amazon, IKEA, Coca Cola, etc.: distribution level 1) → no small haulage companies at the moment (VS2: Truck Operating Centre, country level / VS3: Dealer)
- Most important customer needs / claims:
 - Investment costs for DEPOT (with/without subsidy)
 - Reliability, dependability, maintenance, etc. after charging infrastructure is in place → in truck business there is more to it than that
 - Support with planning

Financing and Fundings

- No financing of customer projects through DTAG (e.g. contracting through DTAG)
- Vehicles and charging infrastructure are currently being promoted a lot
 - None / very few would invest a lot on their own only
 - funding is offered for pioneering role (promotion: Germany, Netherlands, France, Spain)

Goals and Approach of DTAG

- Approach:
 - Aim to unify many projects into "standards"
 - Much standardisation of the entire process for optimised customer processing and support
 - scaling of projects through new tools and templates (tool for route analysis with data from vehicle planning system)

- Data:
 - Data from vehicles are used for product development and internal analysis → route analyses for chargers
 - Target for sales of own chargers: data → less for PV and storage (offered directly via DT rather unlikely)

2.2.2 Interview with Julius Kaiser

The next interview we conducted was with Julius Kaiser. He is also a project manager at KEM. The summary is in the following section.

Motivation and Client Relationship

- Motivation is mixed, sometimes marketing is most important
- Some customers have a clear idea on how to contribute to reducing emissions in transport sector → special budget for pilot projects
- Some customers are coerced by their own customers e.g. medium-sized company drives for large corporation, the corporation demands that e is driven → marketing effect
- Sustainability / Long-term goals
- Many companies have long-term goals → all use subsidies for cost reduction (vehicle and charging infrastructure)
- Some customer have clear targets
- Batteries / Second-Life-Batteries
- Investment for battery storage large vs. grid connection extension → price should become more attractive for storage
- Most customers do not have battery storage (because investment is so large that it is not worth investing in battery, because grid connection cheaper, if possible)
- Second-Life-Batteries could be used if capacity is sufficient → driving cost reduction

Usability

- Different customers for e-Trucks → testing them
- Customer 1:
 - eActros in Köln/Bonn for distribution to drugstores
 - Charging over night
 - Ca. 200km per truck, 15 different stops
 - Different routes → ca. 1kWh per km
- Customer 2:
 - For grocery shops
 - Charging over night and when truck is loaded with goods during the day → charging at depot with charger next to loading ramp
 - 350-450km per day
 - First test were made more conservative with fewer stops than usual → testing what is possible as a maximum
- Other projects for shuttle operations and on-site operations like intralogistics → easier to plan since routes are always the same
- Customers with special use cases like waste collection need also energy for extra devices → shorter routes
- Most customers won't need MW charging at their depots → not cost effective → more for stops at the highway → change of routes or different planning is most often cheaper than a MW Charger → battery capacity would be negatively influenced as well

Integration

- High potential for PV on empty spaces
- Electricity of PV could be used for trucks to lower kWh prices → but many trucks can only be loaded after 5pm → thus generate energy is often sold
- Battery system could be a solution but is often too expensive in comparison to grid connection and normal kWh price → battery system could be used to cushion peak loads
- Not for all customers a sufficient grid connection is possible → for now, most of them won't change to an e-truck then → PV and storage could be a solution

Scalability

- depot should always be scalable (larger expansion e.g. in 5 years avoid extra civil engineering etc., therefore empty pipes are laid) → currently a consideration and consulted this way by DTAG
- customer should be able to expand / ramp up the project individually
- PV is often already installed or could get expanded
- Funding don't include future use cases so implementing an already bigger system is limited to financial possibilities

Adaptability

- Energy from PV is currently most often used for production, offices, etc. or is fed into the grid

Reliability

- Customers don't want to risk that the trucks can't be charged → grid connection is always installed if possible
- PV and Battery could be an extra option for load peaks and lower energy costs

Flexibility

- In pilot project there often is extra time planned for spontaneous problems etc.
- Expectation of customers is that the system would work without any issues in general
- If a truck has to load for an extra 15min due to traffic jam etc. this would be fine and can be arranged within the route planning → but charging system has to be available all the time

Maintenance and Service

- Repair
 - If charger is not available or cannot be repaired quickly, the truck is not able to operate
 - Truck is often combined with goods or loading of truck with new goods must happen at a special place → charger must work
- infrastructure for service of chargers as important as for trucks → remote access to charger, problem analysis, technicians should be soon at the site → short reaction times necessary
- Producers of chargers haven't thought about such a high service level in detail → if Charger breaks down more often they just completely replace it currently (no long term solution)
- Extra charger could be helpful for less tight planning but high service level is still needed

Partner

- Partner for many integration/installation jobs

- Are usually tested before → have to fulfil certain requirements to ensure high customer satisfaction
- Partner Database with different capabilities etc. (e.g. electrician, planning office, etc.)
- Sometimes useful to involve only few partners (general contractor) → too many parties slow down the process
- Goal: expansion of a big regional partner network where potential partners can also apply for (e.g. if they already worked with the customer for an earlier project)

Trust and Customer's Perspective

- Most important customer needs / claims:
 - Total costs for change to E-Mobility
 - Secured energy supply and availability (including grid connection, chargers, etc.)
 - Individual solutions for every customer
- Being transparent with customers is very important and finding for them the most cost effective solution

Financing and Fundings

- Willingness to invest strongly depends on the company
- Funding is not for future expansion → only one charger per e-Truck and related infrastructure
- Funding start above certain mileage per year (CO₂-reduction must be worth being funded) → e.g. 100km/day is not enough
- Usual Amortization of a truck:
 - 400,000 km mileage in 6 years and then it should pay off against diesel
 - for e-technology to become established the TCO must be lower over the lifetime
 - Effect of tolls will be noticeable in the future (or CO₂ penalty) vs. the costs for charging infrastructure & electricity
 - Currently it only pays off over the lifetime with subsidies
 - Subsidies: Climate protection commercial vehicle and infrastructure funding KSNi second funding call, several billion, a lot of information about applications and current funding and "numbers of units" → RESEARCH (for chargers important for us)
 - Subsidies will expire and it must also work without them → pay off for the customer through scaled up products etc.

2.2.3 Customer Needs & Values Evaluation

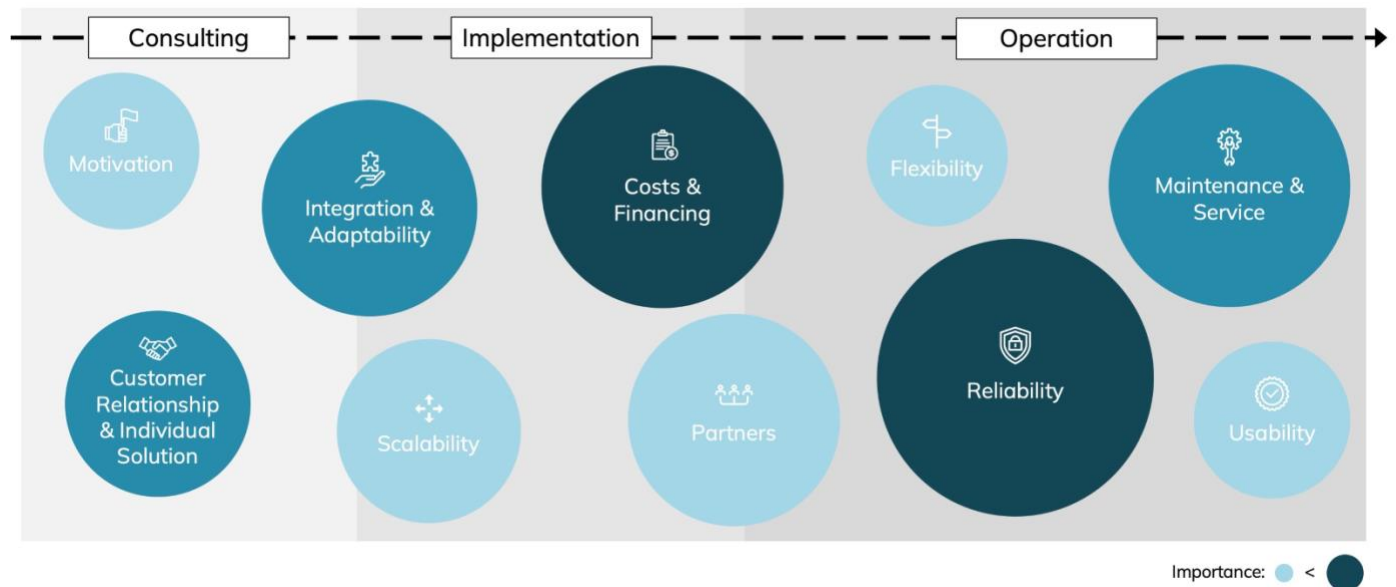


Figure 2.14: Prioritized customer needs & values

The interviews gave us further insights into current topics, challenges and focal points of e-depots resulting in those 10 customer needs and values (Figure 2.14). These are clustered in two ways: On the one hand, there is an allocation to the different phases of a customer project - consulting, implementation, and operation. And on the other hand, the size and coloring of the individual customer needs reflects their importance. The greater the size and the darker the coloring, the proportion of relevance increases.

It becomes apparent that the Costs & Financing of an e-depot as well as the reliability of the system are most important, both being emphasized as key customer needs in the interviews.

To ensure these and enable a sustainable and future oriented operation, moreover a high maintenance and service level is required besides a good customer relationship which builds on trust and individual assessment. However, the integration of the components needed to build an e-depot is essential as well as the possibility to adapt the systems to different use cases.

Partners play hereby a significant role to enable local and cost-efficient solutions regarding the implementation and service. Additionally, the motivation to have a transition to electrified trucks and an e-depot as well as the scalability, flexibility and usability of the e-depot should be considered when developing a solution.

Nevertheless, the graphic only reflects a rough evaluation and weighting of the customers' needs, which must be determined individually for each customer project. This is supported by an interview guideline, which was created over the past weeks and regarding the interviews conducted.

2.3 Customer Personas

In order to better understand Daimler Truck's customers and assess their needs and challenges, customer personas were created. Customer personas are fictional characters that represent a specific target customer.

Big Freight Forwarder & Early Adopter

Major Customer Needs			
 Reliability	 Scalability	 Maintenance	 Sustainability
Key Features	Motivation & Goals	Expectations	Challenges
• Big fleet • Multi-national operation • Operation at full capacity • Large investment capital	• Be a pioneer • Reduced Total Cost of Ownership (TCO) • Meet climate goals	• Whole-in-One solution • Not much effort with planning, implementation & operation	• No failures • Time critical operation • Limited truck ranges (Scaling up to long routes in the future)

Figure 2.15: Customer persona: Big Freight Forwarder & Early Adopter

Medium-sized Freight Forwarder & Early Majority

Major Customer Needs			
 Reliability	 Integration	 Client Relationship	 Scalability
Key Features	Motivation & Goals	Expectations	Challenges
• Medium-sized fleet • Nationwide & regional operation	• Meet client expectations • Reduction of CO2 emissions	• Modular system • Compatibility with existing infrastructure	• Restricted investment capital • Pressure from own clients

Figure 2.16: Customer persona: Medium-sized Freight Forwarder & Early Majority

Small Freight Forwarder & Late Adopter

Major Customer Needs			
 Financing	 Adaptability	 Usability	 Scalability
Key Features	Motivation & Goals	Expectations	Challenges
• Small fleet • Local operation • Short routes	• Waiting until system is mature & costs are reduced	• Modular system • Start with small investments • Reduce Total Cost of Ownership (TCO) in the long-run	• Low investment capital • No expenses for external trainings

Figure 2.17: Customer persona: Small Freight Forwarder & Late Adopter

2.4 Daimler Truck Needs

Three overall goals were defined in Phase 1 for the Daimler needs as well as five requirements for the business model:

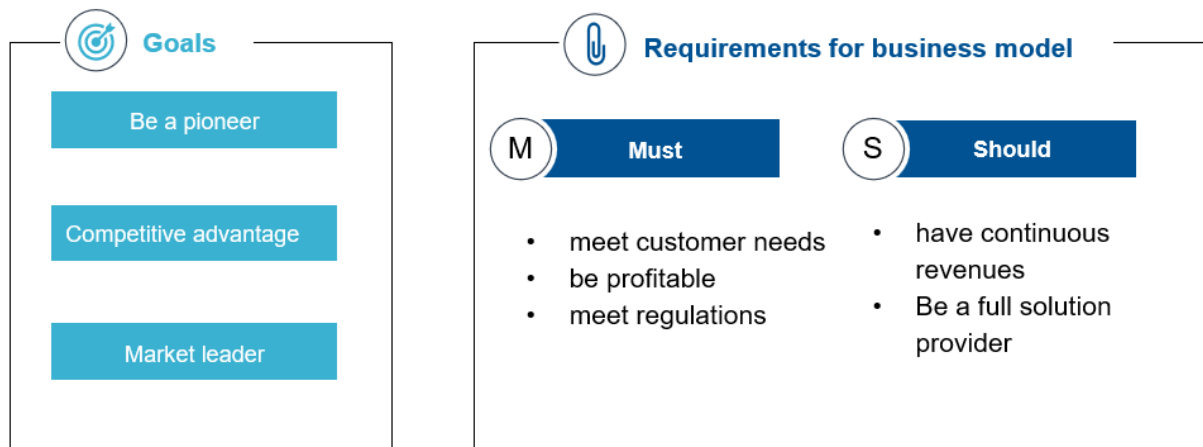


Figure 2.18 Goals and requirements for business model

In Phase 2, the Daimler Truck needs became a bigger focus point:

The Daimler Truck Needs are divided in 8 categories. It is really important to know which ones are particularly important and how they are connected to each other. Eventually, there should be a balance of the Daimler Truck needs as they are directly interconnected.

Table 2.2: Overview over Daimler Truck needs

Market & Competition	Goal	- Be the market leader for electric-trucks-as-a-service / have a big market share - Build a competitive advantage (whole solution: trucks + depot) - Electrification of key markets (EU 30)
	Must	- Solution is competitive viable - Offer solution for target groups
	Should	Offer Trucking-as-a-Service / Be full solution provider (truck incl. charging infrastructure + depot planning, services e.g. maintenance + trainings)
Technology	Goal	Aiming to provide comprehensive solutions that include charging infrastructure and energy generation & energy management systems
	Must	- Solution must meet regulatory requirements - Modularity: Have a basic solution which can be adapted (to location, customer, fleet size, existing depots, with low effort) - Give options to scale (more chargers, bigger battery, more PV)
Innovation	Goal	Learn and optimize: use data for further development (no own prototype needed)
Sustainability	Goal	- Design a sustainable future for trucks (long battery life) - Help meet the climate/CO2-regulation
Marketing	Goal	- Show Reduction of Total Cost of Ownership (TCO) comparing to diesel trucks - Be a pioneer (depot consulting, Daimler Truck as sustainability pioneer, focus on sustainability)

Financing & Business Model	Must	• Be profitable with e-depot consulting (have a high margin, low investments, low resources need) • Financially viable solution for every costumer
	Should	• Have continuous revenues through service solutions (not only selling of trucks, long duration of service contracts) • Provide different business models: Provide a financial solution for all customers
Customer Relationship	Must	• Meet customer needs (reliable solution, durable, few losses etc.)
Partnership	Must	• Get the right partners

The importance and interdependencies of Daimler Truck needs are visualized in *Figure 2.19*. The importance is divided in three layers. The first layer are the most important Daimler Trucks needs. They have a direct influence on each other and on the layer underneath. The second layer is less important but still influences the third layer. It is important to be aware of the interdependencies and balance them accordingly.

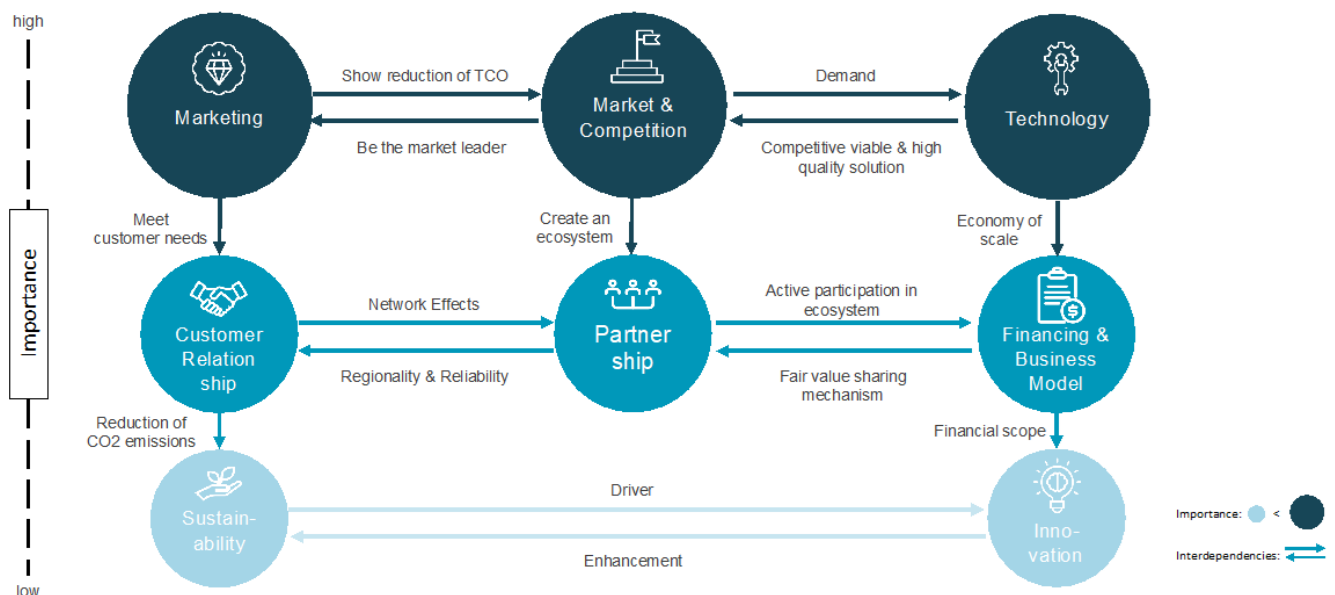


Figure 2.19: Importance and interdependencies of DT needs

3 Tool

The Energy Analysis System, short EASy, is a tool to calculate how many PV panels and/ or wind turbines costumers would need in order to supply their hub with renewable energy. The tool is optimized for the most renewable solutions, which means the power supply will be mainly generated by renewable solutions, here PV panels and/or wind turbines. If those solutions won't generate enough energy, the difference will be supplied by the grid.

The program gives the user an idea, how many renewable resources will be needed. The output of the EASy therefore has to be considered thoughtfully. Depending on the location the program will calculate a neither financially nor technical feasible number of PV panels and wind turbines based on the current state of technology.

The tool EASy therefore has a totally different approach compared to the CIPOD, which is a tool that was already previously developed by Daimler Truck AG. The CIPOD in comparison to the EASy is optimized for a business case and supplies the costumers with the most financially reasonable solution. The CIPOD is also more complex regarding its input parameter.

As the CIPOD already existed at the beginning of the project, EASy was primarily developed to support the on-going research during this project. After the midterm the tool was used to implement features that the CIPOD doesn't have. Those features are the implementation of wind turbines and the optimisation towards renewable energies.

3.1 Basic principles

In the following *Figure 3.1* you can see a radiation map of Europe. As you can see in the figure, the radiation towards the equator increases, whereas the radiation decreases towards the north pol. The higher the radiation at a specific location the less PV panels a costumer would need in order to generate the same output compared to a location with a lower radiation.

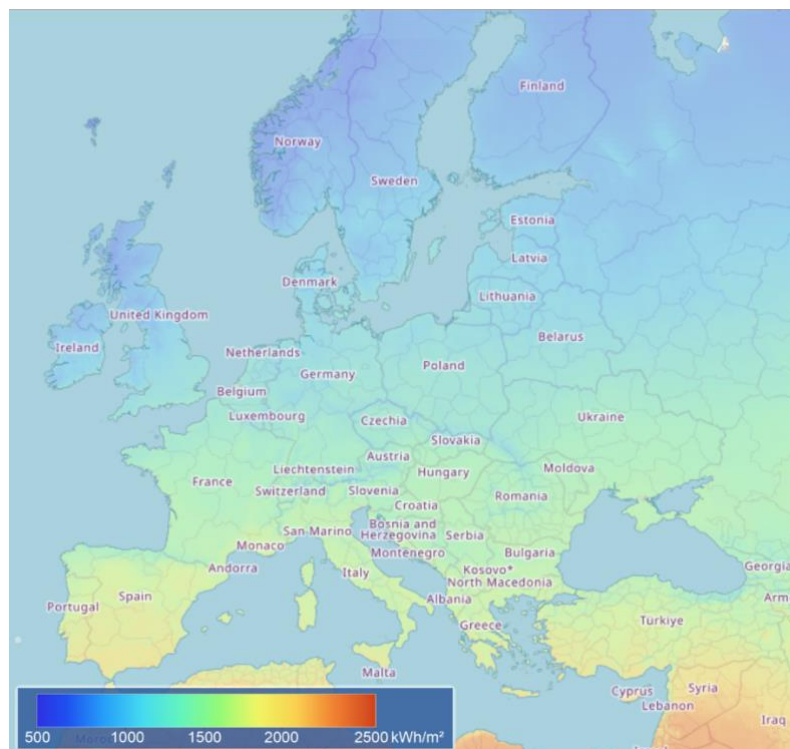


Figure 3.1 Radiation map of Europe by PVGIS¹

¹ https://re.jrc.ec.europa.eu/pvg_tools/en/

The following *Figure 3.2* depicts a map of Europe that shows the windspeed at 10m. Based on this map it can be recognized that the windspeed offshore is especially high. The windspeed decreases towards the inland. It can be therefore mentioned that coastal areas wind turbines are more suitable for the use of wind turbines compared to the inland. To generate the same amount of energy at locations with a high windspeed a costumer would need to build less wind turbines compared to areas with a low wind speed.

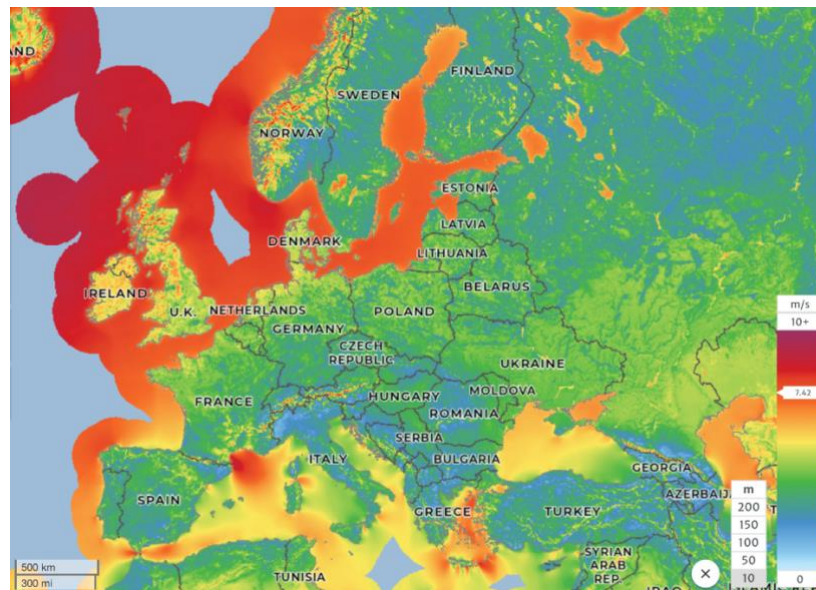


Figure 3.2 Wind speed map at 10m height by the Global Wind Atlas²

3.2 How to work with EASy

3.2.1 Background: PVGIS

PVGIS, which stands for “Photovoltaic Geographical Information System”, is an online tool designed to support the planning and assessment of solar energy systems. It gives a free and open access to photovoltaic (PV) electricity generation potential for different technologies and configurations. PVGIS was developed by the European Commission’s Joint Research Centre (JRC). When using PVGIS the processing of personal data is based on Regulation (EU) 2018/1725.

In general, there are two ways to access PVGIS. The first one is based on the ready-to-use web API (Application Programming Interface) provided directly by PVGIS. The second one consists of integrating API non-interactive interface calls into a customised code. The API non-interactive interface calls are provided by PVGIS. The EASy is based on the second approach, the self-written code with integrated API non-interactive interface calls. Since March 2022 the latest release of PVGIS is PVGIS 5.2, which is used for EASy.

PVGIS provides a variety of different input and output features and functionalities to analyse and evaluate the potential of solar energy generation in specific areas. In the following there will be just an introduction of the data, that will be taken from PVGIS in order to write the program of EASy.

Based on the geographical location, which is determined by the longitude and latitude, the following parameters can be determined:

² <https://globalwindatlas.info/en>

Solar Radiation

The following figure shows a map of the default solar radiation databases that are used to determine the solar radiation for the locations. In some areas multiple databases are available in order to calculate the solar radiation. EASy is based on the default databases. Those databases are **not** covering every location worldwide. Off-shore and some high-latitude areas are not covered, depicted by the grey colour scale, therefore a calculation with EASy for those areas is not possible. The solar radiation data for most of the databases is calculated based on satellite images. The solar radiation is needed to calculate the number of PV-panels needed.

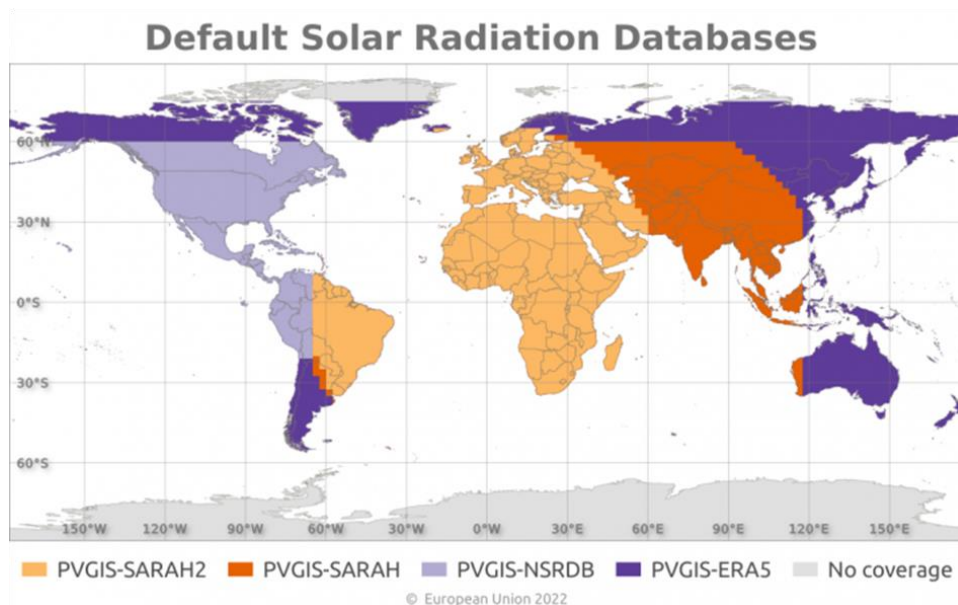


Figure 3.3 Map of used satellite imaging systems by PVGIS³

Windspeed at 10 meters above ground

Additionally, to the solar radiation, PVGIS provides a number of different TMY (Typical Meteorological Year) data. In EASy, just the windspeed at 10m will be incorporated from PVGIS. The windspeed at 10m will be the bases for the wind turbine calculation.

It has to be mentioned that PVGIS does not disclose how or where it takes this data from, therefore results based on this variable have to be used with caution.

For further insights into PVGIS, please refer to the user's manual.

https://joint-research-centre.ec.europa.eu/photovoltaic-geographical-information-system-pvgis/getting-started-pvgis/pvgis-user-manual_en#ref-1introduction

3.2.2 Input parameter

There are two options to set the input parameters for the program. The first option is changing the input parameters directly within the python program. For those users, who are not familiar with python code, a GUI was implemented to enhance the user experience for this group of users. The GUI is based on the library "Tkinter".

The following Figure 3.4 shows the GUI with the necessary input parameters.

³ https://joint-research-centre.ec.europa.eu/photovoltaic-geographical-information-system-pvgis/getting-started-pvgis/pvgis-user-manual_en#ref-1introduction

Figure 3.4 Input sheet for EASy

Every input cell, except for the location data latitude and longitude, is equipped with an additional button “?” to explain the input parameter.

For example, for the input cell “include wind turbines?” the explanation window looks like the following Figure 3.5.

Figure 3.5: Explanation window for input cell “include wind turbines?”

The Figure 3.6 below shows possible input parameter. Numbers should always be entered the following way: “13.567”. Entering the numbers with “,” instead of “.” will cause an error. The figure also highlights that the inputs for “including wind turbines?” and “Combine PV and WT?” are dropdown values.

Figure 3.6: Input sheet for EASy with possible input parameters

Detailed explanation of the input parameters

GUI inputs	Units	Detailed Explanation
Location Data		
Latitude	[°]	-
Longitude	[°]	-
Years (Max. 11 Years)	[a]	How many years should be taken into account for the calculation of the mean meteorological year? (Max. 11 years)
Battery Data		
Charges needed in 24h	[-]	Please insert the number of charges needed in 24h. [-]
Grid availability	[kVA]	Please insert the grid availability in 1h without constant power. [kVA]
Energy required per Truck	[kWh]	Please insert the energy consumption per truck. [kWh] e.g. 336kWh
PV Data		
Efficiency of PV module	[-]	Please insert the efficiency of the PV modules. [-]
Area of one PV module	[qm]	Please insert the area of one PV module. [qm]
Constant grid support	[kWh]	How much power can be drawn from the grid constantly? [kWh] e.g. 1000kWh or 0kWh
Wind Turbine Data		
Include Wind turbines?	No VAWT 3kW HAWT 7,5kW HAWT 10kW HAWT 3,3MW	Do you want to include wind turbines? Please select one.
Combine PV and WT?	No Yes	Do you want to combine PV modules and wind turbines?
Number of WT (Max. value)	[-]	Maximum number of wind turbines to be installed when combining PV and wind turbine systems. [-]

Steps to use the GUI

1. Run PV_Truck.py program
2. GUI will pop up. Enter the input parameters
3. For the detailed description of the parameter fields, click on the
4. Enter the "Okay" button to submit the inputs
5. Program will run
6. Close the GUI after the program execution

Relevant background information about different technologies can be found in the chapter *Tech.*

3.3 Comments on EASy

The code is a simulation program for analysing renewable energy systems, specifically photovoltaic (PV) and wind energy systems. It takes user inputs such as location data, battery specifications, PV efficiency, and wind turbine type.

The program consists of several modules and classes:

- The "Battery" module contains the "battery" class, which calculates the energy storage requirements for charging electric trucks. It considers the number of charges needed, energy consumption per truck, and grid availability. The class determines the total energy needed from the battery energy storage system (BESS) and the required battery capacity.
- The "Area" module contains the "calculation" class, which calculates the optimal PV panel area based on average meteorological data. It uses the PVGIS API to retrieve meteorological data for a specified location and year range. The class determines the best tilt and orientation angles for PV panels and calculates the required PV area.
- The "E_ex" method in the "Excess_electricity" module calculates the excess electricity and other metrics for the PV system. It takes parameters such as solar radiation, time, battery demand, tilt, orientation, and PV panel area. It iterates through each hour, calculates the PV panel output based on the solar radiation and panel parameters, and compares it with the battery demand. It calculates the excess electricity and other metrics such as grid support.
- The "Wind" module contains the "wind" class, which calculates the wind power output and determines the number of wind turbines needed. The class considers different wind turbine types (VAWT and HAWT) and their power curves. It calculates the power output based on wind speed data and determines the number of wind turbines required to meet the energy demand.
- The "W_ex" method in the "Wind_extra" module calculates the wind energy production, excess electricity, and other metrics. It takes parameters such as wind speed, time, power curve, number of wind turbines, and battery demand. It iterates through each hour, calculates the wind turbine output based on the wind speed and power curve, and calculates the total wind energy production. It also determines the excess electricity by comparing the wind energy production with the battery demand.
- The "Combo" module contains the "combo" class, which combines PV and wind energy systems. It determines the optimal combination of PV panels and wind turbines to meet the energy demand. It considers the maximum number of wind turbines and calculates the combined power output.

The main program starts by taking user inputs and then performs calculations using the modules and classes mentioned above. It generates outputs such as the optimal PV area, wind turbine number, and power outputs. It also provides graphical representations of the simulation results.

Overall, the code allows for the analysis and optimization of renewable energy systems by considering location-specific data and user-defined parameters. It provides insights into the required system components and their performance in meeting energy demands.

For more details, please refer to the comments in the code.

3.4 Output and results

EASy has four graphical outputs:

1. Analysis of the PV area with variant tilts and orientations and output of the needed battery capacity and number of battery units. The output can be used to assess the severity of misplacing the PV panels.
2. PV modules power output at the best orientation and tilt over a mean meteorological year; the baseline is the needed energy to charge the given number of trucks. On the negative y-axis is the grid support. The grid feed-in is the power that is harvested, but not used to charge the trucks. It's given as a sum over the whole year. The sum of grid support power is given as well. This output is an indicator for the usability of PV panels at the given location.
3. The third figure shows the number of needed wind turbines to charge the given number of trucks. The power output is drawn over a mean meteorological year, as well as the grid support. Total grid feed-in and output are shown as sums over the year. The output gives insights in the technical feasibility of wind turbines.
4. At last, EASy gives the graph of the combined power output of PV panels and wind turbines. The maximum number of wind turbines is pre-set by the user. If more PV modules are needed, they are calculated on top of the wind turbines power output. The grid output power and sums of the feed-in power and grid output are given. The output gives insights on the possibility of combining the two technologies to become less dependent on one weather condition.

The conclusions to draw from the outputs are explained in this chapter as an example of Stuttgart. 10 eActros300 should be charged, three are charged twice to have 13 charging cycles in total over the course of a day.

The outputs for all scenarios are placed in the *Appendix*.

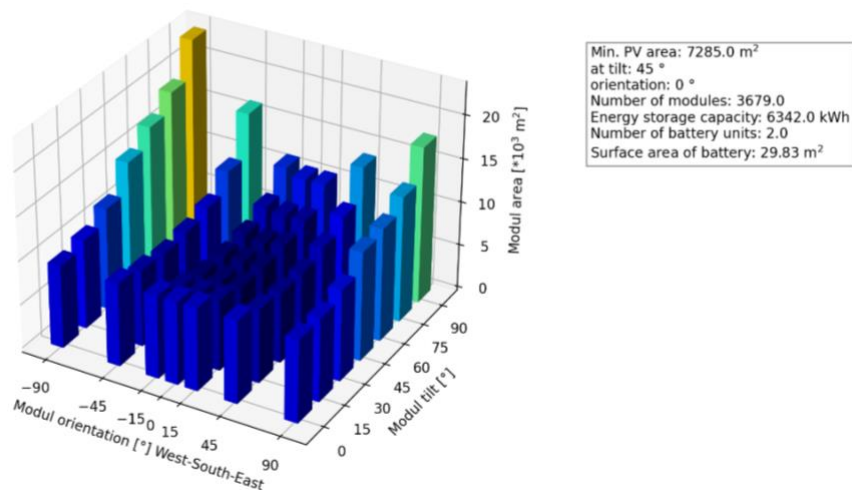


Figure 3.7: Output 1 - PV area varying with module tilt and orientation and battery data

In Stuttgart, 3679 PV modules are needed, when positioned at an angle of 45° facing southwards, as seen in *Figure 3.7*. That is a common position for PV panels in the central Europe. 30° tilt is usually acceptable as well. A varying position comes with the significant increase of area, especially an azimuth change. The sun's elevation and azimuth are tied to the seasons. It rises higher in the summer time and lower in winter. Therefore, the PV panels should be installed at a greater tilt in winter and lesser tilt in the summer. 30-45° is the middle ground for the panels to receive enough direct sunlight throughout the year. The sun's azimuth changes as well. In the winter sunrise is at less than 90°, so in south-east direction. And the sunset is at south-west

direction. Any PV panel facing to the east or west at a great tilt angle wouldn't have direct radiation in winter time. In the summer month the sun rises at a greater azimuth a little over 90°.

For the specifics of the battery calculation, please refer to the chapter *Battery calculation*.

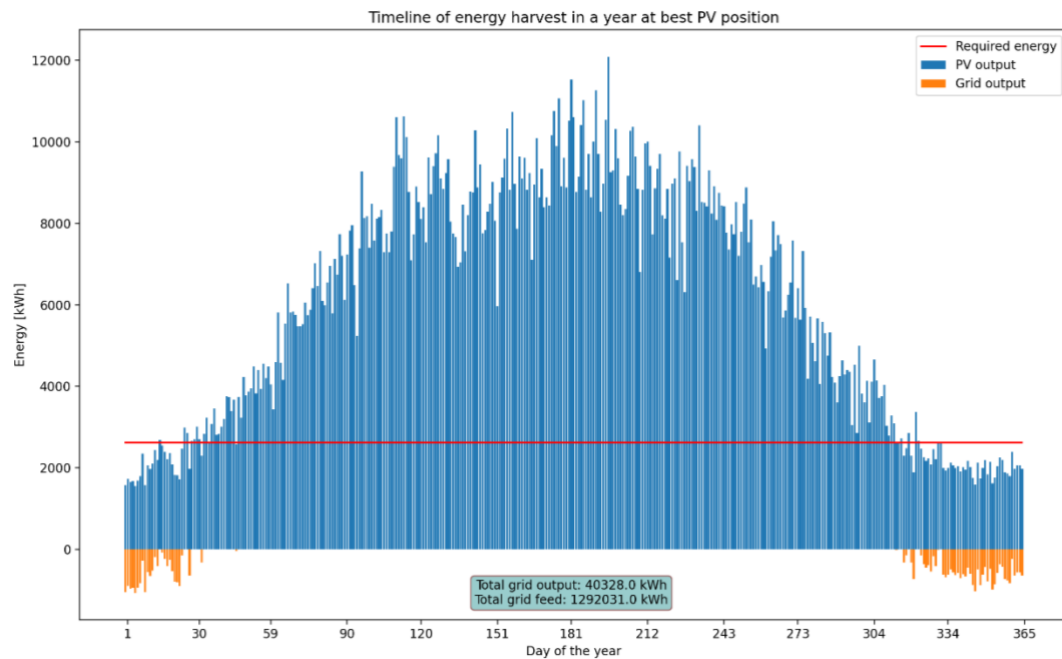


Figure 3.8: Output 2 - Power output of PV panels at best position and with grid support

The power output of the said number of PV panels at their best position is given over the days of the mean meteorological year in *Figure 3.8*. The red line indicates the needed charging power. The blue PV power output shows the dilemma of PV power harvest in Europe: In the winter there is a lack of radiation and the number of panels has to be scaled up to meet the demand. The higher number of modules then convert almost three times the needed power in the summer. The same phenomena can be observed in all the other scenarios as well: the further north the location, the greater the variance of winter and summer time.

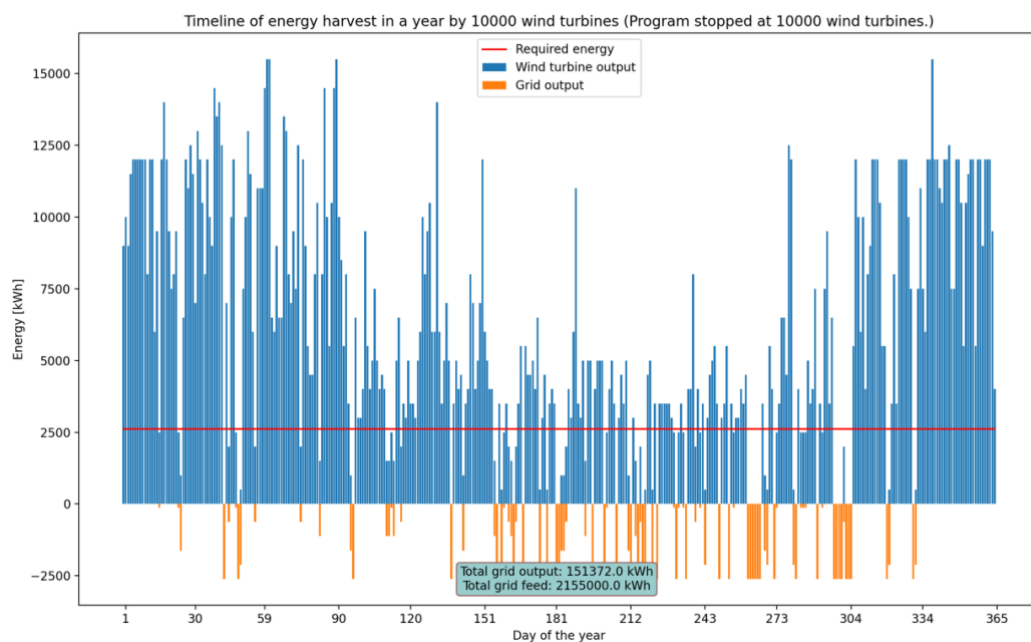


Figure 3.9: Output 3 - Power output of VAWTs and with grid support

Next up is the output of power harvested by vertical wind turbines over a mean meteorological year, seen in *Figure 3.9*. It needs to be mentioned that the wind data of PVGIS is not the most

accurate. Before building any wind turbine there should be a measurement period of one year at the exact location. Turbulence and wind speed are too variable from location to location, to accurately predict them. The wind turbines output is calculated for wind classes: 0-2m/s, 2-3m/s, ... For each class there is an according power output given by the producer. The graphs show discreet values because of these wind classes. Stuttgart is a very difficult location to place VAWTs at low heights. More than 10.000 of them would be needed to fulfil the energy demand. It is in no way feasible. For the other scenario locations there is a similar conclusion. The height of the wind turbine is the most significant factor, because the wind speed rises logarithmically. Instead of over 10.000 VAWTs only six HAWTs at the height of 119 meter would be needed to charge the trucks 13 times in Stuttgart, as shown below in *Figure 3.10*. This is only an estimation of the output, because of the lack of information on wind directions.

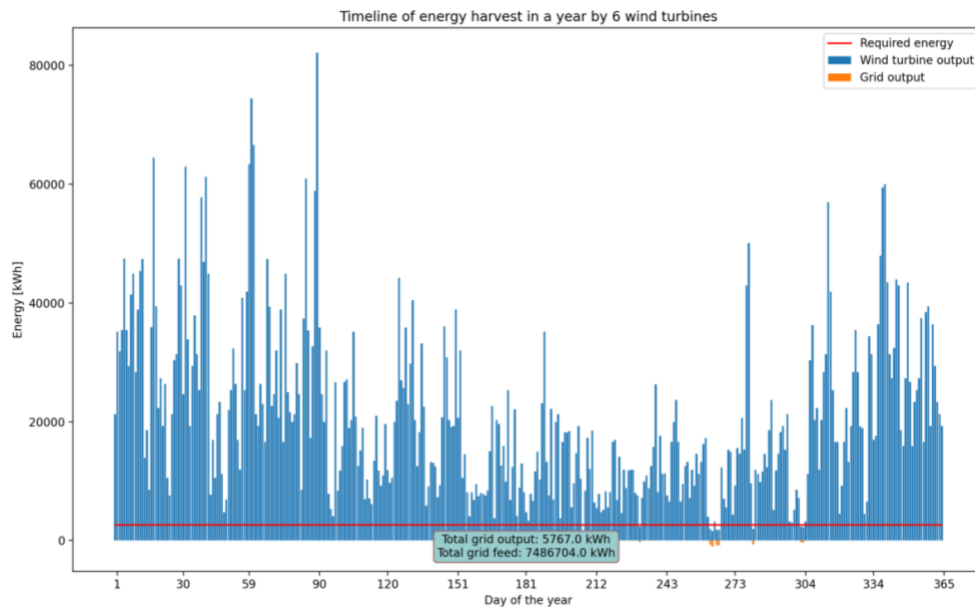


Figure 3.10: Output 3 - Power output of HAWTS at the same location

The technology of vertical wind turbines seems promising at first sight, as they are more silent, use less space and are less dependent on wind direction. But their lower efficiency in comparison to HAWTs and the low wind speeds at 10m disqualifies them as reasonable renewable energy source.

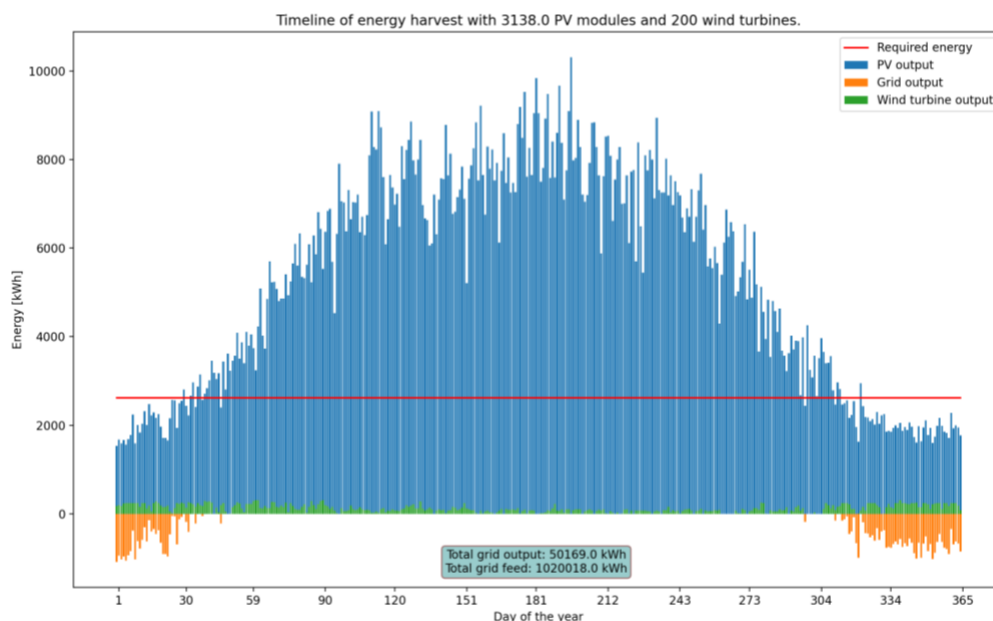


Figure 3.11: Output 4 - Combined power output of VAWTs and PV panels with grid support

The last output of the program is the graph of combined energy output over a mean meteorological year of PV panels and wind turbines, seen in *Figure 3.11*. The user can input a maximum amount of wind turbines to be used for this calculation. In the example 200 VAWTs were used. The program checks first if the energy demand can be satisfied with the wind turbines only. If not, PV panels are added. 200 VAWTs are not enough to charge the trucks in Stuttgart, but the amount of PV panels drops. Theoretically, wind turbines could lower the dependency on one weather condition and seasonal changes. Storms usually occur in the spring, autumn, and winter, when the PV power output is low. Combining these technologies could dampen the upscaling of needed modules in the wintertime. But using vertical wind turbines does not generate the wanted effect in a significant amount of reduced PV panels.

3.5 Use cases for EASy

DTAG already has their own analysing tool for implementing electrical trucks: CIPOD. What can EASy offer in addition to CIPOD?

- EASy optimizes the PV, wind turbine and battery systems towards a high degree of self-sufficiency. The advantages are the independence from the local grid infrastructure, avoiding costly peaks in the grid and revenue generation from feed-in. In addition, the hybrid system is highly flexible and can support different demands of energy output. In times of high demand, the grid support can be used more frequently. Are there less trucks to charge, the whole energy can be provided by the depot themselves without added electricity costs.

Implementing PV systems for power generation requires a significant upfront investment. The costs involve procuring solar panels, inverters, batteries, and associated equipment, as well as installation and maintenance expenses. However, over time, the operational costs are relatively lower compared to relying solely on grid electricity. PV systems for charging electrical trucks do not have a universal solution that applies to every situation. Factors such as geographical location, available sunlight, energy demand, and space constraints need to be considered to design an optimal system. Customized solutions tailored to specific needs and conditions are crucial for maximizing efficiency.

- The overall calculation of the energy output by the PV panels is more detailed in EASy than it is in CIPOD. Radiation data from PVGIS is verified, while not being as accurate as measuring at the location. The program uses the hourly data and is therefore able to simulate the suns position depending on the time of the year. The PV power output is more accurate than using an average radiation of a country, as it is done in CIPOD.
- Wind turbine calculations are not yet part of CIPOD. The power output of VAWTs and HAWTs are generated in EASy based on the wind data from PVGIS and therefore not accurate. But it allows the user to get an insight into the usability of wind turbines at the location. If the regulation towards height restrictions, technical and financial feasibility, change in the future, wind turbines might be considered as a power source for truck charging.

In future projects, Daimler Truck can compare the numbers calculated by CIPOD to the ones EASy generates and get a better understanding of the renewable energy systems. Still, the data is gathered through simulation and should always be verified thoroughly.

4 Tech

The structure of this chapter is divided into the two phases in which we worked. Phase 1 is characterized by basic research in the field of technologies for energy generation and energy storage. The work in phase 2 focuses on the promising technologies and introduces other interesting aspects such as second life of batteries or smart charging. The focus will be on advancements and technologies slated for release by the year 2035.

Phase 1

What are the available technologies in the fields of energy harvest and storage?

How can that be utilized to implement the concept of decentralized energy supply?

How can we apply our knowledge about them to pave the way towards the electrified depot of the future

These central questions have shaped the work of the first phase of our Innolab in the Tech Team.

4.1 Harvest

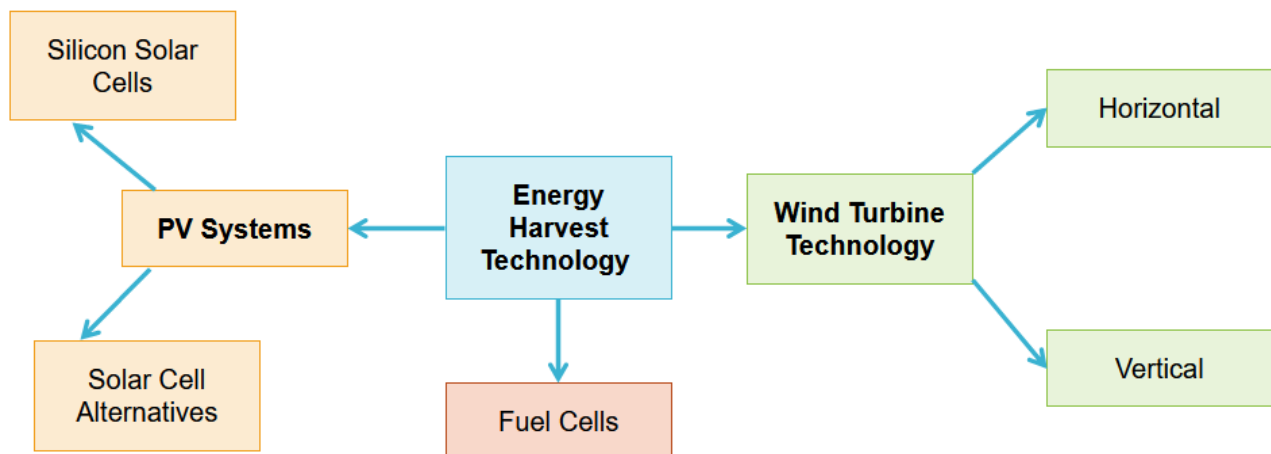


Figure 4.1: Overview over different energy harvesting technologies

This chapter deals with the different sources of renewable and sustainable energy harvesting technologies currently present on the market and which one of them would be most suitable for our project. In the following we will present the three major renewable energy resources we focused our research on, namely PV systems, fuel cells and wind turbines, our findings regarding them, their evaluation and the decisions made based on that.

4.1.1 Fuel cells

First of all, it should be mentioned that fuel cells can be utilized as harvesting as well as energy storing systems, so they shall be discussed two times in this report.

For further information on the function of a fuel cell see the Storage section, Alternatives, Chemical.

Technology

Fuel cells are used in a wide range of applications, from providing power to homes and businesses and being used in the mobility sector. Furthermore, they do not need to be periodically recharged like batteries, but instead continue to produce electricity as long as fuel is provided.

There are many different types of fuel cells including various components:

Typ	Anodengas	Kathodengas	Elektrolyt	Arbeitstemperatur	Leistungsbereich	Zellen-Wirkungsgrad
Alkalische Brennstoffzelle AFC	Wasserstoff	Sauerstoff	Kalilauge	20 °C - 90 °C	bis 100 kW	60 % - 70 %
Membran-Brennstoffzelle PEMFC	Wasserstoff	Luftsauerstoff	Polymer-Membran	20 °C - 80 °C	bis 500 kW	50 % - 70 %
Direkt-Methanol-Brennstoffzelle DMFC	Methanol	Luftsauerstoff	Polymer-Membran	20 °C - 130 °C	bis 100 kW	20 % - 30 %
Phosphorsäure-Brennstoffzelle PAFC	Wasserstoff Erd- bzw. Biogas	Luftsauerstoff	Phosphorsäure	160 °C - 220 °C	bis 10 MW	55 %
Schmelzcarbonat-Brennstoffzelle MCFC	Erd-, Kohle-Biogas	Luftsauerstoff	Alkalicarbonatschmelzen	620 °C - 660 °C	bis 100 MW	65 %
Oxidkeramische Brennstoffzelle SOFC	Erd-, Kohle-Biogas	Luftsauerstoff	Yttriumstabilisiertes Zirkonoxid	800 °C - 1000 °C	bis 100 MW	60 % - 65 %

Figure 4.2: Different types of fuel cells

A detail that immediately is noticed, is that the overall efficiency for each type is rather poor.

Advantages of fuel cells

- with green H₂ as fuel completely carbon free, also possible to use natural gas from gas grid
- higher efficiency, when used in combined heat and power systems scalable in stacks → large scale multi megawatt installations possible
- power spectrum of hydrogen fuel cells ranges from the sub-kW range of individual cells to the MW range in the form of virtual power plants⁴
- quiet
- no need for lot of space
 - example:
A 10 MW fuel cell installation can be sited in a about an acre of land. This is compared to about 10 acres required per MW of solar power and about 50 acres per MW of wind.
- DTAGs joint venture with Volvo → Cellcentric
- prices are dropping, example on 120kW fuel cell⁵:
 - 2010: 1 Mio\$
 - 2022: 200.000\$
 - next decade expected to be under 100.000\$

Disadvantages of fuel cells

- hydrogen is expensive to produce and not widely available yet
- lack of infrastructure to support distribution of hydrogen

⁴ <https://www.tuev-nord.de/de/unternehmen/energie/wasserstoff/wasserstoff-brennstoffzelle/>

⁵ <https://www.horizoneducational.com/why-are-the-prices-of-fuel-cells-dropping/t1422>

- if carbon free solution is wanted, need for green hydrogen source is necessary, else connection to gas grid is also possible or biogas
- high costs due to expensive catalysts and maintenance
- efficiency: first generating renewable electricity with PV or wind is needed to produce H₂
→ overall efficiency of about 30-60%, when electricity and heat are used around 90%

Conclusion

To conclude, in our opinion we should not consider fuel cells as solution for energy harvesting, because it might be more efficient to use renewable electricity directly and there is no/little hydrogen infrastructure and production as of now. Additionally, improvement regarding efficiency is needed.

4.1.2 Wind Turbines

Horizontal and vertical wind turbines are two distinct types of wind energy conversion systems used for generating electricity from the power of the wind. Furthermore, a wind turbine turns wind energy into electricity using the aerodynamic force from the rotor blades, which work like an airplane wing or helicopter rotor blade. When wind flows across the blade, the air pressure on one side of the blade decreases. The difference in air pressure across the two sides of the blade creates both lift and drag. The force of the lift is stronger than the drag and this causes the rotor to spin. The rotor connects to the generator, either directly (if it's a direct drive turbine) or through a shaft and a series of gears (a gearbox) that speed up the rotation and allow for a physically smaller generator. This translation of aerodynamic force to rotation of a generator creates electricity. It should be noted that wind turbines have therefore a strong wind respectively weather dependency.⁶

Horizontal wind turbines, also known as horizontal-axis wind turbines (HAWT), feature large blades mounted on a tall tower and can be single-, two and three-bladed. These turbines are commonly seen in wind farms and other large-scale installations and are generally the most used type of wind turbine.⁷

HAWT can capture stronger winds and have greater efficiency. Based on the direction of wind towards the turbine blades, the turbine is classified into upwind and downwind.



⁶ <https://www.energy.gov/eere/wind/animation-how-wind-turbine-works>

⁷ <https://www.sciencedirect.com/topics/engineering/horizontal-axis-wind-turbine>

Advantages of HAWT

- the output power is high as compared to the vertical axis wind turbine
- the efficiency of a HAWT is high
- less expensive than a VAWT (see following section)
- more consistent and rotational speed is high
- on variation in the wind shear, the tall tower captures more wind
- long life span
- blades of the turbine can be bent using a gearbox to get the best wind attack angle, which results in better performance under stormy conditions
- rotor can be tilted by the blades during storms

Disadvantages of HAWT

- available only in large sizes and are challenging to use in distributed generation
- transportation from one place to another is difficult due to large size and heavyweight
- mounting of a heavy generator and gearbox at the top of the tower requires a stronger structure, which increases the complexity and cost of the structure
- installation and maintenance is a difficult process because of the tall tower and heavy turbines
- noise from the HAWT is high compared to other wind turbines
- to design and manufacture a HAWT, heavy machinery is required

On the other hand, vertical wind turbines, also known as vertical-axis wind turbines (VAWT), have a vertical rotor shaft and blades that rotate around it. They are typically smaller in size and are suitable for urban and residential areas. Additionally, they come in several varieties, including the eggbeater-style Darrieus model, named after its French inventor. These turbines are omnidirectional, meaning they don't need to be adjusted to point into the wind to operate.⁸ Moreover, VAWTs represent a unique form of power-generating technology. Historically, they have been relegated to fulfilling a small niche market in commercially available wind turbines due to their “yaw-less” design.⁹ Current VAWT designs lag behind their HAWT counterparts in terms of efficiency, as measured by their power coefficient.¹⁰ However, new research suggests that these types of wind turbines may be better suited for wind farm installations than previously thought. In addition, they also can be utilized in combination with other renewable energy sources, such as solar panels and be connected to a energy storing application.

⁸ [Vertical Axis Wind Turbines: Farm and Turbine Design - ScienceDirect](#)

⁹ <https://www.sciencedirect.com/topics/engineering/wind-turbine>

¹⁰ <https://www.sciencedirect.com/topics/engineering/power-coefficient>

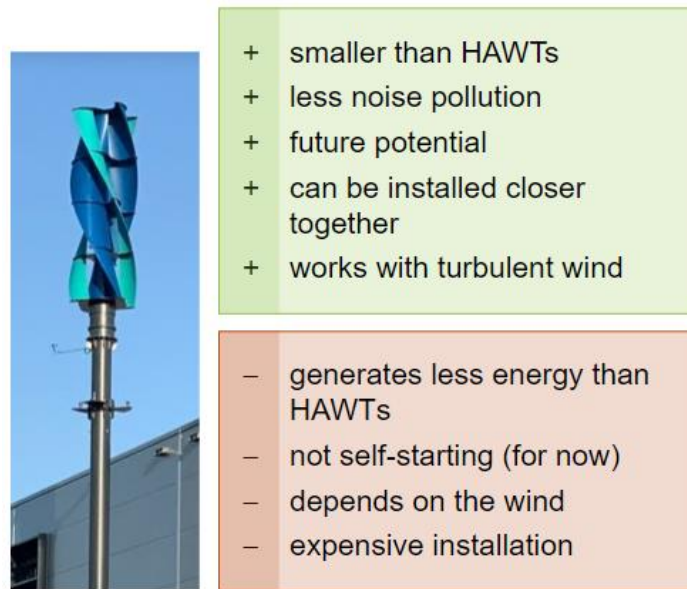


Figure 4.3: Advantages and disadvantages of VAWTs

In the following paragraph the pros and cons for both turbine kinds are discussed based on the project's needs:

Characteristics	HAWT	VAWT
Axis of rotation with respect to wind stream	axis of rotation of turbine is parallel to the wind stream	axis of rotation of the turbine is perpendicular to the wind stream
self-starting	self-starting	not self-starting, hence a starting mechanism is required to start it from stationary position
design and installation	design and installation is complex	design and installation relatively simple
operation space of blades	requires large space for blade's operation	requires small space for blade's operation
dependency on wind direction	dependent on wind direction	independent of the wind direction because it receives wind from all directions
height from ground	height from ground is large	installed at comparatively smaller distance from the ground
power coefficient	high power coefficient	low power coefficient
tip speed ratio	high tip speed ratio	considerably low tip speed ratio
noise produced	operation is noisy	produces comparatively less noise
efficiency	ideal efficiency around 50% to 60%	ideal efficiency usually more than 70%
cost	more expensive due their complex design and installation	less expensive because their design and installation is quite simple

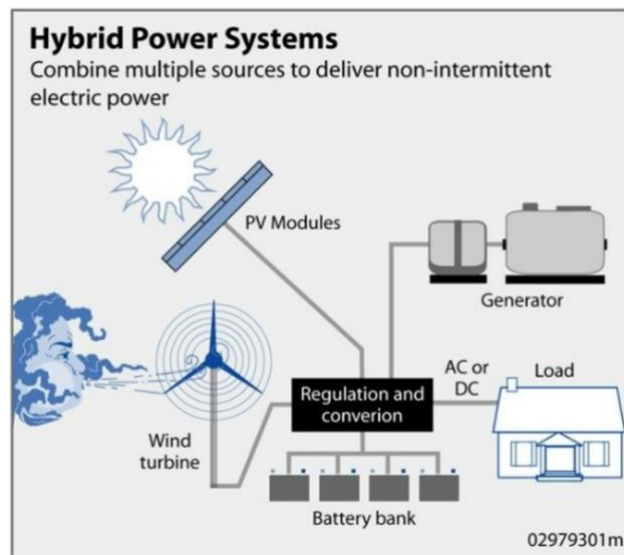


Figure 4.4: Example for a hybrid power system

Both vertical and horizontal wind turbines can be used in a hybrid system to power a ZEV. The idea behind hybrid systems is that they can produce power 24-hours a day despite the weather conditions. However, the suitability of each type of turbine depends on several factors, including the site location, wind conditions, and the energy requirements of the ZEV.

Vertical wind turbines have a smaller footprint and can operate in turbulent and changing wind conditions. They are generally easier to install and maintain and can be mounted on the ground or a building rooftop. However, VAWTs may not be as efficient as horizontal wind turbines in areas with consistent and strong wind conditions.

In comparison, the energy output of a VAWT or HAWT depends on several factors, including the size and design of the turbine, the wind conditions, and the efficiency of the energy conversion system. On average, a typical VAWT might have a rated capacity of 1-10 kW, while a HAWT might have a capacity of around 1-5 MW.

Assuming a VAWT with a capacity of 1 kW and a capacity factor of 30%, the VAWT could generate approximately 2,628 kWh of energy per year. A HAWT with a capacity of 1 MW and a capacity factor of 35% could generate approximately 3,066,000 kWh of energy per year.

Horizontal wind turbines are typically larger and more efficient than VAWTs, making them a better option for sites with consistent and strong wind conditions. However, they require more space for installation and maintenance and are generally more expensive to install. Finally, there are regulatory and safety considerations that must be taken into account when considering wind turbines in general. Depending on the size and location, they may be subject to certain regulations and permits, and safety measures, such as fencing or warning signs, may be required to prevent injury or damage.

Conclusion

In summary, based on the pros and cons of horizontal and vertical wind turbines, it is determined that horizontal wind turbines are not considered a viable option for the rest of the project due to regulatory constraints and their sizing. However, vertical wind turbines show potential as an interesting choice in the future. Their smaller size, reduced noise pollution, and compatibility with turbulent wind conditions make them a promising technology. Ongoing advancements in vertical wind turbine design and efficiency may make them more economically feasible and attractive in the coming years. However, it should be noted that at present, there is insufficient information available to proceed further with vertical wind turbines for the project, emphasizing the need for additional research and data to assess their feasibility and performance accurately.

4.1.3 Photovoltaic Systems

Photovoltaic (PV) systems, also known as solar power systems, have gained immense popularity in recent years due to their renewable energy generation capabilities. PV systems use semiconductor materials, such as silicon, to turn the sun's energy into electrical power. Sunlight striking the semiconductor material creates a flow of electricity that can be harnessed and used to power homes, businesses, and other applications. The solar panels convert sunlight into direct current (DC) electricity through what's called the photovoltaic effect; when energy from the sun strikes a certain material, like silicon, it produces electricity. The photovoltaic effect, so named by French physicist Edmond Becquerel in 1839, is a basic physical process. Photons – packets of light energy from the sun – knock electrons out of their orbitals.¹¹

These electrons flow freely through the solar cell then, creating an electrical current. Naturally, the more photons that hit a solar cell, the more electrons are displaced and the more current is produced. This is why, on consistent, sunlit days, solar cells produce more electricity than on cloudy days.

Advantages and disadvantages

- + easy to install
- + install as small or as large as needed
- + more modules can be added later on
- + low maintenance
- + long lifespan



- offgrid system needs a backup storage system
- high initial investment cost
- substantial surface required
- sunlight dependance

Technologies

In addition, it is essential to consider the various solar cell technologies available when evaluating PV systems. Here are some notable options:

Dye Sensitized Solar Cells

Dye-sensitized solar cells (DSSCs) are known for their relatively inexpensive production costs and the ability to create thin film-colored solar cells. However, DSSCs typically have lower efficiency compared to other solar cell technologies. Despite their cost advantages, their lower efficiency may make them less suitable for projects where maximizing energy generation is a priority.

Perovskite Solar Cells

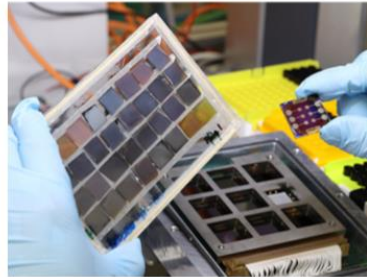
Perovskite solar cells have gained significant attention in recent years due to their potential for high efficiency and relatively low production costs. Although they show promise, perovskite solar cells are still in the research and development phase and have not yet reached commercial market readiness.

¹¹ <https://www.hoymiles.com/2021/10/19/how-do-solar-panels-work/>



Dye Sensitized Solar Cell

- + cheap production
- + thin film colored SC
- low efficiency



Perovskite Solar Cell

- + cheap production
- + high efficiency
- not yet market ready



Silicon Solar Cell

- + mass production
- efficiency development stopped

Silicon Solar Cells

Silicon solar cells are the most common and mature technology used in PV systems. They have been extensively researched and developed over the years, resulting in a well-established mass production capability. Silicon solar cells offer a balance between cost, efficiency, and reliability. However, the efficiency development of silicon solar cells has reached a plateau, and significant improvements in efficiency are unlikely in the near future.

Conclusion

Considering the various solar cell technologies available and their stated dis-/ and advantages, it is important to assess which technology aligns best with the project's requirements. In this case, the project should consider utilizing silicon solar cells due to their established mass production capabilities and reliable performance. Despite the efficiency development in silicon solar cells reaching a plateau, they remain a sensible choice for PV systems, providing a balance between cost-effectiveness and performance.

As the project moves forward, the implementation of silicon solar systems should be seriously considered. Their proven track record, widespread availability, and compatibility with existing PV system infrastructure make them a reliable choice for generating renewable energy. However, it is also worthwhile to keep an eye on emerging technologies, such as perovskite solar cells, as they continue to advance and may become commercially viable in the future, offering even higher efficiencies.

4.2 Storage

In this chapter, the different applicable technologies regarding the energy storage system for our user case are evaluated.

There are many different approaches to store electrical energy from renewable energy resources. Of course, in this day of age batteries are one of the first things that comes to mind. It is of important notices however, that there are significant differences in the various battery technologies on the market, and furthermore, alternative storage methods also need to be considered.

In the following sections, we briefly discuss the research areas we focused on, our results and finally we justify our decision made based on our findings. Moreover, additional details on

different energy storage systems can be found, for example, in the book by Sterner and Stadler "Energiespeicher - Bedarf, Technologien, Integration" ¹².

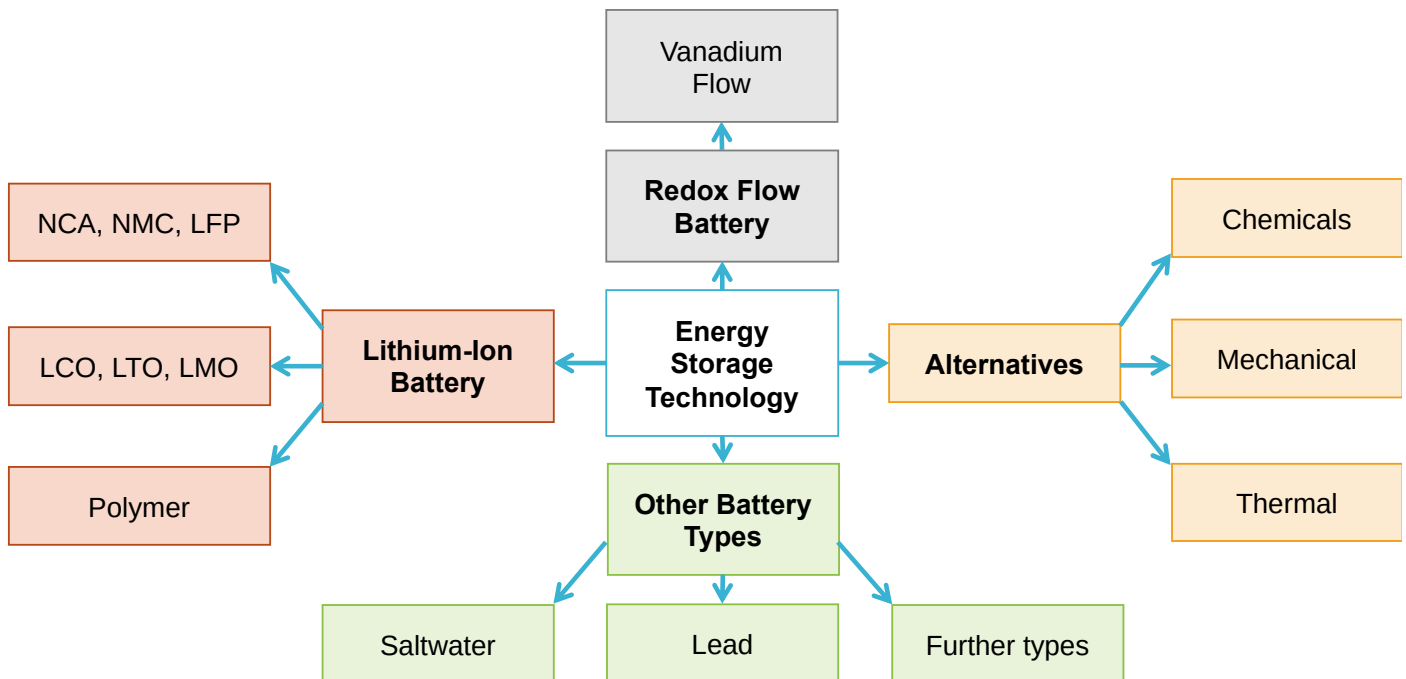


Figure 4.5: Overview over storage technologies

4.2.1 Batteries

How does a battery work? That is another question we asked ourselves in the beginning of our research. Luckily, we had an excellent chemistry student in our group and she explained the basics of battery science to us. A brief summary of our findings in regards to different battery technologies is presented:

Redox-flow-battery

Technology

A redox flow battery (also called a liquid battery) is a type of battery that stores electrical energy through electrochemical reactions in liquids called electrolytes. Unlike conventional batteries where the chemical reactions typically occur within a single cell, the electrochemical reactions in a redox flow battery occur in separate tanks or containers containing the electrolytic solutions. The basic design and operation of a redox flow battery is as follows:¹³

Electrolytic solutions

A redox flow battery consists of two electrolytic solutions stored in separate tanks. Each solution contains chemical compounds (called redox pairs). A redox couple consists of an oxidized form (positively charged, anolyte) and a reduced form (negatively charged, catholyte). Typical redox pairs are, for example, vanadium, zinc-bromide, or iron-chromium.

Electrodes and membranes

A membrane is located between the two tanks to separate the electrolytic solutions. At each side of the battery is an electrode (anode and cathode) made of a conductive material, usually a porous carbon material such as graphite.

¹² Sterner, Stadler: *Energiespeicher – Bedarf, Technologien, Integration*. Springer, 2017, 2. Auflage.

¹³ <https://www.dilico.de/de/redoxflow.php>

Electrochemical reactions

When the redox flow battery is discharged, the electrolytic solution of the anolyte flows across the anode and the electrolytic solution of the catholyte flows across the cathode. At the anode, oxidation of the redox couple takes place, releasing electrons. These electrons flow through an external circuit to the cathode, where reduction of the redox couple occurs, during which electrons are accepted. The electrochemical reaction at the electrodes generates electric current that can be used.

Reaction flow

During the charging and discharging process, the electrolytic solutions are continuously pumped through the battery. This maintains a flow of redox couples through electrolytic solutions. The flow of solutions allows the amount of stored energy in the battery to be increased or decreased regardless of the size of the tanks.

Although this technology is a promising candidate for stationary applications, there are only a few manufacturers, e.g., VRB, Invinity Energy Solutions, Sumitomo electric industries ltd.

Additionally, there are not many big scale operation sites the largest being in Japan (15 MW,16 MWh). Furthermore, it is not suitable for mobility, since the tanks are too big and too heavy.

Advantages

To summarize, the advantages of Redox-flow batteries are:

- does not have the problem of long refuelling times
- high charging power, because the system can be recharged quickly by replacing the electrolytes
- can be used for stationary applications to cover peak loads and load balancing or for uninterrupted power supply
- the unlimited number of cycles within the service life of around 20 years makes redox flow batteries particularly flexible in daily use compared to the limited number of cycles of other battery types

Disadvantages

The main disadvantages to acknowledge:

- not applicable for mobility
- efficiency and the volume to mass-related energy density is lower than that of for example lithium-ion batteries and the space requirement is quite large

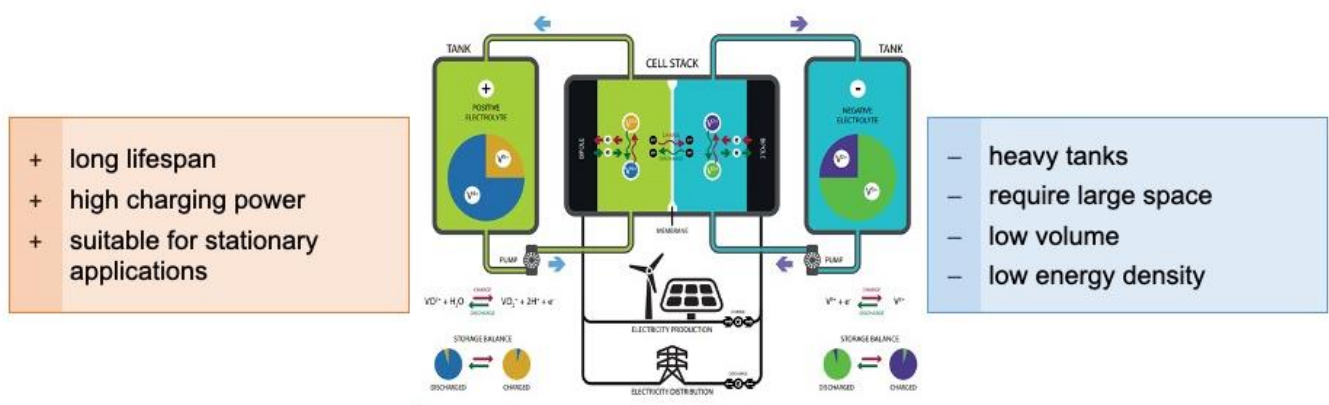


Figure 4.6: Advantages and disadvantages of a redox flow battery¹⁴

¹⁴ <https://www.battery.associates/post/state-of-art-of-flow-batteries-a-brief-overview>

Conclusion

Consequently, we do not consider this battery technology for our use case, because of its large space requirement, heavy tanks, lower volume to mass related energy density and market rareness.

Lithium-Ion Battery

The lithium-ion battery is based on the movement of lithium ions between two electrodes. Lithium-ion batteries are used in a wide range of applications, from portable electronic devices to electric vehicles. The structure is as follows:

Anode

The anode of a lithium-ion battery is made of a conductive material such as graphite, in which lithium is able to intercalate/ can be inserted. During the charging process, lithium ions move from the cathode to the anode and are incorporated into the material of the anode. During the discharge process, lithium ions move from the anode to the cathode.

Cathode

The cathode of a lithium-ion battery is made of a material that is also capable of storing lithium ions. Typical cathode materials are lithium metal oxides, such as lithium cobalt oxide (LiCoO₂), lithium nickel oxide (LiNiO₂), lithium manganese oxide (LiMn₂O₄), a combined oxide LiNiMnCoO₂ or lithium iron phosphate (LiFePO₄). During the charging process, the lithium ions at the cathode accept electrons and form a stable material. During the discharge process, the lithium ions release electrons and migrate back to the anode.

Electrolyte

Between the anode and cathode is an electrolyte consisting of an ionic liquid adept of transporting lithium ions. The electrolyte allows the flow of lithium ions between the electrodes while blocking electron movement. The electrolyte is usually a solution containing a lithium salt, typically LiPF₆ in an organic solvent.

Separator

To prevent a short circuit, a separator is placed between the anode and the cathode. The separator is a porous membrane that separates the electrodes but allows the flow of lithium ions.

Electrochemical reactions

During charging, lithium ions move from the cathode to the anode through the electrolyte. At the cathode, reduction of lithium ions occurs, while at the anode, oxidation occurs. The lithium ions intercalate into the structure of the electrode materials, storing electrical energy in the battery. During the discharge process, the reverse electrochemical reactions take place, with the lithium ions migrating from the anode to the cathode and releasing the stored electrical energy.

Although we evaluated and compared most of the available Li-Ion technologies today such as LCO, NMC, LNCA, LTO, LMO it soon became clear to us that especially the LFP technology is of great interest for our application. When considering a stationary utilization, factors such as safety and a long life span play a more enhanced role than for example an extremely high specific energy or energy density which is needed for the e-car sector.

Li-technologie	rated voltage [V]	specific energy [Wh/kg]	energy density [Wh/L]	life cycles	discharge rate [C]	usable capacity [mAh/g] DOD	rating for our case	additional info
LCO	3,6	200		400 500-1000	1		not usable	mobile applications
polymer	3,6	200		450 300-500			not usable	poor lifetime
LFP	3,2	170		350 >4000	1 or 3	165 80-100%	good choice	environmentally friendly, safest, improvement on density to be expected
NMC	3,6	220		500 2000 2 or 3		170 50-80%	could be a choice	mainly in e-cars, various types (newest NMC811), 2nd life?
LNCA	3,6	250		550 1000 2 or 3		200 50-80%	could be a choice	high energy densities, also used in e-cars, 2nd life?
LTO	2,4 or 2,8	70		177 15000 4 or 8			rather not usable	low energy density, very long life cycle
LMO	3,7	150		350 300-700 1 or 10			not usable	mobile applications

Figure 4.7: Data for different Lithium-Ion battery technologies

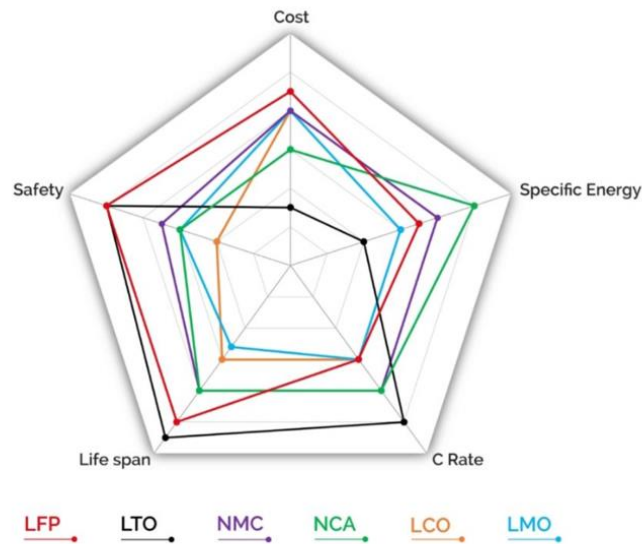


Figure 4.8: Comparison of Lithium Ion battery technologies

Figure 4.7 and Figure 4.8 show a comparison of the different lithium-ion battery technologies when regarding various important characteristics.

Advantages

To summarize, the advantages of the LFP technology are:

- safety
- long cycle life
- depths of discharge (DOD) of 80-100%
- temperature tolerance
- cost-effectiveness
- environmentally friendly (no cobalt; iron and phosphate are abundant/lower environmental impact)

Disadvantages

The main disadvantages to acknowledge:

- higher upfront cost
- lower energy density BUT improvement is expected

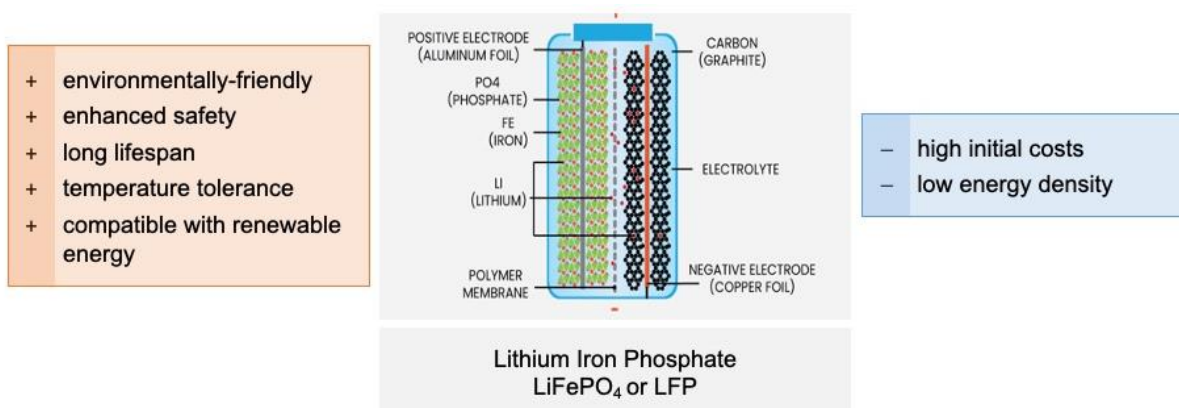


Figure 4.9: Advantages and disadvantages of a Lithium Ion Battery

Conclusion

Due to its advantages and the expected upcoming improvement of the energy density it was decided that this Li-ion battery type is the most suitable for our use case.

4.2.2 Other Battery types

We shortly want to address some other battery types, which were excluded by us early in the research phase:

Saltwater

although non-flammable, environmentally friendly in terms of recycling and materials and a long lifespan, they also show low energy density, higher cost and a low C-rate (0,5C)

Thermal batteries (NaS/ZEBRA)

need heating to operate, small systems have a high self-discharge, are costly, have limited lifespan, but it should be noted that ZEBRA batteries have a high efficiency and energy density

Lead acid

lead is toxic, recycling problematic, lower lifetime and poorer performance than Li technologies

Ni/Cd

Cd is toxic, recycling problematic

NiMHydride

lower energy density, higher self-discharge, limited operating temperature (compared to Li technologies)

4.3 Alternatives

In addition to the battery technologies, we also looked at alternative technologies which can be used to store electrical energy from renewable energy resources.

4.3.1 Chemical

It is possible to store electrical energy chemically. The chemical storage of electrical energy by means of electrolysis and fuel cells takes place in several steps.

Electrolysis

In electrolysis, water (H_2O) is split into its components hydrogen (H_2) and oxygen (O_2). This is done by passing an electric current through an aqueous solution of electrolytes, usually an acid such as sulfuric acid or a base such as potassium hydroxide. Electrolysis takes place in what is called an electrolytic cell, which consists of an anode (positively charged) and a cathode (negatively charged). The electric current splits water into hydrogen (at the cathode) and oxygen (at the anode).

Hydrogen storage

The hydrogen produced can then be used to store electrical energy. Hydrogen is an energy-rich gas and can be stored in various forms, such as compressed gas (at high pressure), liquefied hydrogen (at very low temperatures), or in chemical form (e.g., as a metal hydride). The appropriate form of storage depends on the application requirements.

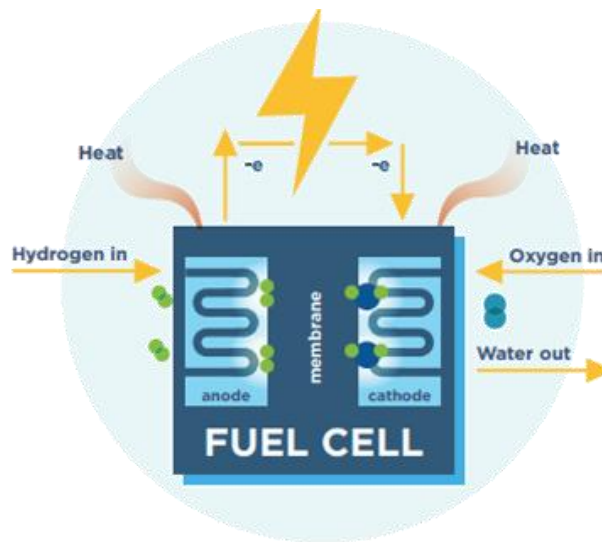


Figure 4.10: Working principle of a fuel cell

Fuel cell

Though, fuel cells and their characteristics were already mentioned in the last chapter we would like to explain more about their function here: To convert the stored energy back into electrical energy, the hydrogen is used in a fuel cell. A fuel cell consists of an anode and a cathode, with an electrolyte between them. When the fuel cell is operated, the hydrogen migrates to the anode and the oxygen (usually from the air) migrates to the cathode. At the anode, the hydrogen is split into protons (H^+) and electrons (e^-). The protons pass through the electrolyte while the electrons flow through an external circuit to the cathode. On their way through the external circuit, the electrons generate electric current that can be used. At the cathode, the protons, electrons and oxygen come together to form water (H_2O) and heat as a byproduct.

Utilization of the oxygen

The stored oxygen can be used for further chemical processes or, for example, in a combustion process in a power plant.

Losses

Regarding overall losses, the following Figure 4.11 is very interesting:

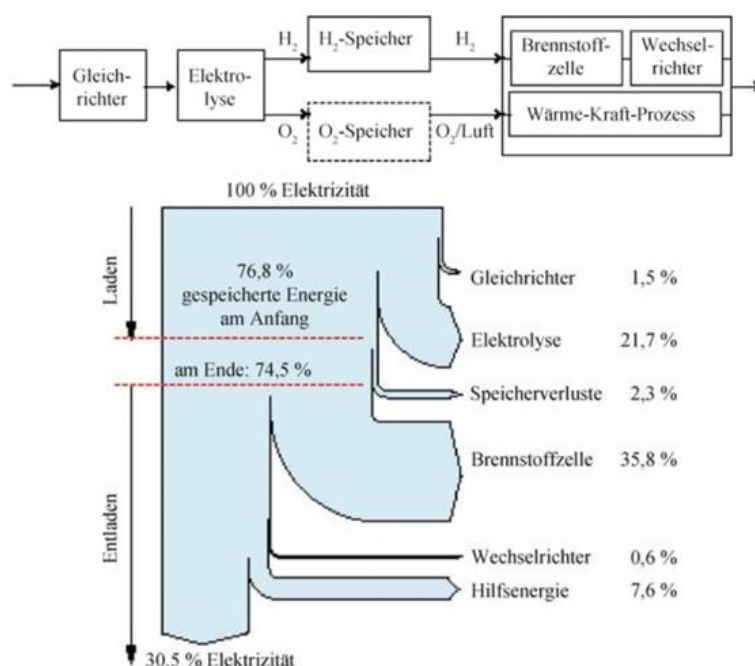


Figure 4.11: Losses in chemical energy storage

Here it can be seen that only less than one third of the electrical energy can be stored in form of chemical energy.¹⁵

Conclusion

Due to poor efficiency, high system costs, lack of infrastructure and a potential safety risk due to large hydrogen storage facilities, this technology is not considered further for our project. However, hydrogen-based technologies are strong in the coming. Although, not applicable for now they should definitely be considered in the future.

4.3.2 Mechanical

Mechanical storage of electrical energy is possible, for example, by means of a flywheel or a pumped storage power plant.

Flywheel

A flywheel works as follows:

A rotor/flywheel is accelerated to a high speed and storing the energy as rotational energy (kinetic energy) and the energy can be extracted by coupling an electric generator to the rotor. Since the flywheel is accelerated by an electric motor, it reaches its energy capacity much quicker than other storage forms. Furthermore, the rotor spins nearly frictionless. This technology is mostly used to balance peak loads, smooth power peaks, increase the power of charging stations for electric vehicles and for uninterruptible power supply.

The mentionable advantages of a flywheel are:

- maintenance is cheaper (and seldom) than for traditional battery systems (0,5 the cost of traditional battery UPS systems)
- long-life span (up to 100.000 to 175.00 full depth discharge cycles)
- negligible environmental impact & no carbon emissions
- Further advantages over chemical energy storage:
- high energy density
- substantial durability → can be cycled frequently with no impact to performance
- also have very fast response and ramp rates
- flywheel energy storage systems are increasingly important to high power, relatively low energy applications

Flywheels are already used in uninterruptible power supply, aerospace, test laboratories, motor sports, wind turbines, and the transportation sector (experimentally).

The disadvantages are:

- limited energy storage time of around 15 minutes
- better suited for quick applications

Therefore, it is not suitable for our use case.

Pumped storage power plant

A pumped storage power plant is a very old and well-known technology for both storing and generating electrical energy. When a surplus of electricity transpires, a pump is operated to raise water to a higher level (into a reservoir). Assessed accurately, this electricity can then be converted into potential energy. If an increased demand for electricity is registered, the water can be brought back to the lower level, driving a turbine, which are specially designed for this

¹⁵ Zahoransky: Energietechnik. Systeme zur Energieumwandlung. Springer Vieweg, 2019, 8. Auflage.

system, such as the Pelton turbine. The mechanical energy is converted into electrical energy via the turbine and an attached generator. Pumped-storage power plants are extremely important for grid stability, precisely because they have black-start capability. This means that they can release the stored energy without any additional energy supply.

The disadvantage is the large infrastructure that is required for them involves structural intervention in the surrounding area.

Since this form of storage is too complex for a truck depot, the technology will not be considered further.

Compressed Air Storage

Storing energy in a compressed air storage is going hand in hand with a gas turbine power plant. Energy is stored as compressed air underground. It is commonly used for grid control: when more electricity is produced than consumed, energy is used to pump air under pressure into a storage facility. Then when electricity is needed, the compressed air is used to produce electricity in a gas turbine.

The challenge is the management of thermal energy. The compression of air leads to an unwanted temperature increase (reduces efficiency and can lead to damage), while the decompression of air leads to cooling. Therefore, the turbine needs to be heated by burning gas during the decompression to prevent it from icing up.

The energy storage efficiency depends on the gas and electricity as input values (60-70%), for instance: The generation of 1 kWh of electrical energy requires 0.8 kWh of electrical energy and 1.6 kWh of gas.

As it is a big infrastructure project and not too promising, we are not looking further into that technology.

4.3.3 Thermal

Thermal storage of electricity is a method of storing surplus electrical energy in the form of heat in order to convert it back into electricity at a later date. There are two types of thermal energy storage: latent heat storage and sensible heat storage.¹⁶

Latent heat storage

In latent heat storage, excess electrical energy is used to heat a material and convert it to a latent state where it can absorb large amounts of thermal energy in the form of phase change heat. A typical example of a latent heat storage system is a heat storage tank containing a phase change material (PCM) such as kerosene or salt hydrate. These materials have the advantage of being able to melt or solidify at relatively low temperatures, allowing large amounts of heat to be stored. When the storage tank is charged, the PCM is heated and melts by heating elements or by direct introduction of hot water or steam. The heat released in the process is then stored. When the accumulator is discharged, the stored PCM is cooled again and solidifies, releasing the stored heat energy. This released heat can then be used to generate steam, which in turn drives a turbine to generate electrical power.

Sensitive heat storage

Sensible heat storage uses excess electrical energy to directly raise the temperature of a material and store thermal energy in the form of temperature-dependent heat capacity. Typical

¹⁶ Sterner, Stadler: *Energiespeicher – Bedarf, Technologien, Integration*. Springer, 2017, 2. Auflage.

materials for sensible heat storage are water, oil or air. In a sensible heat storage system, the medium, for example water, is heated by electrical heating elements or heat exchangers. The thermal energy is stored in the medium and released when needed by passing the hot water through a heat exchanger to produce steam, which then drives a turbine to generate electricity.

Unfortunately, thermal energy storage is not suitable for our application due to poor efficiency and high expense.

4.4 Battery calculation

In order to obtain a brief overview of our energy storage and harvest system's requirements regarding size, capacity and cost we conducted a few rounds of first calculations based on a simple scenario, assuming no access to a grid connection. We calculated the energy required to charge 10 Long Haul, eActros 400 or 300 Trucks respectively from a 20-80% state of charge and according to that determined the required the PV arrays and battery system's exact capacity and size while also considering possible losses and charging efficiencies and including a safety margin. Losses to consider include the 2-7% for every energy conversion and the ones caused by the efficiencies of each component as well as the self-discharge of the battery. We then additionally repeated these rounds of calculations with various numbers of charging cycles and implementing a grid availability, while making first cost estimations for the battery energy storage in general, its installation and maintenance. The according PV calculations were done using a Python program. More on that can be found in the section about our tool.

Here the results of the first round of calculations can be seen. The EnerC LFP BESS model from CATL was used as a first approximation for the storage system for conducting the calculations:

Table 4.1: First calculations

	No of trucks	Energy consumption of each truck	Battery capacity	charging efficiency	Toatal energy required to charge the trucks	Total energy stored in the battery	Number of stacks required	Needed surface
1	10	600kWh	2.980kWh	3600kWh	$10 \cdot 600 \text{kWh} \cdot 0.6 = 3600 \text{kWh}$	$((3600 \text{kWh} \cdot 1.1) \cdot 3) \cdot 1.2 = 14256 \text{kWh}$	$14256 \text{kWh} / 2980 \text{kWh} = 4.784 \sim 5$	$5 \times 14,915 \text{ m}^2 = 74,574 \text{ m}^2$ of surface
2	10	448kWh	2.980kWh	2688kWh	$10 \cdot 448 \text{kWh} \cdot 0.6 = 2688 \text{kWh}$	$((2688 \text{kWh} \cdot 1.1) \cdot 3) \cdot 1.2 = 10644,5 \text{kWh}$	$10644,5 \text{kWh} / 2980 \text{kWh} = 3,572 \sim 4$	$4 \times 14,915 \text{ m}^2 = 59,66 \text{ m}^2$ of surface
3	10	336kWh	2.980kWh	2016kWh	$10 \cdot 336 \text{kWh} \cdot 0.6 = 2016 \text{kWh}$	$((2016 \text{kWh} \cdot 1.1) \cdot 3) \cdot 1.2 = 7983,36 \text{kWh}$	$7983,36 \text{kWh} / 2980 \text{kWh} = 2,679 \sim 3$	$3 \times 14,915 \text{ m}^2 = 44,745 \text{ m}^2$ of surface
					1: Long Haul	2: eActros 400	3: eActros 300	

The following tables show the calculation results with an available grid connection left one being for the eActros 300 and the right one for the Long Haul:

Table 4.2: Calculations for eActros 300 and LongHaul

Grid Availability Percentage for charges overall	0,4 %	Grid Availability Percentage for charges overall	0,4 %
Number of whole Charges needed	13	Number of whole Charges needed	13
Energy Consumption per truck	336 kWh	Energy Consumption per truck	600 kWh
charging from 20%-80%	0,6 %	charging from 20%-80%	0,6
Total Energy required from BESS to charge trucks	1572,48 kWh	Total Energy required from BESS to charge trucks	2808 kWh
		losses of converter/charging efficiency	10,00%
losses of converter/charging efficiency	10,00%	number of charging cycles	2
number of charging cycles	2 range(1,3)	safety margining	10,00%
safety margining	10,00% range(5-25)	Needed energy storage capacity	6795,36 kWh
Needed energy storage capacity	3805,4016 kWh		
		Battery capacity with 80% DOD	2980 kWh
Battery capacity with 80% DOD	2980 kWh	Number of Units required	2
Number of Units required	1		
total energy required to charge trucks overall	2620,8 kWh	total energy required to charge trucks overall	4680 kWh
Energy percentage covered by BESS	0,6 %	Energy percentage covered by BESS	0,6 %
total losses of the battery system	157,248 kWh	total losses of the battery system	280,8 kWh
safety margining	172,9728 kWh	safety margining	308,88 kWh
Surface of one Unit	14,915 m ²	Surface of one Unit	14,915 m ²
Total Surface required	14,915 m²	Total Surface required	29,83 m²
Cost estimation Stationary BESS per kWh	350 €	Cost estimation Stationary BESS per kWh	350 €
Cost estimation only for BESS overall	1331890,56 €	Cost estimation only for BESS overall	2378376 €
Cost estimation for installations per kWh	45 €	Cost estimation for installations per kWh	45 €
Cost estimation for BESS overall installation	171243,072 €	Cost estimation for BESS overall installation	305791,2 €
Cost estimation overall rounded	2000000 €	Cost estimation overall rounded	3000000 €
for yearly maintenance assuming 1% of invest	20000 €	for yearly maintenance assuming 1% of invest	30000 €

As one can see, the total energy and surface required, as well as the overall costs change significantly when looking at different truck designs, grid availability and number of charging cycles required.

For the sake of simplicity and effortless operation it was decided to merge the calculations regarding the battery system and the PV array together into the Python program. For further information and results concerning this topic see the section regarding the tool.

4.5 Harvest-Storage System Combination

Depending on the scenario and user case different arrays of the whole system are possible:

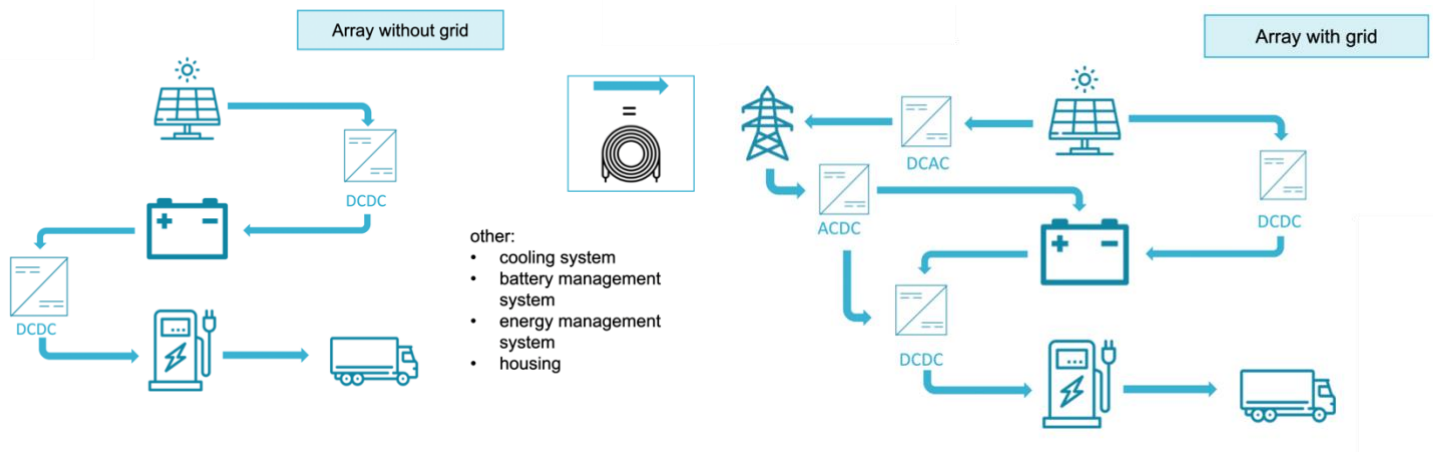


Figure 4.12: Components needed for the whole system

Furthermore, components needed overall include:

PV system

- PV modules¹⁷
- PV fundamental construction¹⁸
- cables¹⁹

Converter system

- depending on scenario at least two DC/DC converters or inverters, for charging as well²⁰
- cables
- DC/AC converters from/for grid and a bi-directional counter

Charger station

- depending on charging from grid, battery, both

Battery system

- battery packs
- cooling system
- battery management system
- energy managing system
- housing
- (usually implemented in whole products: product used for calculation CATL EnerC²¹)

General information about an energy storage system was found here:

<https://www.energytoolbase.com/newsroom/blog/the-primary-components-of-an-energy-storage-system-that-you-need-to-know>

¹⁷ <https://www.photovoltai4all.de/solarmodule-?p=1>

¹⁸ <https://www.photovoltai4all.de/montagesysteme/?p=1>

¹⁹ <https://www.photovoltai4all.de/elektro/kabel-leitungen?p=1>

²⁰ <https://www.photovoltai4all.de/pv4all-insel/dc-dc-wandler/>

²¹ CATL: Storing Infinite Energy - Energy Storage System Solutions and Products. ESS Brochure, 02/2023.

4.6 Conclusion

In conclusion, based on the comprehensive analysis of the pros and cons of the considered technologies, the most promising options as a solution for DTAG e-truck costumers to decentralized produce renewable energy to charge their trucks are PV systems with silicon cells in combination with lithium-ion batteries, specifically LFPs. These systems offer a range of advantages, including scalability, market readiness without complicated regulations and long lifespans. Additionally, the compatibility of silicon solar cells and lithium-ion batteries make them a reliable and efficient choice for energy harvesting and storage.

While perovskite PV cells and vertical wind turbines and hydrogen-based technologies show potential for future development and may offer additional benefits, their current limitations and market readiness make them more suitable for consideration in the coming years.

Therefore, the business plan created by FEMTEC Innolab will primarily focus on PV systems with silicon cells in conjunction with lithium-iron-phosphate batteries, ensuring a sustainable and reliable energy solution for the project.

Phase 2

Considering the research results regarding the future technologies (advanced solar and wind technologies as well as advanced lithium-ion batteries, sodium-ion batteries, and hydrogen-based technologies), which are holding big potential for the DT use case for 2035, we continued to work on further investigation in Phase 2

Furthermore, the application of second-life batteries offers many benefits while simultaneously posing various challenges, like will be described in the according chapter. In order to make decisions for a successful business plan, it is important to examine the key factors for cost effectiveness in regard to second-life batteries for energy storage applications in comparison to new batteries and/or recycling. Further information on this specific topic will be provided later. Careful consideration is essential for successful implementation of second-life batteries and overall, second-life batteries offer a promising avenue for extending the usefulness of retired EV batteries and contributing to a more sustainable energy ecosystem.

Additionally, the extension of the use of Smart Charging will enable DT to optimize the energy efficiency, reduce the costs of charging, minimize the impact on the power grid and manage the distribution of renewable energy. An idea of how a Smart Charging Algorithm could look like was developed and can be seen in the according chapter.

To summarize the results, there are interesting technologies in the coming and they should be kept in mind when making decisions for the future. Second Life Batteries could be the key to a successful business plan and Smart Charging offers a big potential for price and grid optimized charging.

To recall, based on the comprehensive analysis of the pros and cons of the considered technologies, the most promising options as a solution for DTAG e-truck costumers to decentralized produce renewable energy to charge their trucks are PV systems with silicon cells in combination with lithium-ion batteries. These systems offer a range of advantages, including scalability, market readiness without complicated regulations and long lifespans. Additionally, the compatibility of silicon solar cells and lithium-ion batteries make them a reliable and efficient choice for energy harvesting and storage.

While perovskite PV cells and vertical wind turbines show potential for future development and may offer additional benefits, their current limitations and market readiness make them more suitable for consideration in the coming years. Therefore, the business plan created by FEMTEC

will primarily focus on PV systems with silicon cells in conjunction with lithium-ion batteries, ensuring a sustainable and reliable energy solution for the project.

4.7 Outlook

In Phase 2 of this Innovation Project, the objective of the tech team was to conduct a more in-depth analysis of the technologies expected to enter the market by the year 2035. Overall, making predictions for the future is challenging due to the very rapidly evolving nature of the field regarding energy storage and harvest technologies. However, based on current trends and research a few potentially promising technologies can be listed.

4.7.1 Energy Harvest Systems

In terms of energy harvesting there are especially three different types of technologies that are predicted to evolve until 2035: Advanced Solar technologies, Advanced Wind turbines and Solid-State Energy Harvest.

In the field of Advanced Solar technologies, we anticipate the emergence of various solar cell types, including perovskite, multi-junction, and tandem solar cells. Additionally, the integration of photovoltaic (PV) systems into building materials will become a prominent topic. These technologies promise a range of benefits, such as enhanced efficiency, increased durability, and cost reduction.

The area of wind turbines is also poised for remarkable progress. Design advancements will result in the proliferation of vertical-axis wind turbines, floating wind turbines, and combined arrays incorporating solar technologies. These innovations will yield similar advantages to those observed in the PV sector, including improved efficiency and cost reduction. The integration of wind and solar technologies in combined arrays holds immense potential for maximizing energy generation and ensuring a consistent power supply.

Another promising technology in the coming are solid-state energy harvesting materials. These innovative technologies such as advanced thermoelectric, electromagnetic, or piezoelectric materials are said to be able to convert waste heat, ambient radio waves, and vibrations into electricity.

In the context of decentralized energy supply only the first two innovations are assumed as overly interesting.

4.7.2 Energy Storage Systems

In the field of energy storage technologies, numerous advancements are expected by 2035, encompassing diverse approaches to address the growing demand for efficient and reliable energy storage solutions. The following developments hold significant promise:

Advanced Lithium-Ion Batteries: The evolution of lithium-ion batteries will continue, incorporating innovations such as silicone anodes, solid-state electrolytes, and new anode materials like Lithium Manganese Iron Phosphate (LMFP). These advancements will yield improvements in safety, higher energy density, longer lifespan, and reduced costs. The enhanced performance of advanced lithium-ion batteries will facilitate their integration into various applications, ranging from portable electronics to electric vehicles and grid-scale energy storage systems.

Sodium-Ion Batteries: Sodium-ion batteries are poised to emerge as a compelling alternative to lithium-ion batteries. They offer a cheaper and more abundant alternative, as sodium is more

readily available compared to lithium. Furthermore, advancements in solid-state sodium-ion battery technology will enhance their efficiency, safety, and overall performance.

Hydrogen-Based Technologies: Hydrogen fuel cells and related technologies are expected to play a significant role in the storage of renewable energy. Hydrogen, a versatile and abundant element, can be produced through various renewable sources and stored efficiently. Fuel cells enable the conversion of hydrogen into electricity, providing a clean and sustainable power source. The continued development of hydrogen-based storage solutions will enable the utilization of surplus renewable energy and contribute to a more resilient and decarbonized energy system.

Advanced Redox Flow Batteries: Redox flow batteries exhibit potential for long-duration and scalable energy storage applications, particularly for grid-scale deployments. These batteries employ liquid electrolytes that facilitate the flow of charged species, providing flexibility in terms of capacity and power output. Ongoing advancements in redox flow battery technology will enhance their efficiency, durability, and cost-effectiveness, making them suitable for large-scale energy storage requirements.

Metal-Air Batteries: Metal-air batteries, particularly lithium-air and zinc-air batteries, hold promise for achieving higher energy densities. These batteries utilize oxygen from the air as one of the reactants, resulting in a higher energy-to-weight ratio. The development of metal-air batteries will enable the storage of more energy within a smaller footprint, enhancing their viability for portable electronics, electric vehicles, and other energy-intensive applications.

Thermal Energy Storage: Thermal energy storage offers a unique approach by harnessing and storing thermal energy generated from renewable sources or waste heat. This stored energy can be utilized later for heating, cooling, and power supply, contributing to overall energy efficiency. Advancements in thermal energy storage technologies will enhance their capacity, efficiency, and flexibility, enabling better integration with renewable energy systems and supporting diverse heating, cooling, and power requirements.

In the context of our project the advanced lithium-ion batteries, sodium-ion batteries, hydrogen-based technologies and perhaps the advanced redox flow batteries are considered as interesting technology options for the future.

4.7.3 Second Life Batteries

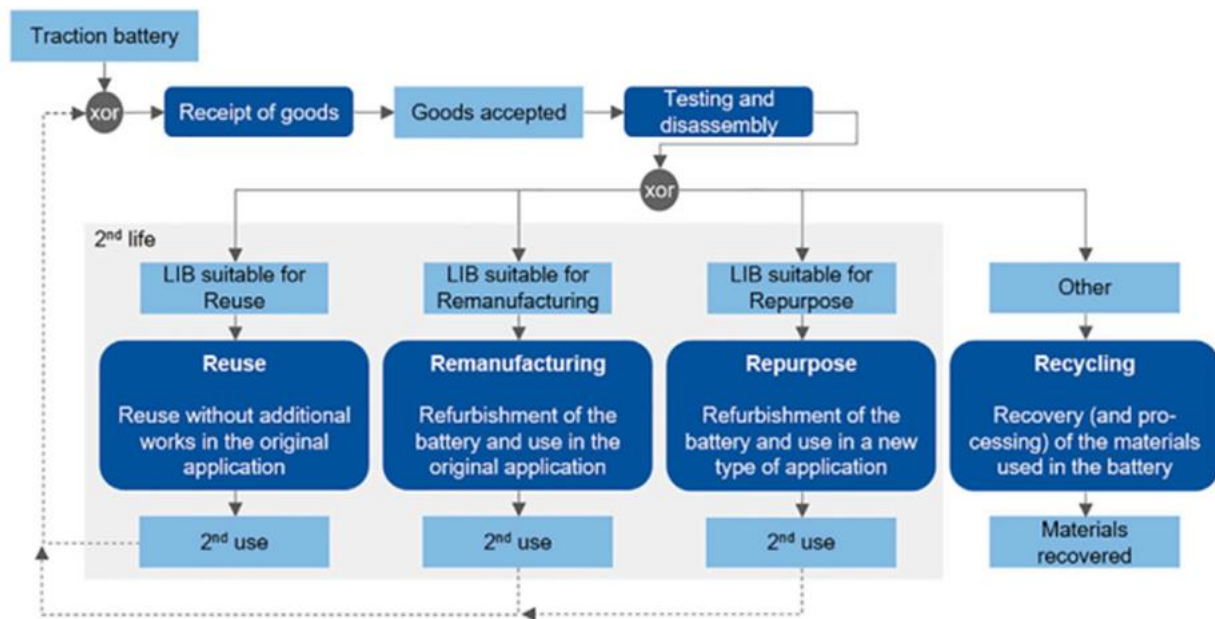


Figure 4.13: Concept of second life of batteries

The concept of second-life batteries arises from the fact that even after being removed from EVs, these batteries can still serve a useful purpose in stationary energy storage systems. While their capacity might have degraded compared to when they were new, they can still store a substantial amount of energy. Once EV batteries degraded to 70–80% of their initial capacity, EV owners will have to replace the EV's batteries as the residual capacity becomes insufficient for automotive use.

Battery technology has witnessed significant advancements, leading to the emergence of second-life applications. The following graphic shows the process of second life determination. Retired batteries need to be tested, disassembled and then categorized into one of the 4 categories: Reuse, Remanufacturing, Repurpose, Recycle. The focus of the following section lies in repurposing the batteries of retired electric vehicles in various other applications, extending their lifespan beyond their initial use.

While this approach brings several advantages, it also presents challenges that need to be addressed. This section of the report discusses the advantages of technology for our use case, along with the associated disadvantages and challenges.

Advantages

1. **Waste Management and Zero Waste:** Second-life applications contribute to waste management efforts by extending a product's life cycle. By repurposing retired EV batteries, we can reduce waste and promote a more sustainable approach.
2. **Environmentally Friendly Battery Manufacturing:** Utilizing second-life batteries reduces the need for manufacturing new batteries, resulting in a more environmentally friendly process. This approach conserves resources and minimizes the environmental impact associated with battery production.
3. **Peak Shaving and Load Shifting:** Second-life batteries can be employed in smart charging systems to stabilize the grid. By charging batteries during off-peak hours and utilizing their stored energy during peak demand, we can prevent power demand spikes and ensure a more balanced distribution of electricity.
4. **Lower Investment Costs for Electricity Storage:** Incorporating second-life batteries into energy storage solutions reduces investment costs. By distributing the cost burden, this

approach presents business opportunities and makes electricity storage more financially viable.

5. **Building a Green Image:** From a marketing perspective, engaging in second-life applications can enhance a company's environmental image. Embracing sustainable practices and showcasing a commitment to green initiatives can attract environmentally conscious customers and stakeholders.
6. **Collaborative Opportunities:** Many automotive companies have already partnered with battery manufacturers and electricity companies to explore second-use applications. Following suit, Daimler can leverage collaborations to gather valuable experience and further develop its presence in this growing market.

Associated Challenges

1. **Safety Requirements:** Implementing second-life batteries requires strict adherence to safety protocols. The handling, transportation, and installation of retired batteries must meet stringent safety standards to mitigate potential risks.
2. **Unclear Warranties and Liability:** Determining warranties and liability for second-life batteries remains a challenge. Clear guidelines need to be established to define the responsibilities of manufacturers, users, and other stakeholders involved in the second-life battery ecosystem.
3. **Status of Retired Batteries:** Assessing the condition and performance of retired batteries can be challenging. Proper testing and evaluation protocols must be developed to ensure the reliability and suitability of batteries for second-life applications.
4. **Mismatch of Requirements:** Batteries optimized for vehicle range and charging speed may not align with the requirements of second-life applications. The design and performance of batteries must be tailored to meet the specific demands and lifetime expectations in their second-use scenarios.
5. **Regulatory and Testing Standards:** To facilitate the adoption of second-life batteries, regulations and testing standards need to be developed and regularly updated. Standards such as UL 1974 and IEC 62933-5-3 address the safety and performance evaluation of used battery systems and should be considered in the development of a comprehensive regulatory framework.
6. **Competition with New Battery Cells:** Companies engaged in second-life applications face competition from competitors using new battery cells and modules. Balancing cost-effectiveness, performance, and environmental benefits will be crucial in positioning second-life batteries as a viable alternative.

Cost effectiveness

This report highlights the key factors to consider in evaluating the cost-effectiveness of second-life batteries for energy storage applications. It is of great need to differentiate between the use of 2nd life batteries in comparison to new batteries and/or recycling.

If we are looking at the first scenario, where the 2nd life battery competes against a new one in terms of cost-effectiveness, the following aspects are relevant.

1. **Initial Cost:** Second-life batteries are typically available at a lower initial cost compared to new batteries. However, the exact price difference can vary based on factors such as the condition, age, capacity, and availability of the second-life batteries. A thorough assessment of pricing options is essential to determine the potential cost savings.
2. **Remaining Capacity:** Second-life batteries may have reduced capacity compared to new batteries due to their previous usage in EVs. Assessing the remaining capacity, condition, and requirements of the intended application is crucial. Lower capacity can affect the

performance and overall efficiency of the energy storage system, which must be considered in the cost-effectiveness evaluation.

3. **Lifespan:** Second-life batteries may have a shorter remaining lifespan compared to new batteries. This factor needs to be considered as it may require earlier replacement or refurbishment, which can affect the overall cost-effectiveness of the system.
4. **Performance and Warranty:** Second-life batteries may not have the same level of warranty coverage as new batteries. Additionally, their performance and reliability can be more uncertain. Detailed assessment and testing of the second-life batteries are necessary to understand their performance characteristics and potential risks associated with their use.
5. **Total Cost of Ownership:** Evaluating the cost-effectiveness of second-life batteries requires considering the total cost of ownership over the system's expected lifespan. This includes initial costs, capacity degradation over time, maintenance requirements, potential replacement costs, and any additional expenses associated with integrating the batteries into the system. A comprehensive analysis of these factors is essential to make an informed cost-effectiveness assessment.

Of course, additional considerations should be made taking into account the specific circumstances such as the budget, performance requirements, available options, and the risk tolerance of the company.

Following, we are looking at the key factors that determine the cost-effectiveness of 2nd life battery application in comparison to recycling.

1. **Recycling Costs:** Recycling costs vary depending on factors such as battery chemistry, size, recycling processes, transportation, and handling costs. These costs need to be compared with the cost of utilizing second-life batteries to determine the most economically viable option.
2. **Second-Life System Costs:** The cost of refurbishing, testing, and integrating second-life batteries into the energy storage system should be considered. This includes labor, equipment, and any necessary modifications to the batteries or the system itself.
3. **Remaining Battery Life:** The remaining life of the battery should be assessed to ensure that the benefits of utilizing second-life batteries outweigh the costs, taking into account their potential lifespan limitations.
4. **Market Demand and Prices:** The market demand for second-life batteries influences their prices. Evaluating the current market conditions and pricing trends is crucial in determining the cost-effectiveness of utilizing second-life batteries.
5. **Environmental Considerations:** Choosing recycling options for batteries aids responsible waste management and resource recovery. While recycling costs are incurred, they can be viewed as an investment in sustainable practices and the recovery of valuable materials.

Other important factors are the specific battery chemistry, the local recycling infrastructure, market conditions, project requirements as well as the goals of the company.

4.7.4 Smart charging

Smart charging refers to a charging system where electric vehicles, charging stations and charging operators share data connections. Through smart charging, the charging stations may monitor, manage, and restrict the use of charging devices to optimize energy consumption.

The extension of the use of Smart Charging will enable Daimler Truck to optimize the energy efficiency, reduce the costs of charging, minimize the impact on the power grid and manage the distribution of renewable energy.

Smart charging systems leverage software and communication technologies to establish a seamless connection between electric vehicles (EVs) and the electricity grid. By doing so, they empower EVs to charge at optimal times, taking advantage of the lowest electricity prices and surplus capacity on the grid.

Within the Innolab, Femtec has developed an idea for an algorithm with the goal of optimizing the charging for trucks, focusing on minimizing costs while considering specific load curves. This algorithm not only optimizes the usage of electricity from the grid but also the utilization of storage facilities. The primary aim is to ensure that the costs incurred by customers for charging their trucks are minimized, providing them with the most cost-effective solution.

Objective: $\min(Z)$

$Z = \text{costs} - \text{revenues}$

$\text{Costs} = \sum (\text{source_price_per_kWh} * \text{energy_amount_source_needed})$

$\text{Revenues} = \text{price_per_kWh} * \text{sold_electricity}$

The following diagram is visually representing the input parameters and the application of the algorithm.

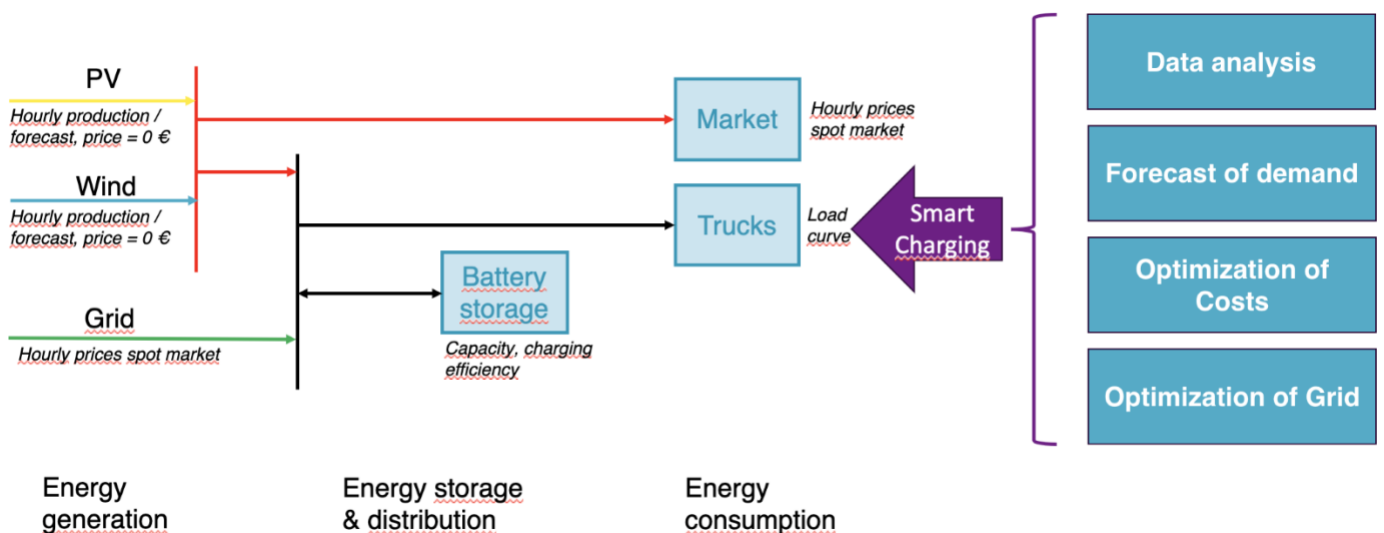


Figure 4.14: Input parameters and algorithm for Smart Charging

On the left side of Figure 4.14, the electricity generation is depicted. The developed solution for DT's customers considers renewable energy generation in the form of PV or wind generation. Customers also have the option to use electricity from the grid. In the middle of the system, we have energy storage and distribution. Electricity can either be stored in battery storage or distributed to consumers. On the right side of the diagram, electricity consumption is shown. The main consumers in our use case are the e-Trucks that need to be charged. Surplus electricity can be sold on the electricity market.

Firstly, the basics of energy system modelling without consideration of smart charging are explained. In the depicted energy system, electricity generated from renewable sources can be utilized in two ways: charging the trucks or storing it in the battery, along with the option to sell any excess electricity to the market. To effectively model this system, several input parameters are required:

- Load curve of electricity demand.

- Hourly PV production forecast.
- Hourly wind production forecast.
- Forecast of Electricity prices from the spot market.
- Storage capacity
- Storage charging and discharging efficiency.

In this model, renewable energy is assumed to have a price of 0 €.

To satisfy the electricity demand, the optimizer analyzes different options for each time step and selects the most cost-effective solution. For instance, utilizing renewable electricity directly would be the ideal scenario. However, if the generated energy is insufficient to meet the demand, the stored electricity can be utilized, or electricity from the grid must be purchased.

When we include Smart Charging to this modelling approach, we don't want to give a fixed demand curve as input data, but rather some parameters and variables that lead to a range in which the demand needs to be at each point of time, combined with the information about how much energy is needed in total.

In the following section, our concept for the smart charging algorithm is explained.

The first crucial step is data analysis, where all available data is collected, including vehicle information, electricity prices, and electricity availability from the grid and renewable sources. To forecast demand, historical data, patterns, deep learning or statistical methods, and factors such as driving behavior and planned routes are taken into account. The demand forecast does not yield a fixed demand curve but provides a range of potential demand for each time point. This range serves in combination with the total energy needed as input for the cost optimization process. In the cost optimization phase, the electricity prices are considered to determine the most cost-effective charging times. Additionally, constraints like truck departure times are taken into consideration. The optimization of the grid follows, aiming to evenly distribute the charging operations and avoid peak loads or bottlenecks.

Considering all the preceding steps, a vehicle charging plan can be formulated. The goal is to find the optimal balance between costs and grid optimization. The output of the smart charging algorithm is an individualized charging plan for each vehicle, considering variables such as the current state of charge, expected energy demand, optimal tariff times, and grid load.

4.7.5 Conclusion

When making decisions for the future, it is crucial to consider upcoming technologies that have the potential to shape the industry and ramp up the game of energy harvesting and storing applied sciences. Two additionally notable technologies that were discussed in depth in this report are second life and smart charging. Incorporating these technologies into a business strategy has promising prospects. Moreover, the topic of smart charging offers big potential for price and grid optimized charging, leading to a more efficient use of resources.

5 Regulations, Market & Finance

5.1 Tasks and Goals

For the first phase, the following steps were planned to be carried out:

1. Definition of target market → customer oriented
2. Market analysis (including market size, competitors and entry barriers)
3. Regulations overview (border to technology department)
4. Profitability model (consultancy)

Accordingly, it must be researched how the current market in which Daimler Truck operates is divided up and which reactions are to be expected in this market for the next relevant years. Furthermore, it must be analyzed which model of financing is to be selected for the provision of the charging infrastructure.

Much of the relevant information was taken from the listing prospectus of Daimler Truck, which was published as part of the IPO. Among other things, information on the financial structure, current strategic partnerships, risks, and regulations affecting Daimler Truck.

The subteam “Regulations and market” planned to do research on law and subsidy regulations, market situation and public acceptance for the target markets now as well as a little bit of risk management. The results will be part of the benefit analysis (Nutzwertanalyse) and risk analysis. It is tried to estimate the situation for the technologies for the year 2035 as well, depending on the current information.

The subteam “Finance” aimed to create an excel regarding the calculation from the customer point of view. For a further comparison between the technologies, it was planned to create a benefit analysis (Nutzwertanalyse) between Photovoltaic and Windpower, as well as between battery solution without grid and batterie solution with the grid.

For the profitability model a risk and chance model, as a SWOT Analysis is planned, so the solutions from Daimler Truck perspective like leasing, renting or only consulting can be compared.

Based on the findings in the first phase, it is planned to elaborate these in detail in the next phase and to develop fixed models and calculations.

For the second phase, the Regulations, Market and Finance team determines an overview of the regulations and the financial calculations of CAPEX and OPEX for the technical solutions for the different scenarios (see *Scenarios*) from a customer’s point of view. The biggest challenge for DTAG is a very expensive depot infrastructure for decentralized energy supply. Thus, DTAG customers (further only customers) meet liquidity problems to buy the whole depot solution for charging their trucks from decentralized energy at once. Therefore, we filter the highest cost factors of the depot infrastructure solution for each scenario. Furthermore, our team has researched various financial models like leasing, renting, white labelling, contracting and pay per service models and how these models could be of use for this problem. As a result of the research the team has formulated two solutions. The customer can choose either of them to avoid paying the entire cost for the depot upfront.

- Renting/Leasing models (for highest cost factor - components)
- Pay per use – model (investors are required)

The characteristics of the two models and the role of DTAG in both these models are analyzed. DTAG’s interaction in the value chain of decentralized energy supply of the depot is integrated into the Business model. Moreover, the key partners for the two solutions are also investigated

and CAPEX, OPEX, revenue streams, key partners, key activities and key resources from DTAG perspective are described.

The documentation for the business model is created together with the Scenario team in the last part of this report, Chapter *Business Model*.

5.2 Prospectus Daimler Truck

The following information was summarized and filtered from the prospectus and kept in mind for the further process.

5.2.1 General Risks

DTAG is dependent on the general economic development, in particular on the development of the commercial vehicle markets. A deterioration in economic conditions or a recession could adversely affect demand for commercial vehicles and thus reduce Daimler Trucks revenues and earnings.

The company operates in a highly competitive market and faces intense competition from other commercial vehicle manufacturers as well as new market entrants, especially in the field of electromobility. This could reduce DTAG market share and put pressure on margins. DTAG is highly dependent on the development and introduction of new technologies, especially around electromobility. A delay or misguided development in technology could have a negative impact on the competitiveness and growth of Daimler Trucks & Buses.

Daimler Trucks is affected by many regulations and laws, especially in environmental and emissions regulations as well as labor and social regulations. Changes or tightening of these regulations could lead to additional costs and a delay in the introduction of new technologies. The success of Daimler Trucks also depends on the reputation of the company and its products. Negative press, especially in connection with product defects or regulatory violations, could affect the image of Daimler Trucks & Buses and reduce the confidence of customers and investors in the company.

5.2.2 Market

The company has a strong market position in Europe and North America and also operates in Asia, Africa and North America. Daimler Truck is striving to expand its leadership position in the field of electric commercial vehicles and plans to have fully CO₂-neutral production in Europe and North America by 2030.

The company is also active in the field of automated driving systems and plans to offer Level 4 driving functions on selected highways in Europe and North America by 2024. To counter these challenges, DTAG has taken a variety of measures, such as cost reductions, product innovations and strategic partnerships.

5.2.3 Strategic Partnerships

There is a partnership with Waymo, a company that specializes in autonomous driving. Under the collaboration, trucks from Daimler Truck will be equipped with Waymo's technologies to enable Level 4 driving functions. For our use case, it is not relevant.

The partnership with battery manufacturer Contemporary Amperex Technology (CATL) for development and manufacturing battery systems for electric commercial vehicles is relevant. There are also partnerships with the electric mobility company Proterra to advance the development of electric vehicles and charging infrastructure. The partnership with Shell subsidiary NewMotion is to facilitate the charging of electric commercial vehicles. The

collaboration with Volvo Group and Daimler Truck to jointly develop and produce hydrogen-based fuel cell systems for heavy commercial vehicles plays a considerable role in our use case.

5.2.4 Financial information

Daimler Truck AG plans to invest around 70% of its capital expenditure in electric and hydrogen trucks and related infrastructure by 2025. The company also plans to invest in the areas of digitalization and automated driving.

5.3 Regulations overview

In this following subchapter, we will give a quick overview about regulations that may should be considered.

5.3.1 Standards

By 2023, the development of the charging infrastructure should initially focus on the charging scenarios for depot charging and on the development of an initial public network based on the CCS standard. Where possible, the maximum charging capacity for CCS (500 kW) should be maintained for the intermediate charging and intermediate ad-hoc charging scenarios until the MCS standard is introduced. Certification bodies require the corresponding capacities in order to rapidly complete the certification processes for the MCS from 2023.

In principle, at such locations where sufficient commercial vehicle traffic prevails or is to be expected, an upgrade capability to MCS should also be considered (not particularly relevant for depot charging for the time being).

- depot charging capacities in general rather lower than for intermediate charging
- usable up to 500kW CCS

5.3.2 Economy

The economic viability of operating a battery-electric truck fleet and the associated private charging infrastructure is a key factor for a successful ramp-up of electromobility in the commercial vehicle sector. Since the profit margins of logistics companies are generally very small (between 0.1% and 1%), the switch to BEV trucks must not lead to additional costs for the broad mass of logistics companies or jeopardize existing business models. Otherwise, from the logistics industry's point of view, the ramp-up of BEV truck fleets will be very slow, as only a few companies will be able to afford the switch.

In terms of economic efficiency, it is therefore important to find financing solutions that allow companies to make the switch.

- after 2035, fundings for PV, batteries and electric vehicle charging stations are not very likely to exist anymore
- infrastructure will already be there and will be the cheapest way

5.3.3 Regulations

Charging Infrastructure

With the guideline "Klimaschonende Nutzfahrzeuge und Infrastruktur", the *federal government* promotes investments in charging infrastructure for the operation of electric trucks with up to 80 % of the costs (KsNI 2021). Until 2024 5 billion in funding for charging infrastructure has been approved.

Further funding foreseeable in the short term, as *federal government* is working on "Masterplan Ladeinfrastruktur II der Bundesregierung" at the moment.

Independent of this, individual *federal states* in Germany also promote the expansion of the charging infrastructure in the commercial vehicle sector. (Example: North-Rhine-Westphalia supports expansion of charging infrastructure with connected PV and Batteries Til 2024 with 53 Million Euro NRW; "Emissionsfreie Mobilität")

Forecast that should be considered (long term): Since we are looking at the period up to 2035, it is important to emphasize that til then fundings in PV, batteries and EV-charging stations are not very likely to exist anymore. Infrastructure will be already there and will be the cheapest way, so governments will not fund it.

PV in open spaces

In legally protected areas such as nature reserves, national parks, core zones of biosphere areas, area-like natural monuments or areas according to § 30 BNatSchG and § 33 and orchard meadows according to 33a NatSchG BW, the construction of facilities is not not permitted in any case.

In addition, the following areas are also to be excluded: Natura 2000 areas - if the conservation objective is impaired, maintenance zones of biosphere areas, mapped FFH habitat types - if conservation is endangered, bird sanctuaries, meadows or pastures with four or six species of the FAKT species catalogue, breeding sites, resting places and essential resting areas of strictly protected species, and near-natural waters.

Compensation area regulation: The additional compensation area required depends on the quality of the area and the previous use. The relevant compensation factor is usually around 20 percent for (PV-FFA for short). For example: a 10-hectare PV FFA requires 2 hectares of compensation area.

In Spain, in 2019 the "tax of the sun" was derogated, meaning that the energy produced by self-consumption installations is completely free of taxes, and there is no electric power limitation. Environmental and public utility authorizations must be consulted for each autonomous community. Nevertheless, in general, installations with electric power greater than 10 kW must submit a validated technical project, and usually need to pass an initial inspection and periodic inspections every 5 years. Moreover, the installation company must request the "CAU (Código de autoconsumo)" which translates to 'self-consumption code'. And it is also responsible of process the connection accesses to the distribution grid.²²

Furthermore, if the electric power of the installation is higher that 100 kW, the produced energy surplus can be sold directly to the energy market for an agreed price with the energy company. On the other hand, if the installation is lower that 100 kW, there's the possibility to compensate the surplus by subtracting it from the electricity bill, but there is no direct economic benefit.

²² <https://selectra.es/autoconsumo/info/normativa>

In Sweden, the regulations and incentives for solar panel installations are primarily governed by the Swedish Energy Agency (Energimyndigheten) and the Swedish Electricity Safety Authority (Elsäkerhetsverket). The regulations for PV panel installations for self-consumption by companies may vary depending on factors such as system size, connection to the grid, and the type of installation.²³

As of August 1, 2018, is no longer necessary to apply for a building permit to install solar panels and solar collectors on buildings in a detailed area, as long as the panels follow the shape of the building and comply with electrical safety regulations. Moreover, the installation has to be carried out by a qualified electrician who follow the appropriate safety standards.

Companies wishing to install solar panels for self-consumption must have a grid connection agreement with the local distribution system operator (DSO). The DSO will assess the grid capacity and provide guidelines for the connection process.

Net metering is a common practice in Sweden, allowing companies to offset their electricity consumption with the electricity generated by their solar panels. Excess electricity can be fed back into the grid, and the company receives compensation or credits for the surplus.

Sweden has various financial incentives and support programs to promote renewable energy installations. These incentives may include investment grants, tax deductions, and reduced VAT rates. Companies should check with the Swedish Energy Agency for the latest information on available incentives.

Companies with solar panel installations may be eligible to receive renewable energy certificates (Elcertifikat) for the electricity generated. These certificates can be sold on the energy market, providing an additional source of income.

It's important to note that the regulations and incentives can change over time, so it's recommended to consult with local authorities, industry experts, or specialized solar installation companies to ensure compliance with the latest regulations and to take advantage of available incentives.

Wind

The height of wind turbines is a decisive criterion for their approval:

In most several states, small wind turbines **under 10 meters** do not require a permit/approval. Small wind turbines **over 10 meters** are subject to approval in all federal states. Wind turbines **over 30m** are classified as special constructions and therefore have high requirements for the building permit/approval. Turbines **over 50 m** are considered large wind turbines and must be approved in accordance with the Federal Immission Control Act and can only be built on designated priority areas.

Also, distances are relevant to look at:

A small wind turbine must comply with minimum distance regulations, for example minimum distances to the property line, to residential areas, but also to natural areas and habitats. These regulations also vary greatly from federal state to federal state.

²³ <https://svensksolenergi.se>

Energy storage

Germany:

- storage facilities are treated as consumers when drawing electricity and as generators when providing electricity.
- storage projects benefit from some exceptions and reliefs, the regulatory framework is still highly complex and requires case-by case consideration, especially when a device is supposed to be operated in multi-use scenarios
- That is more important for stationary energy storage directly on the grid, but also can effect depot storages if it is planned to feed electricity from battery storage back into the grid
- key challenge: price development, since political decisions highly effect large-battery storage options and demand, which further effects scale of battery production, 2nd life cycle and prices

France: several legal and commercial challenges for large energy storage systems (French energy code)

- current regulatory framework allows for energy storage, but there is no legal framework designed for its development.
- article L142-9-I creates a “National register of electricity production and storage facilities”²;
- article L315-1 provides that an individual plant for self-consumption may include the storage of electricity;
- article L121-7 specifies that in non-interconnected areas, the costs of storage facilities managed by the grid operator are offset through the public service contribution of electricity (CSPE)
- EDF has presented a major electrical storage plan with the objective of becoming the European leader in the sector by 2035
- Grid Motion project was launched by, amongst others, PSA, Direct Energie and Enel to develop vehicle-to-grid technology, using second-life batteries from EVs
- Renault has also launched its Advanced Battery Storage project, with the aim of building a 70 MW battery storage facility from second-life batteries by 2020
- TURPE 5 now gives energy-intensive industries using storage a reduction up to 50 per cent, and reinforces the difference in rates between peak consumption hours and low consumption hours, with the aim of controlling peak consumption and developing decentralized renewable production and self-consumption

Netherlands:

- National Action Plan 2019 on Energy Storage and Conversion⁵ published by the industry group Energy Storage Netherlands
- increase in interest into energy storage projects from both project developers and (project) financiers
- absence of a comprehensive strategy to create a level playing field for energy storage projects in the Netherlands still affects viability and bankability of these projects
- Although energy storage projects are considered interesting from an equity perspective in the Netherlands, debt financiers are still assessing if and how sufficiently stable cash flows can be generated by projects to service the debt

5.4 Fundings and incentives in the EU

In this paragraph, we are shortly talking about relevant fundings and which role the European countries play considering renewable energies.

An agreement between the European Investment Bank and the European Commission sets their cooperation for blending under the "Alternative Fuels Infrastructure Facility" (EUR 1.5 billion of EU grants available) with financing from the EIB, as primary Implementing Partner. This is relevant funding for charging infrastructure.

Germany: In Germany, there is the Renewable Energy Sources Act (EEG), which promotes the expansion of renewable energies. There are also specific funding programs for the expansion of solar energy, wind energy, and biomass.²⁴

Austria: In Austria, there is funding for renewable energies, which is financed by the Climate and Energy Fund. The funding is aimed at individuals, companies, and municipalities and covers various technologies such as solar energy, biomass, and geothermal energy.²⁵

Switzerland: In Switzerland, there are various funding programs for renewable energies at the cantonal level. For example, in the canton of Zurich, there is the "Energie-Region Zurich" funding program, which supports the use of renewable energies and energy efficiency measures in companies and municipalities.²⁶

France: In France, there are various state subsidies for renewable energies, which are managed by the National Agency for the Environment and Energy (ADEME). The subsidies cover various technologies such as solar energy, wind energy, and biomass.²⁷

Netherlands: In the Netherlands, there is the "SDE++" subsidy program, which promotes the expansion of renewable energies. The program is aimed at companies and non-profit organizations and covers various technologies such as solar energy, wind energy, and geothermal energy.²⁸

Sweden: In Sweden, there is a support system for electricity from renewable energy sources, known as the Electricity Certificate System. This system aims to increase the share of electricity from renewable sources and involves the issuance of certificates to eligible renewable energy producers.²⁹

Denmark: In Denmark, there are various subsidy schemes for renewable energy, including a feed-in tariff for wind power and biogas, as well as subsidies for solar energy and district heating. The funding is managed by the Danish Energy Agency.³⁰

5.5 Classification of financial models

Until now, customers looking to finance a heavier asset/ product have traditionally had four options: purchasing, financing, leasing, or renting. These four options have major differences in how they are designed (see *Table 5.1*), which shows the classification of Financing models from

²⁴ <https://www.bmwk.de/Redaktion/EN/Dossier/renewable-energy.html>

²⁵ <https://www.bmk.gv.at/en/topics/climate-environment/climate-protection/climate-energy-fund.html>

²⁶ <https://www.local-energy.swiss/programme/projektfoerderung/energie-regionen.html#/>

²⁷ <https://www.ademe.fr/en/our-missions/funding/>

²⁸ <https://english.rvo.nl/subsidies-programmes/sde>

²⁹ <https://www.energimyndigheten.se/en/sustainability/the-electricity-certificate-system/>

³⁰ <https://ens.dk/en>

a Customer's perspective (OEM). In the case of Traditional Sale, the asset becomes part of a customer's assets. With financing, the company pays a fixed sum to a financial services provider over a set length of time. The other two variants (leasing and renting) are more flexible and less capital-intensive. They differ primarily in the type and measurement of payment for the use of the asset/product.

Table 5.1: Classification of finance models from customer's perspective

	Traditional Purchasing	Financing	Leasing	Renting	Pay-per-Use (PpU)
On the Balance sheet	CAPEX (infrastructure)	CAPEX (infrastructure)	CAPEX (Fixed cost)	OPEX (Fixed Rent)	OPEX (Variable Cost)
Asset commitment	Permanent	Permanent	Duration of leasing contract	Duration of Renting contract	Duration of Use
Service/ Maintenance	Usually not included	Usually not included	Depends on the leasing contract	Depends on Renting contract	Full-Service offering
Ownership	Buyer/ Customer	Buyer/ Customer	Manufacturer/ Supplier/ Lessor	Manufacturer/ Supplier	PpU Provider/ Manufacturer/ Supplier
Risk	Buyer/ Customer	Buyer/ Financial Service provider	Lessor	Manufacturer/ Supplier	PpU Provider

Boosting sales through leasing dates back to the 19th century. Essentially, the leasing partner purchases the asset, with the end user company paying the partner at a fixed rate over a set term. In contrast to simply renting, the purchaser can then buy the item for a residual price at the end of the term.

5.5.1 Leasing

Leasing is a commercial contract in which the lessor lets the lessee use an asset instead of periodical payments for the agreed period. Two main types of leasing can be distinguished:

- **Financial Leasing:** in which the lessor lets the lessee use an asset instead of periodical payments for the usually long period. In this case the ownership is transferred to the lessee through a long-term contract and is responsible for maintaining the asset as well.
- **Operating Leasing:** where the lessor allows the lessee to use an asset in place of periodical payments for a small period. In this case the ownership remains with the lessor and the contract is short term rental contract. In this case the lessor needs to take care and maintain the asset.

In our business case the more indicated type would be financial leasing, since the assets that would be for leasing have long life spans (like PV panels or converters) and the costumers would end up owning them at the end of the contract. Nevertheless, if Daimler would act as the lessor, purchasing the assets first it would be a too large initial investment. Hence, a viable solution would be that the financial leasing contract is directly between the asset production company and the costumer, and Daimler only serves as a connecting point.

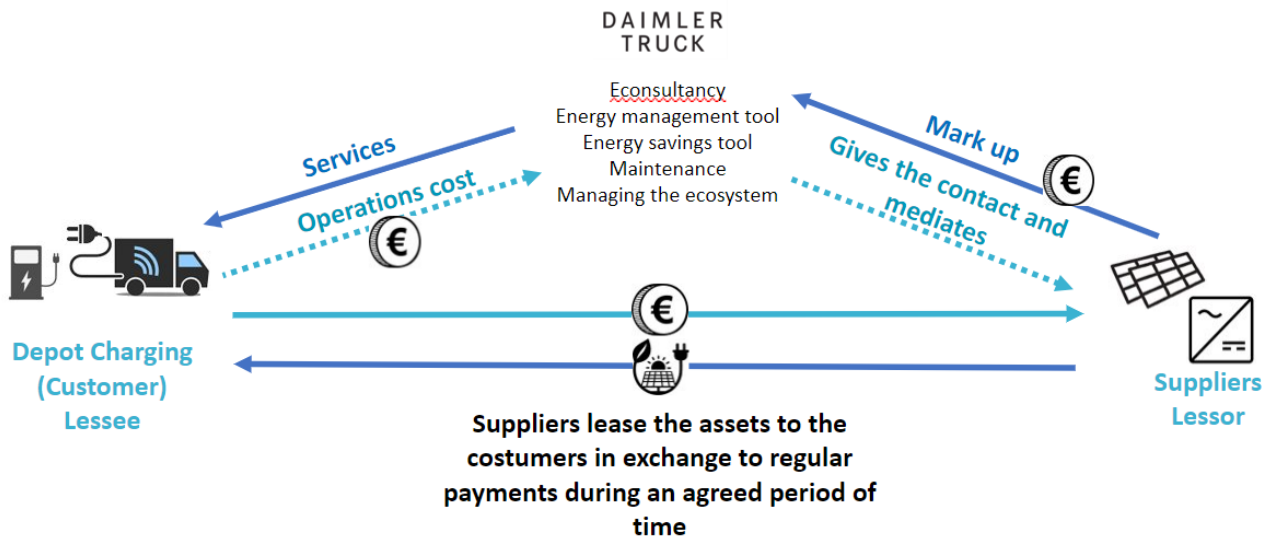


Figure 5.1: Leasing Financial Model

For financial leasing, the lease period covers at least 75 % of the life span of the asset. Moreover, the present value of the minimum lease payments totals at least 90 % of the fair value of the asset at the beginning of the lease.³¹

5.5.2 Renting

Batteries contribute up to half of the overall investment of the client. Renting batteries for storage can be an efficient solution for client's charging infrastructure needs, especially when considering electric trucks. Here are some factors to consider:

- **Flexibility:** Renting batteries allows for flexibility in scaling the storage capacity based on your client's changing needs. They can adjust the number of batteries rented depending on the fleet size and charging demands.
- **Cost-effectiveness:** Renting batteries can be a cost-effective option compared to purchasing and maintaining batteries. The rental cost can be factored into the overall operational expenses rather than a significant upfront investment.
- **Technology upgrades:** Battery technology is rapidly evolving, and renting batteries allows your client to take advantage of newer and more advanced battery technologies as they become available. This can lead to improved energy storage capacity, longer lifespan, and better performance.
- **Maintenance and support:** Renting batteries often includes maintenance and support services provided by the rental provider. This can help ensure the batteries are regularly inspected, serviced, and replaced if necessary, minimizing downtime and optimizing performance.
- **Battery lifecycle management:** Renting batteries also relieves your client from the responsibility of managing the end-of-life disposal or recycling of the batteries. The rental provider typically takes care of this aspect, ensuring proper environmental practices are followed.

The rental prices for batteries can vary depending on various factors, including the type of battery, its capacity, the rental duration, market conditions, and the specific terms and agreements with the battery provider. It is best to reach out to battery rental providers or consult

³¹ <https://www.accountingtools.com/articles/what-is-the-accounting-for-a-finance-lease.html>

with industry experts who can provide you with up-to-date and accurate information on rental prices in your region.

However, to give you a general idea, battery rental prices are typically determined based on a combination of factors such as the battery's energy capacity (measured in kilowatt-hours, kWh), the rental period (monthly, annual, etc.), and any additional services or maintenance included in the rental agreement. Rental prices can range from a few hundred dollars per month to several thousand dollars per month, depending on the factors mentioned above.

It is important to consider your specific requirements, budget, and the cost-benefit analysis of renting batteries versus other alternatives, such as purchasing batteries or utilizing other charging infrastructure options. Obtaining quotes and negotiating with battery rental providers will give you a more accurate estimate of the rental prices based on your specific needs and circumstances.

5.5.3 White labeling

White labeling occurs when the manufacturer of an item uses the branding requested by the purchaser, or marketer, instead of its own. The end product appears as though it has been produced by the purchaser. Why would white labeling make sense for a company?³²

- *Cost-effective:* research & development and manufacturing costs are cost-intense processes, that hinder companies in extending their profiles. Outsourcing that takes away a lot of upfront costs.
- *Fast to market:* Research & development are time intense. Not having to develop a product from scratch allows company to market quickly and to outpace competitors.
- *Benefit of industry experts:* the manufacturers are likely experts in the field and have established routines, quality control systems. Additionally, already established large production sites allow for faster upscaling and lower minimum order quantities for the customer, which again take away from big upfront investments and allow flexibility in order quantities depending on the demand.

Since DTAG was not interested in providing any the consumer with a product in these scenarios, this was not discussed further.

5.5.4 Contracting

Contracting models can be an effective strategy for DT. By leveraging contracting models, the company can benefit from specialized expertise, cost savings, and increased flexibility in managing their business model.

A very common form of contracting is Joint Ventures or Partnership Agreements: This model involves sharing ownership, responsibilities, and profits with the partner by contract. The partnership could leverage the partner's expertise, infrastructure, and resources to build and operate the depot charging business jointly.

In such contracts, parties contribute their financial resources, knowledge, and assets to the venture. This can reduce the individual financial burden and risk for each partner, making it easier to fund the establishment and ongoing operations of the depot charging business.

For contracting it is very important that the partners should define the terms of the partnership in a detailed agreement, addressing aspects such as governance, profit sharing, decision-making authority, and exit strategies.

³² <https://www.bigcommerce.com/ecommerce-answers/what-is-white-labeling/>

5.5.5 Outsourcing

Outsourcing refers to the practice of contracting or delegating specific tasks, functions, or processes to external companies or individuals. Instead of handling those tasks in-house, a business or organization hires a third-party service provider to perform them. This external service provider is commonly referred to as an "outsourcing partner" or "vendor."

Outsourcing can cover various areas of business operations, including customer support, IT services, manufacturing, data entry, software development, human resources, accounting, and more. It is a strategic decision made by companies to leverage specialized skills, resources, or cost advantages offered by external entities.

Since DTAG was not interested in providing any service management support, this was not discussed further.

5.5.6 Pay-per-Use-Model (PpU)

With Pay per use (PpU), assets/products are no longer purchased, financed, or leased by the user; instead, they are purchased on a pay-per-use or pay-per-output basis, where users pay only for actual use (see Table 2). These new business models transfer the familiar concepts of other "as-a-service" models, which are already common for software solutions, to tangible assets such as machinery and equipment.

In PpU models, billing is based on usage rather than at a flat rate. This means that customers/users have much greater flexibility in how they use assets. For example, they can just use them for a short time (e.g., project-based) and then relinquish the asset once it is no longer needed. This generates new opportunities for investors — both on the debt and equity side — by creating new asset classes. These are attractive options, especially given the current limited investment opportunities and liquidity in the market.

PpU models are already being used in certain industries, particularly in mechanical and plant engineering. For example, Rolls-Royce is considered one of the first engineering companies to offer pay-per-use models with its "Power by the Hour" performance-based contracts for its jet engines. Other examples of companies integrating IoT technology with pay-per-use models include machinery and equipment manufacturers DMG Mori and Trumpf.³³

Quick and short: What is Pay-per-Use?

Definition:

- The customer pays a fee for the time that machines are used.
- It is irrelevant what the asset is used for; the user is charged only by time (or intensity of use).

Charging Detail:

- Time (seconds, minutes, hours, days)
- Intensity of use

Example:

- Rolls-Royce turbines ("Power by the hour")
- Car sharing

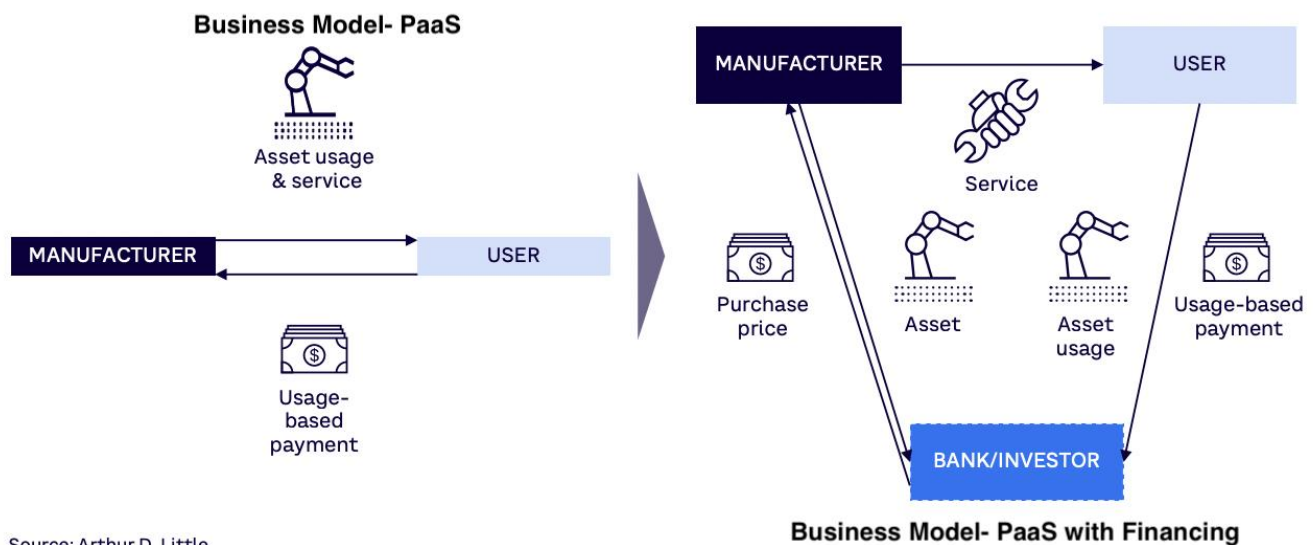
³³ Arthur D. Little: *Asset as a Service – Transforming ownership and business models promising significant value*. Report 03/2022. https://www.adlittle.com/sites/default/files/reports/ADL_Asset_as_a_service_1.pdf

Benefits

- Reduced CAPEX: Migration from OPEX to CAPEX : this is the #1 reason equipment suppliers stated their customers were interested in moving to PaaS.
- Lower Total Cost of Ownership (TCO): by only paying for defined outcomes, customers can realize a lower TCO of equipment.
- Increased flexibility: PaaS end users have more flexibility to scale their operations up or down as their needs change.
- Improve margins: OEMs can adapt their pricing by utilization: in hours, days, months, etc.
- Acquire new customers: by providing PaaS, OEMs access to a bigger market of customers, find out more below in the market size point.
- Retain existing customers: existing customer has the possibility to combine offers and access to more services with the same provider.
- Reduce environmental impact: the materials can be easily recycled or reused by the OEMs if the equipment is damaged or out of service.

PpU in our use case

As explained above, with PpU, the asset/product user benefits from a lighter balance sheet. By contrast, a PpU business model significantly extends the balance sheet of the asset's manufacturer. On a small scale, this may still be acceptable, and sometimes even desirable. However, if the business model is to be scalable, the manufacturer must ensure that assets are not capitalized on its balance sheet. To ensure this, it is crucial to differentiate between the two types of PpU model — business model and financing — depending on ownership of the asset as shown in *Figure 5.2*.



Source: Arthur D. Little

Figure 5.2: Business model PaaS with financing

For the use case with Daimler Trucks AG (DTAG) to implement a decentralized energy supply at the customer without having to invest in the technology following business model has been implemented as shown in *Figure 5.3*.

In this financing model, DTAG is responsible as a service provider to the customer for maintenance/operations, energy management and monitoring with the help of IoT service provider.

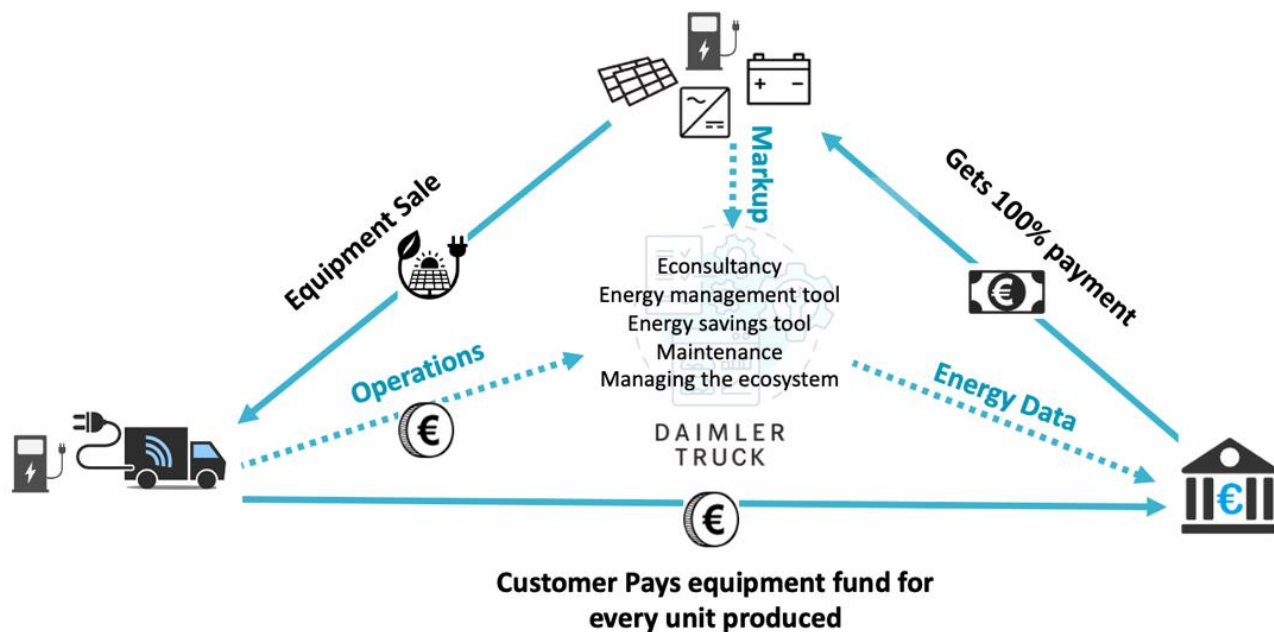


Figure 5.3: Financing model for DTAG

As DTAG does not want to invest in the technology in terms of purchasing the entire system from suppliers, the suppliers also become a part of this Financing ecosystem and the customer will take the assets directly from the suppliers suggested by DTAG. This way DTAG can also earn a markup value against the amount of goods sold.

The CAPEX investment required in such type of heavy asset oriented business is very high and the possibility of SME customers having to pay such huge investment upfront is low. Also, even if the PpU model is introduced the supplier would not agree to keep such high capital on their Balance sheet.

For these reasons, a Financing investment through investors/ banks/ SPVs are required to pay the upfront CAPEX to the suppliers and taking this amount from the customer based on the pay per use of the equipment. By allowing an outside investor to become the owner of the asset, the manufacturer/supplier can remove the asset from its own balance sheet. The different financing options are as follows:

Pay-per-use credit for the customer: If the asset user is interested in usage-based billing but the manufacturer is not willing to take the assets onto its own balance sheet, assets can be covered by pay-per-use financing with various offers covering this area already available (including those from Germany's Commerzbank). In the case of pay-per-use financing for the customer, the manufacturer sells the asset to the user. The user then takes out financing from the bank at an interest rate based on the use of the asset.

To implement flexible financing successfully, the financing bank needs access to IoT data generated by the asset, as well as the skills to analyze the data, in order to complete a full risk assessment that determines the pricing as well as the fluctuation margins of the interest rate. The added value is obvious: the manufacturer can satisfy customer needs and de facto offer a simple form of usage-based billing. The user's financing rate is based on actual usage, but the asset remains on the user's balance sheet. The bank can expand its business model toward

PpU, meet changing customer needs, and potentially generate higher returns by assuming part of the utilization risk.³⁴

Financing by means of a special-purpose vehicle (SPV): The other approach to financing PpU is a solution that does not burden the balance sheet of either the manufacturer or the user. A special purpose vehicle is a subsidiary created by a parent company for a variety of purposes. The SPV can be used to isolate financial risk, securitize assets, and perform separate financial transactions. The SPV is a structure that offers a solution that is in many ways similar to the approaches of original equipment manufacturers (OEMs) in the automotive and mechanical engineering sectors that have their own captive finance companies for sales financing. In this model, the manufacturer sells the asset to the SPV, receiving payment of the purchase price. The SPV becomes the owner of the asset, offers it to the user, and in return receives use-dependent cash flows.

SPVs have been used in the past to alter company financials and misrepresent their financial health. It's critical to analyze SPVs along with other aspects of a company's financial statements before making any investments.³⁵

The financing model applied in our use case is the first model, where the asset remains still on the user's balance sheet.

5.6 Calculation and Analysis

In this subchapter, one can find a chosen selection of the important calculations we worked on during the Innolab. The whole document with every calculation will be provided separately.

5.6.1 Price sheet & financial overview

Table 5.2: Price sheet for financial feasibility of a PV charging station

component		unit	current price	source
PV system				
	PV modules (monocrystalline)	€/kWp	300	https://www.solaranlage-ratgeber.de/photovoltaik/photovoltaik-wirtschaftlichkeit/photovoltaik-kosten
	PV fundamental construction system	€/kWp	100	https://www.solaranlage-ratgeber.de/photovoltaik/photovoltaik-wirtschaftlichkeit/photovoltaik-kosten
	PV construction work	€/kWp	200	https://www.solaranlage-ratgeber.de/photovoltaik/photovoltaik-wirtschaftlichkeit/photovoltaik-kosten
	Maintenance PV	€/kWp	14	DTAG
Converter system				
	Converter (DC/AC), (AC/DC)	€/kW	150	https://www.sunstonepower.de/products/hybrid-wechselrichter-10kw?gclid=CjwKCAjw04yjBhApEiwAJcvNocsZSsaMf6_Vmflvq_lmJjEothDZ

³⁴ Arthur D. Little: *Asset as a Service – Transforming ownership and business models promising significant value*. Report 03/2022. https://www.adlittle.com/sites/default/files/reports/ADL_Asset_as_a_service_1.pdf

³⁵ <https://www.investopedia.com/terms/s/spv.asp>

					vp59q3VBzFVr9HmhTJskRDIXhoCVsYQAvD_BwE
	DC/DC Converter	€/kW	150		
	Connection Converter → PV and Grid	€	1000		https://www.solaranlage-ratgeber.de/photovoltaik/photovoltaik-wirtschaftlichkeit/photovoltaik-kosten
Cables		€/100 meter	145		https://www.reichelt.de/de/de/solarkabel-6-mm-100-m-schwarz-vt-11415-p340618.html?PROVID=2788&gclid=Cj0KCQjw6cKiBhD5ARIsAKXUdybvgvkwAvHtzeFsLdAjyInQs3q7S5cT6x6Qc0cNxdBI_rIPNRxpl-EaArQQEALw_wcB&r=1
Battery System					
<i>second life like on KEM</i>	Battery packs				
	Energy management system	€	400		https://www.solaranlage-ratgeber.de/photovoltaik/photovoltaik-wirtschaftlichkeit/photovoltaik-kosten
	Housing				
	Whole battery product	€/kWh	350	DTAG	
	Battery installation	€/kWh	45	DTAG	
	year maintenance → 1% of hardware invest	€		DTAG	
Charger Hardware					
	50 kW DC	€	35.000	DTAG	
	350 kW DC	€	70.000	DTAG	
	400 kW DC	€	80.000	DTAG	
Transformer Hardware					
	1000 kVA	€	30.000	DTAG	
	600 kVA	€	20.000	DTAG	
Grid Connection	Realising grid connection	€	500		https://www.solaranlage-ratgeber.de/photovoltaik/photovoltaik-wirtschaftlichkeit/photovoltaik-kosten
	Maintenance grid connection	€/kVA	10	DTAG	
	Grid electricity energy costs	€/kWh	0,2138		https://www.eha.net/blog/details/strompreise-unternehmen.html#:~:text=Der%20durchschnittliche%20Strompreis%20im%20Jahr,26%2C64%20Cent%20pro%20kWh.

grid electricity high power costs				
grid feed in price	€/kWh	0,03	https://www.eigensonne.de/ratgeber/photovoltaik/einspeiseverguetung/	

This sheet presents the calculations and estimates the financial feasibility of a PV charging station. It is considering the components like cables, the battery system itself, calculations for the transformer hardware and the grid connection.

In the following, one can find a short financial overview. The figures provided by Daimler Truck after inquiry:

Battery storage – range of costs

Stationary Battery Storage €/kwh: 300 €/kWh – 400 €/kWh

Installations: 40 €/kWh – 50 €/kWh

For the yearly Maintenance we assume 1 % of the hardware invest per year.

Charger Hardware – range of costs:

50 kW DC: 30 tsd. € – 35 tsd. €

350 kW DC: 65 tsd. € - 75 tsd. €

400 kW DC: ~ 80 tsd. €

Transformer Hardware:

1000 kVA: 25 tsd. € - 30 tsd. €

600 kVA: 18 tsd. € - 20 tsd. €

These figures are, among others, assumptions and figures provided by Daimler Truck. Further intensive calculations are following.

5.6.2 Utility analysis

The utility analysis is a tool in form of a framework and is used to evaluate the suitability and desirability of a planned project. In our case it is about the evaluation of battery systems and photovoltaics/VAWT with and without grid. By considering the key aspects availability, environmental compatibility, technical feasibility, regulatory feasibility and public acceptance, the utility analysis helps making informed decisions and prioritize based on the overall utility and calculated value.

The judging scale is as follows:

0 = not satisfying, 1= ok, 2 = satisfying, 3 = good, 4 = very good

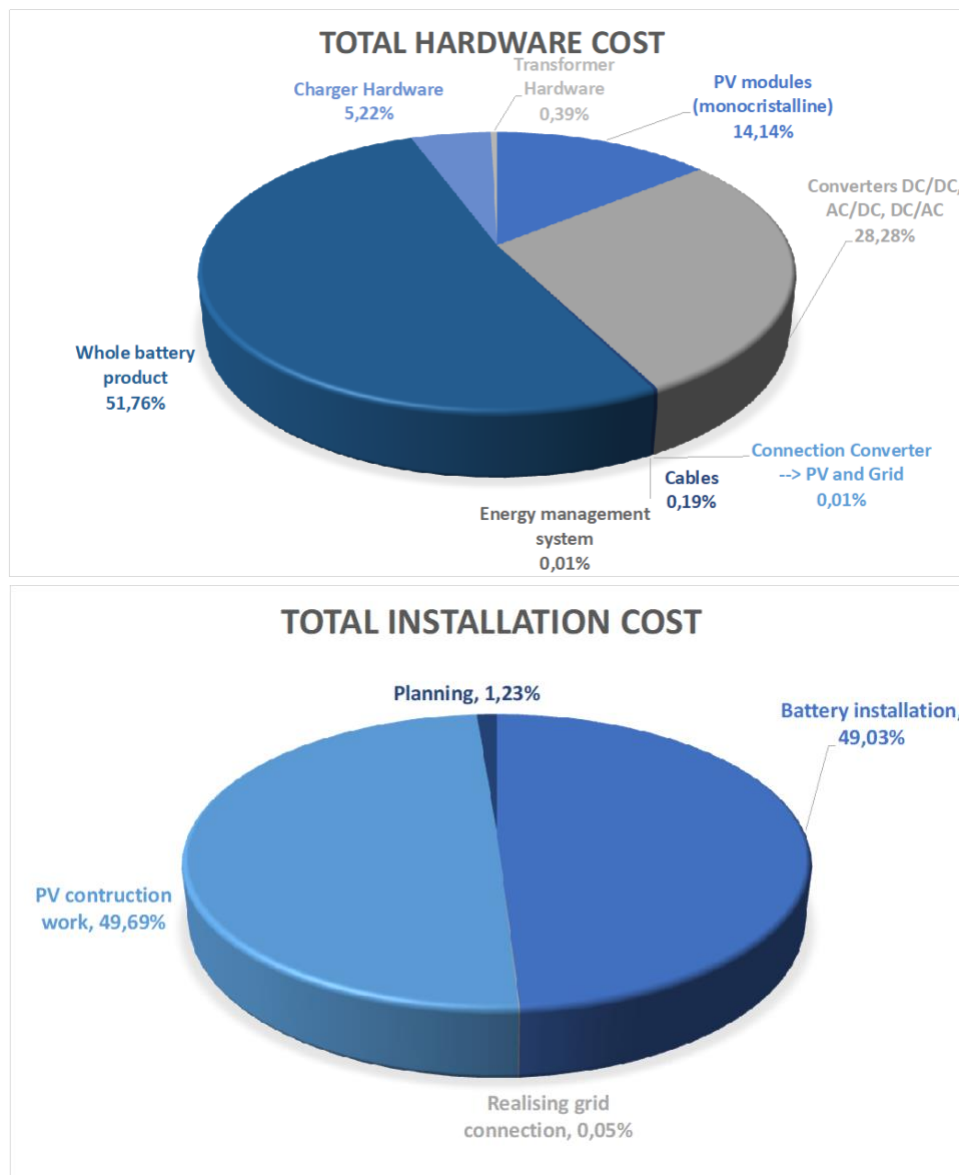
Table 5.3: Utility analysis

	weighting	Photovoltaik	NW	Winpower (VAWT)	NW
Availability (nowadays + Estimation 2035)	0,2	4	0,8	2	0,4
Environmental compatibility	0,1	2	0,2	3	0,3
Technical feasibility e.g. Fundament (and other factors, in text or in excel)	0,3	4	1,2	3	0,9
Regulatory feasibility					
laws	0,25	3	0,75	3	0,75
state subsidy	0,1	1	0,1	0	0
Public acceptance	0,05	4	0,2	3	0,15
result - normalized			0,57		0,43
	weighting	Battery without grid	NW	Battery with grid	NW
Availability (nowadays + Estimation 2035)	0,2	1	0,2	4	0,8
Environmental compatibility	0,1	2	0,2	2	0,2
Technical feasibility e.g. Fundament (and other factors, in text or in excel)	0,3	2	0,6	3	0,9
Regulatory feasibility			0		0
laws	0,25	3	0,75	3	0,75
state subsidy	0,1	2	0,2	2	0,2
Public acceptance	0,05	3	0,15	3	0,15
result - normalized			0,41		0,59
judging scale: 0=not satisfying, 1=okish, 2=satisfying, 3=good, 4=very good					

5.6.3 CAPEX and OPEX calculation scenarios

Total CAPEX	version	per unit	Einheit (unit)	number of objects	total
acquisition price reduction					
Hardware Cost					7.658.055 €
PV	PV modules (monocrystalline)	300 €/kWp		3608,95	1.082.685 €
Converters	Converters DC/DC, AC/DC, DC/AC	150 €/kW		3608,95	2.165.370 €
	Connection Converter --> PV and Grid	1000 €		1	1.000 €
Cables	Cables	145 €/100 meter		100	14.500 €
EMS	Energy management system	400 €		1	400 €
Battery	Whole battery product	350 €/kWh		11326	3.964.100 €
Charger	Charger Hardware	400 kW DC	80000 €	5	400.000 €
Transformer	Transformer Hardware	1000 kVA	30000 €	1	30.000 €
Installation Cost					
	Battery installation	45 €/kWh		11326	509.670 €
	Realising grid connection	1000 €			500 €
	PV construction work	100 €/kWp		5165,56	516.556 €
	Planning	12.800 €			12.800 €
subsequent acquisition costs					
=	Total Acquisition cost				8.697.581 €
Total OPEX					
+ operating costs to be paid to DT					
	Battery maintenance	39641 €			39.641 €
	Maintenance grid connection	10 €		1000	10.000 €
	+ Imputed interest				217.440 €
	+ Depreciation other components				189.339 €
	Grid electricity energy costs	2021	0,2138 €/kWh	23152	4.950 €
	+ Depreciation battery				396.410 €
					857.780 €

considering the base scenario (Long-Haul)



5.6.4 Amortisation calculation (customer point of view)

From a customer's point of view, we looked at the net present value of different technical scenarios. Since a repurchase of battery is needed after 10 years, this has been also considered (see *Other Scenarios*). The net present value highly depends on the customers project scope, already in the base Scenario it changes from a positive value, indicating a beneficial invest to a negative value within eActros and LongHaul.

Regarding amortisation we considered all different financing models including an upfront payment, renting & leasing and PaaS. The different financing options lead to different periods of amortisation.

The following calculation has been made for upfront payment in the Base Scenario LongHaul. After 10 years, we considered a repurchase of the battery.

Table 5.4: Amortisation calculation

	unit	total
profit (revenue + savings - OPEX) per period	€/year	40.615,29 €
- consultancy/service costs	€/year	34.207,32 €
+ imputed interest	€/year	217.439,53 €
+ depreciation	€/year	585.749,24 €
= mean return on capital per period	€/year	809.596,74 €
	unit	total
aquisition costs (hardware + installation)	€/year	8.697.581,00 €
/ mean return on capital per period	€/year	809.596,74 €
= amortisation period	years	10,74
years of savings		9,26

Table 5.5: Amortisation periods

option	2 x battery
upfront payment	in year 15
Pay-per-Use	in year 17
renting & leasing	in year 21 (after the considered period of time/usage)

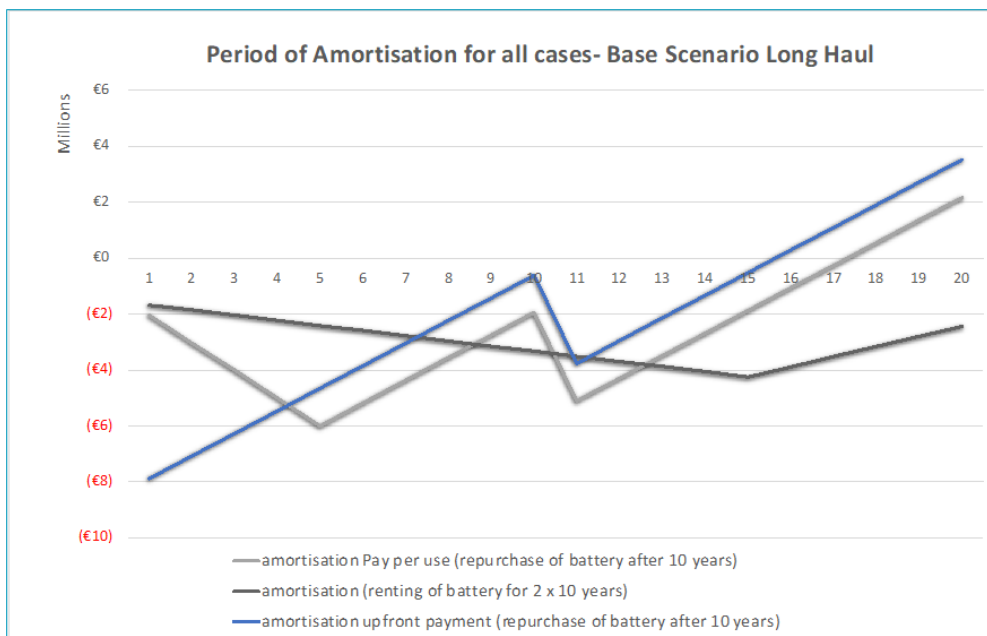


Figure 5.4: Period of amortization

The most advanced financing from customer perspective is in this scenario the upfront purchase, followed by PpU and then leasing.

The amortisation is possible due to savings of the customer reading the avoidance of Diesel usage as well as the independence from costs due to the usage of the grid.

5.6.5 Revenues (DTAG point of view)

Revenue	version	per unit	Einheit (unit)	number of objects	total
Revenues for Customer					
+ revenues from electricity feed in		0,03 €	€/kWh	3182598	95.478 €
savings for decentralized energy park (annually)		0,21 €	€/kWh	1685048	360.263 €
+ savings if diesel not used as fuel for trucks (annually)		1,617 €	/l		442.654 €
Total Revenue+ Savings					898.395 €

Multiple revenue streams for DTAG have been identified. No matter what financial model from customer side will be chosen or will be offered from DTAG side, the revenue streams stay the same.

First revenue stream

The first revenue stream is coming from the customers.

All operational expenses that come with the yearly maintenance of facilities as well as installation costs DTAG would pass on to the customer. EConsultancy and DTAG initial Capital expenses must be priced by DTAG. Project based pricing, hourly based pricing and value-based pricing could be considered for pricing approaches.

Value-based approach

considering the base scenario (eActros 300)

CAPEX	4.954.285,50 €
OPEX without interest & depreciation	39.441,25 €
revenue & savings	838.005,71 €
cash flow	798.564,46 €
cash flow including battery (repurchase after 10y)	2.219.700,00 €
interest rate	0,05 €
net present value	4.997.592,78 €
net present value including battery repurchase	2.777.892,78 €

Hourly-based approach

multiplication factor	1,70 €
average annual income (consultant DTAG)	100.000,00 €
yearly labour costs for employer	170.000,00 €
productive working hours	1.640,00 €
hourly labour costs	103,66 €
margin	0%
hourly pricing	114,02 €

Project-based approach

hourly pricing	114,02 €
fixed amount of hours	300
project based pricing	34.207,32 €

Further calculations are based on a project-based pricing since it is the most predictable approach for DTAG and not strongly dependent on CAPEX, OPEX. 34.000 € is a conservative guess of the minimum pricing of DTAG's consultancy services. Dependant on a customer's individual project scope the customers generated value indicates the maximum pricing DTAG could set. Comparing the results for the 2 different base scenarios Base Scenario eActros 300 (Base Scenario LongHaul) the high impact of the scenario on the customers net present value is visible 2.7 Mio (-2 Mio.).

Notation:
Base Scenario eActros 300
(Base Scenario LongHaul)

Second revenue stream

The second revenue stream is coming from the suppliers, consisting of a mark-up of the customers expenses. This income is therefore dependant on the customer's individual project scope. Assuming a mark-up of 10%, in the base scenario eActros 300 a revenue of 370.000 € (720.000 €) would be generated (PV + battery + converter).

Considering DTAG's needed operational expenses prior to the rollout of the business model, calculating financial ratios for the worthiness of the business model would be a needed step. To do so, the number of potential customers per year as well as detailed calculation of DTAG capital expenses are needed as well as a prediction of the scope of customers scenarios. During this Innolab these calculations are not covered.

5.6.6 High cost factors – components

From the results of the CAPEX/OPEX calculations of the base scenario for the long-haul, the high-cost factors components are the whole battery product, the PV panels and the converters. In this section some financial solutions introduced in the previous section are proposed for the acquisition for each of these high-cost factors.

Financial leasing for PV panels and converters

Given high price and the long lifespan of the PV panels (20 years) and the converters (11 years), and the fact that their performance does almost not decrease during it, both could be good options for a financial leasing.

To have an idea of how much would a leasing contract for these components would cost for the costumers during the leasing term, approximate calculations of the lease monthly payments were made including the interest expense with an annual interest rate of 5% but not including the depreciation. Furthermore, the obtained values were compared with ones obtained with an online lease calculator.

To calculate the monthly interest expense the following formula was used, where the time period in days was approximated to 30 days.

Since the lifespan of the PV panels is around 20 years, and as mentioned before the durations of the lease period cover at least 75% of the lifespan of the asset, the lease period should be 15 years.

Table 5.6 shows the result of the calculations and the online lease calculator.³⁶

³⁶ www.calculator.net/lease-calculator.html?ctype=fixrate&cloanamount=1082685+&cresidualvalue=0&cloantermy=15&cloantermmm=0&cinterestrate=5&cmonthlypay=400&x=58&y=7

Table 5.6: Costs for leasing of PV panels

PV Panels	Our calculation [€]	Online calculator [€]
Asset value	1,082,685	1,082,685
Total interest expense	402,669.80	458,439.72
Total	1,485,354.80	1,541,124.72
Monthly payment	8,252.00	8,561.80

Since the lifespan of the PV panels is around 11 years, and as mentioned before the durations of the lease period cover at least 75 % of the lifespan of the asset, the lease period should be 8 years.

Table 5.7: Costs for leasing of converters

converters	Our calculation [€]	Online calculator [€]
Asset value	2,165,370	2,165,370
Total interest expense	431,590.80	466,317.46
Total	2,596,960.90	2,631,687.46
Monthly payment	27,051.70	27,413.41

Renting a battery

To determine rental battery prices the following three points should be considered:

1. **Rental cost per battery:** What is the monthly or annual rental cost per battery?
2. **Number of batteries:** How many batteries does your client plan to rent for their depot?
3. **Expected battery lifespan:** How long is the expected lifespan of the rented batteries before they need replacement?

Table 5.8: Overview price for the rental battery

Cost of battery product	3,964,100.0 €	From the price list
Installation Cost	509,670.0 €	From the price list
Total Cost	4,473,770.0 €	The client should pay this much every 10-15 years(optimal lifetime of battery)
	447,377 €	10% of the total cost- this is an assumption based on the battery rental cost. (Original scenario -The electric vehicle owner can just rent or swap the battery, when it is out of charge or they want to replace it)
Rental price	37,281.42€	For 1 month

Total evaluation	4,473,770.0€	Considering the lifetime as 10 years.
------------------	--------------	---------------------------------------

Renting a battery could be advantageous when it is about Battery lifecycle management. Renting batteries also relieves the client from the responsibility of managing the end-of-life disposal or recycling of the batteries. The rental provider typically takes care of this aspect, ensuring proper environmental practices are followed.

The depot consumes electricity for various purposes, such as lighting, equipment operation, charging electric trucks, and other electrical loads. The AC electricity generated by the PV system is consumed directly by the depot's electrical loads, reducing the reliance on grid power. The batteries rented from the key suppliers mentioned could be used to store energy which will be used for charging electric vehicles.

5.6.7 VAWT

VAWT-technology is on the market but only considered in the chapter *Wind Turbines* as an interesting option for the future. Since it is still not technical feasible to use these, no further calculations are considered.

5.7 Key partners

In this chapter, you will find an overview over key suppliers and producers.

5.7.1 PV

The following list is ordered based on quality:³⁷

Germany	China	Worldwide
	biggest PV manufacturer – but not clear weather Polysilizium with forced labor from region Xinjiang	
Solarwatt – mono- und polycrystalline module (private homes/small industry) whole PV solution (converter, energy storage, energy management system)	JA Solar mono- and polycrystalline modules conventional solar modules and “HC”-modules	SunPower Maxeon, USA Good quality Good efficiency of modules Known for innovation and sustainability → 40 years guaranty
Axitec (Global Player) - mono- und polycrystalline modules	LONGi Solar monocrystalline modules	REC, Norway Solar panels, solar cells, and silicium production High power 360 Watt and 430 Watt modules Winner 2023: inter Solar Award

³⁷ <https://gruenes.haus/solarpanel-solarmodul-hersteller/>

Q Cells (Global Player) 2012 bought from Korean group Hanwha → good quality but quite cheap prices	ZNShine - patent on graphene-overlayer	Canadian Solar, Kanada Manufacturer of wafer, solar cells, solar modules and custom-made solar systems → specialized in cristalline modules
	Trina Solar	Sharp Japan - Semiconductor researcher, "HC"-modules, 365 – 540 Wp Warranty 30 years
		First Solar Inc, USA Thin-layer cells, eta=18,6% Mostly for industrial application Much cheaper than cristalline modules 455 WP Warranty only 10 years

Suppliers Polysilicium

- China (Tongwei, DCL Technology, Daqo New Energy)
- Germany (Wacker Chemie, market leader 2016-2019)

Suppliers Wafer

- Shin-Etsu Chemical
- Sumco
- Globalwafers
- Siltronic AG
- SK Siltron
- Soitec
- Wafer Works
- Okmetic
- Episil
- Xinsheng Semiconductor

5.7.2 Battery

Companies from Europe³⁸

- Northvolt
- Polarium
- Evyon
- The Mobility House

³⁸ <https://storm4.com/resources/energy-storage/6-energy-storage-companies-in-europe/>

Companies across the World:

Mostly they are known for EV-batteries, which are often LFP solutions. Hence they are compatible for stationary energy storage systems.

Manufacturer	Founded in	Country of Origin	Production in 2022 (Jan-Oct)
CATL	2011	China	137.7 GWh
LG Energy Solution	1992	South Korea	53.7 GWh
BYD	1995	China	51.5 GWh
Panasonic	2012	Japan	30.8 GWh
SK On	2021	South Korea	24.1 GWh
Samsung SDI	1970	South Korea	18.9 GWh
CALB	2015	China	16.3 GWh
Gotion High-Tech	2006	China	11.3 GWh
Sunwoda	2018	China	6.5 GWh
EVE Energy	2001	China	5.1 GWh
SVOLT	2018	China	5.05 GWh
Farasis	2002	China	4.19 GWh
Northvolt*	2015	Sweden	<1.0 GWh

**Northvolt is a special mention on our list, as it is the first European lithium-ion battery cell manufacturer.*

5.7.3 Converter

[Huawei Technologies Co., Ltd.](#)

Huawei's FusionSolar residential inverter portfolio. The company provides FusionSolar smart PV solutions for commercial, residential, and utility applications.

The following are included in their portfolio:

- Smart Energy Controller (single phase)
- Smart Energy Controller (three phase)
- Smart String Energy Storage System
- Backup Box
- Dongle-WLAN-FE/4G
- Smart PV Optimizer
- Smart Power Sensor

The FusionSolar Smart PV Management features a single app for all the access procedures. Moreover, it enables one-click ticket dispatching and site navigation, centralized management of multiple plants and module-level monitoring.

Huawei's FusionSolar utility and commercial portfolio includes a versatile range of smart string inverters and digital PV solutions with significant features such as:

- 4/6/9/10 MPPTs (maximum power point tracking) for adaptability to different layouts
- 8/12/18/20 strings for fast troubleshooting and intelligent monitoring
- AI-powered AFCI (arc-fault circuit interrupter) to proactively reduce fire risk
- Upgraded safety with < 0.5% failure rate

Sungrow Power Supply Co., LTd (China)

String Inverters, Central Inverters and Turnkey Inverters

SMA Solar Technology AG (Germany)³⁹

Their product has a longer lifespan and of top quality.

SolarEdge

Fronius⁴⁰

Symo Hybridwechselrichter with high efficiency of 98,2

ABB

produces inverter from 2 kW up to 120 kW, these are of really high quality. They also bought the company Power-One who originally manufactured inverters.

Market share – converter 2019

- Huawei 22%
- Sungrow 15 %
- SMA 8 %
- ABB 5%
- Solaredge 5%

5.7.4 Leasing/ Renting of PV modules

This is still a new financing option and not many companies provide this as a financing model.

Leasing/renting for private homes

- Enpal⁴¹ battery storage included

Leasing/renting for companies

- Enviria⁴²
- Sunvigo⁴³ EMS and battery storage included, service for laws and tax as well
- Autark21⁴⁴ PV, battery storage, charging infrastructure
- DoLeasing⁴⁵ only PV modules, converter
- DZ4⁴⁶

³⁹ <https://echtsolar.de/wechselrichterhersteller/>

⁴⁰ <https://echtsolar.de/wechselrichterhersteller/>

⁴¹ <https://www.enpal.de/ueber-uns>

⁴² <https://enviria.energy/en/explore-our-services/rent-a-rooftop-solar-system>

⁴³ <https://www.sunvigo.de>

⁴⁴ <https://autark21.de/leasing-fuer-gewerbekunden/>

⁴⁵ <https://doleasing.de/leasing-solar-photovoltaik/>

⁴⁶ <https://www.dz4.de/>

5.7.5 Possible investors

- Abcfinance⁴⁷ supports especially leasing models for PV
- Deutsche Leasing → DAL Deutsche Anlagen-Leasing GmbH & Co. KG⁴⁸
- Tradingtwins⁴⁹
- Munich Re → Transfers assets from Balance sheet of Manufacturer to SPV (Special Purpose Vehicle)⁵⁰
- Linx4 → Pay per use Financing⁵¹
- Commerzbank/Sparkasse → Pay per use credit-based Financing

Future investment offerings into decentralized renewable energy supply can be expected from: TW – TerraWatt, eolia, Formenergy, Group14, AscendElements, GridServe, Arcadia and Redaptive⁵²

5.7.6 Possible Industrial Internet of Things (IIoT) providers

- Relayr-⁵³
- Siemens Advanta⁵⁴
- Software AG⁵⁵
- Hitachi⁵⁶
- ABB⁵⁷

⁴⁷ <https://www.abcfinance.de/leasing/photovoltaikanlagen-leasen/>

⁴⁸ <https://www.deutsche-leasing.com/de/loesungen/spezialloesungen/infrastruktur-und-versorgung>

⁴⁹ https://www.tradingtwins.com/lp/de/gewerbe-leasing/1?ext_cmp=11065294711&ext_adg=114192732691&ext_kw=firmenleasing&ext_mt=p&ext_ad=463230060927&ext_adp=&gad=1&gclid=Cj0KCQjwwISlBhD6ARIsAESAmP4v8JAifXWI7VxVUVLzAxiTpFNyVEjJzr1jqQ-JleooWRc5P_QLOkMaAp2vEALw_wcB

⁵⁰ <https://www.munichre.com/en/company/media-relations/media-information-and-corporate-news/media-information/2020/2020-10-14-pay-per-part.html>

⁵¹ <https://www.linx4.io/linx4-insights>

⁵² <https://pv-magazine-usa.com/2023/02/21/energy-storage-funding-up-55-28-companies-acquired-in-2022/>

⁵³ <https://www.munichre.com/en/company/media-relations/media-information-and-corporate-news/media-information/2020/2020-10-14-pay-per-part.html>

⁵⁴ <https://www.siemens-advanta.com/>

⁵⁵ <https://www.softwareag.com/>

⁵⁶ <https://www.gartner.com/doc/reprints?id=1-2BY92VID&ct=221209&st=sb>

⁵⁷ <https://www.gartner.com/doc/reprints?id=1-2BY92VID&ct=221209&st=sb>

6 Business Model

6.1 Business Model Design

To decide for a way to enter the market of decentralized energy supply, it is necessary to assess different business opportunities for DTAG. With the help of the “sustainable business model canvas” different business model designs were developed.

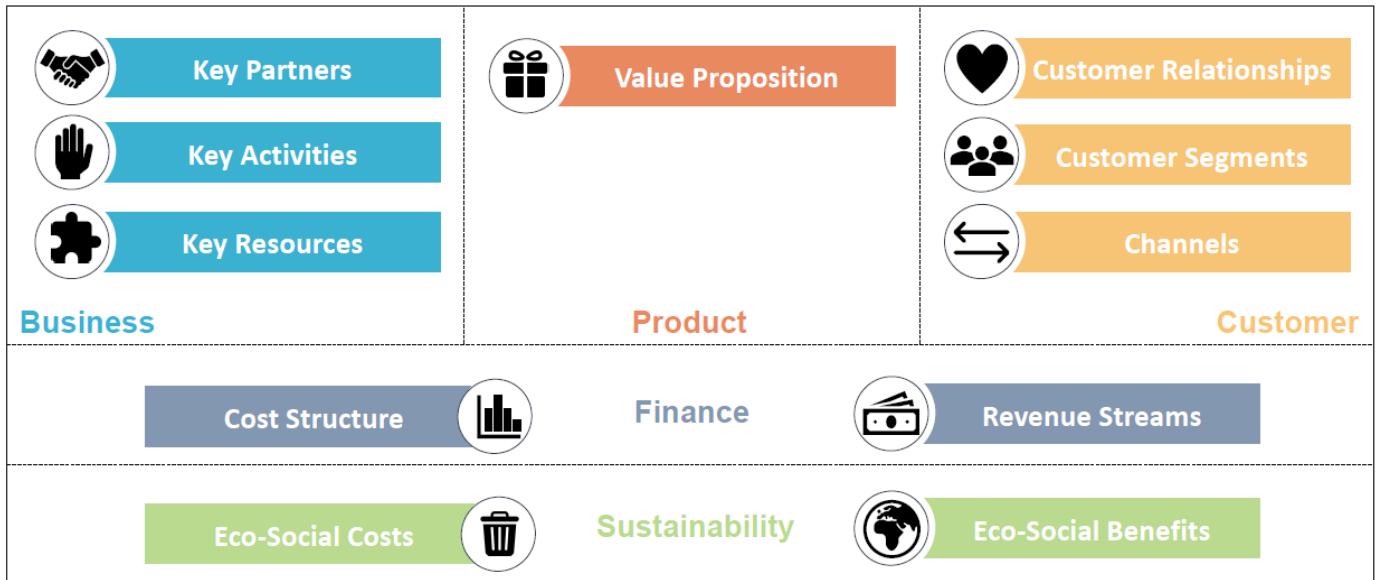


Figure 6.1: Sustainable business model canvas

The canvas consists of eleven building blocks which were summarized to five parts: Customer, Product, Finance, Business and Sustainability. How DTAG can interact with different customer segments, which channels and customer relationships are suitable is outlined in the **Customer** part. The different customer segments are explained in the Customer Personas. Values which can be created by DTAG is explained in the **Product** part. To ensure an economic viable solution the cost structure and revenue stream are assessed in the **Finance** part. The **Business** part assesses key partners, activities and resources required for the value proposition. In addition to the classical canvas, the **Sustainability** of the solution is assessed by looking at eco-social costs and benefits to ensure a sustainable offering.

6.2 Customer

When looking at the customer, the different customer segments and customer relationships are assessed and the channels to approach the customer are identified.

6.2.1 Customer Segments

To ensure that the business plan contains the needs of different customer profiles, we build on the customer personas mentioned in section *Customer Personas* as our customer segments. The most important needs for each of the customer personas have been derived from the customer needs described in section *Customer Needs*. Following, the main needs of the three customer personas are described as well as depicted in *Figure 6.2*.

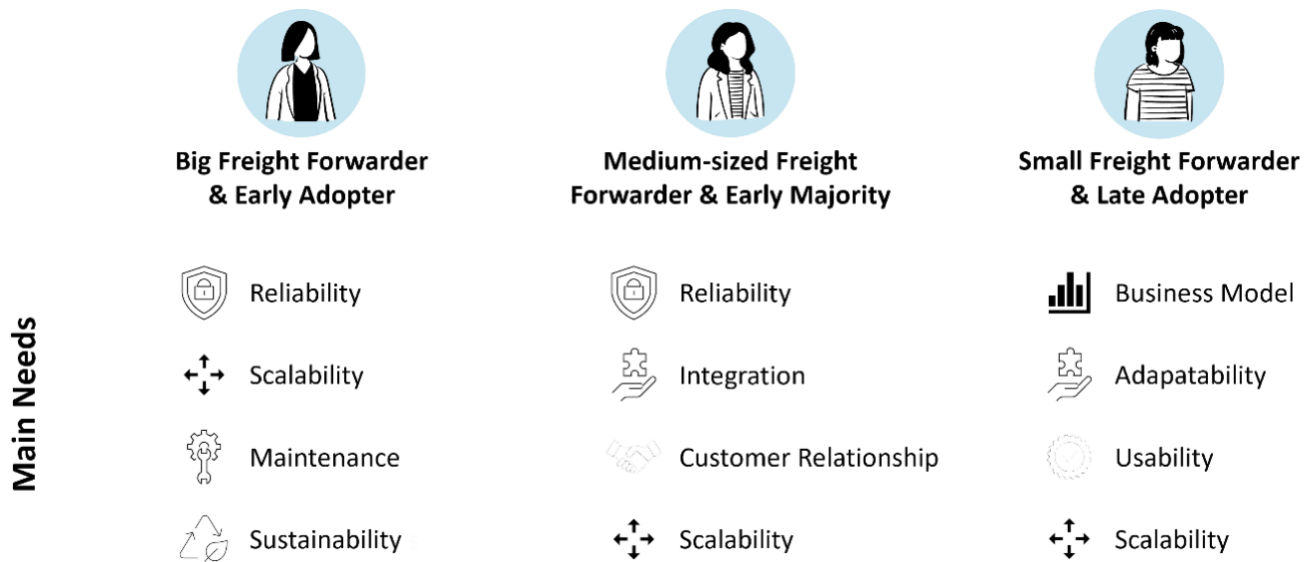


Figure 6.2: Customer segments and their main needs

The **big freight forwarder & early adopter** need the system to work reliably as high costs are at stake. Even small interruptions are fatal for the business. Furthermore, it's important that they can scale it up if they expand and grow further. Maintenance of the depot is crucial as well as it brings new challenges that the customer might not yet be familiar with and thus may prefer it to be handled by DTAG. Additionally, sustainability is an increasing factor in the image of a company and thus also of high importance.

The **medium-sized freight forwarder & early majority** also prioritize reliability for the above-mentioned reasons. Furthermore, it's important that they can integrate the new system in potentially already existing systems they might have. This goes hand in hand with the scalability and thus the possibility to expand. Last but not least, they also put emphasis on customer relationship.

The **small freight forwarder & late adopter** will only change when the system has been proven to be reliable and when it is more common and thus also less expensive. They want a flexible business model tailored to their needs and they need to be more flexible. They therefore prioritize adaptability. The system should furthermore be easy to use as there potentially are no human resources in a small business to handle a more complicated system. Additionally, the system should again be well scalable and allow for expansion and changes.

6.2.2 Customer Relationships

We suggest offering a **dedicated personal assistance** to the customer, which means that each customer has one or two specific employees at DTAG that are always the first contact point for the customer and coordinate the other partners (e.g. Key Account Managers). This type of assistance is more expensive and mostly needed for major customers that have several bigger depots to manage.

For smaller customers, **personal assistance** is suggested as it is less expensive but still entails quick human support from consulting over sales to operation and maintenance. In contrast to dedicated personal assistance the customer will not have one specific single contact-point at DTAG but still profits from DTAGs knowledge.

24h-support will be provided for urgent problems, also happening outside of office hours. It is of high importance as even small interruptions can be detrimental to the customer's business and is included for all customers. This ensures that the customers' need of high reliability can be satisfied.

The customer has the choice to choose the type of assistance needed for the different phases. If wished, they have the option to benefit from continuous services by DTAG over whole lifetime of the depot and the trucks. The assistance can be tailored to the customers' needs in the different phases and thus provide them with the needed flexibility. Through the mentioned assistance models the customer gains a strong attachment to DTAG and its offered services which leads to high customer loyalty and long term relationships.

Awareness and Customer Acquisition

The customer acquisition can be done through sustainability campaigns and other forms of advertisements. This can bring the awareness of the idea to a wide range of potential customers, however is not very specific. Additionally existing DT customers can be approached directly through their Key Account Manager and get the new solution pitched with all its advantages. Existing customers that had good experiences with DTAG before might be more willing to invest as they already have the trust in the company. Furthermore, big operators should be approached first and can be contacted directly.

Evaluation and Purchase

A free assessment could be offered so that customers can explore the possibilities of the idea and their depot without any binding costs. This might bring more potential customers to think about the offered services and thus get into contact with DTAG. The customer gets a personal contact throughout the whole evaluation and purchase phase and benefits from the expertise of DTAG at consulting, planning and the organization of the implementation.

Operation and Maintenance

The 24h-service helps to ensure the needed 100% uptime of the trucks and the depot. Furthermore, optional support with the operation of the depot is given. The type of assistance for the individual customer can be chosen depending on the individual needs during the use phase.

6.3 Product

The main goal of the value proposition is the fulfilment of customer needs (see chapter *Customer Needs*). The proposed solution should create gains for the customer and relive pain points.

The proposed product is a **modular package of services**, which can be adjusted as needed by the different customer segments. By allowing the customer to adjust the service according to their own situation and needs, the modular service significantly increases the convenience and decreases the amount of planning they must do themselves. The important customer needs, reliability and maintenance, are addressed by optimizing the design of the depot and a 24h service for maintenance to ensure full availability of the trucks. Since DTAG will build up internal knowledge on how to best build these charging depots, they will be able to design better depots than customers doing it on their own for the first time.

Services, such as initial consulting, planning and maintenance will be offered by DTAG. Products like the physical infrastructure will be offered by partners, so there is no investment from DTAG in their customers infrastructure. DTAG acts as a facilitator between their customer and the product partners. This can either be a partner recommended by DTAG or a long-term partner of the customer if desired. Since DTAG is bundling all planning activities they can ensure a working final product for their customer and decrease the number of partners the customer has to have individual contact with.

Depending on the customers wishes the offered services can cover the entire process from initial consulting, planning and the implementation to operation and maintenance, like it is explained in *Figure 6.3*. Naturally, depending on the chosen services the prices will vary. This ensures that

even customers with a limited budget can get services and assistance to set up the right depot for their needs.



Service Offering by DTAG

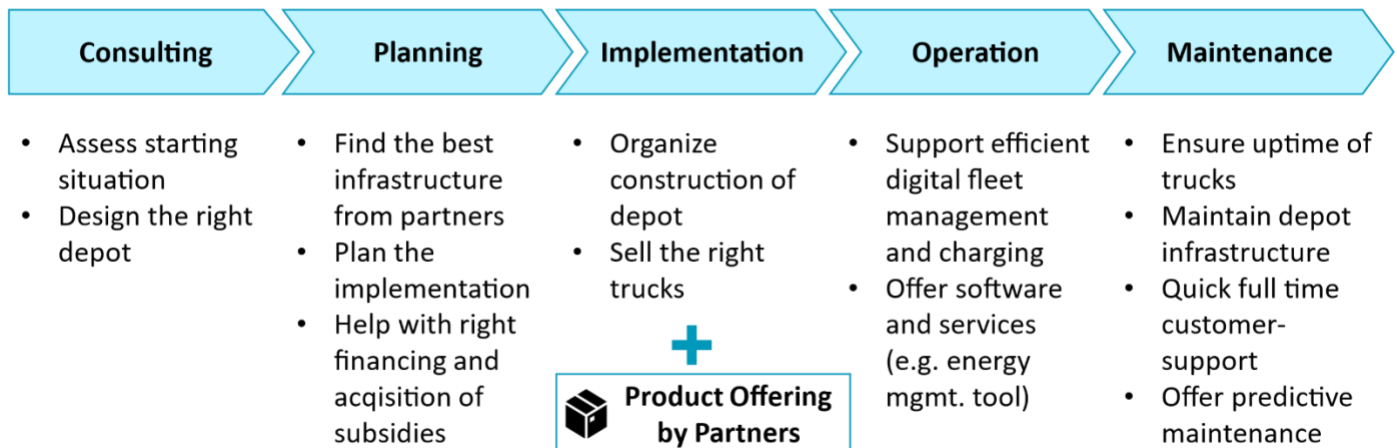


Figure 6.3: Modular service offering by Daimler Truck

6.4 Finance

Since the technical solution is always based on the same components, the following list shows all the components that were considered for the financial calculation. Only number of components or rather its dimension changes between the cases. Since all the calculations and its results is showed in detail in subchapter *Calculation and Analysis*, information is summarized in this chapter to create an overview of the business model.

6.4.1 Cost structure and revenue stream for customer

The technical solutions for all the scenarios provide a network of PV Modules, converter, batteries, chargers, a grid connection and of course the trucks as you can see in *Figure 6.4*. Only dimension of the components and number of components change between each scenario.

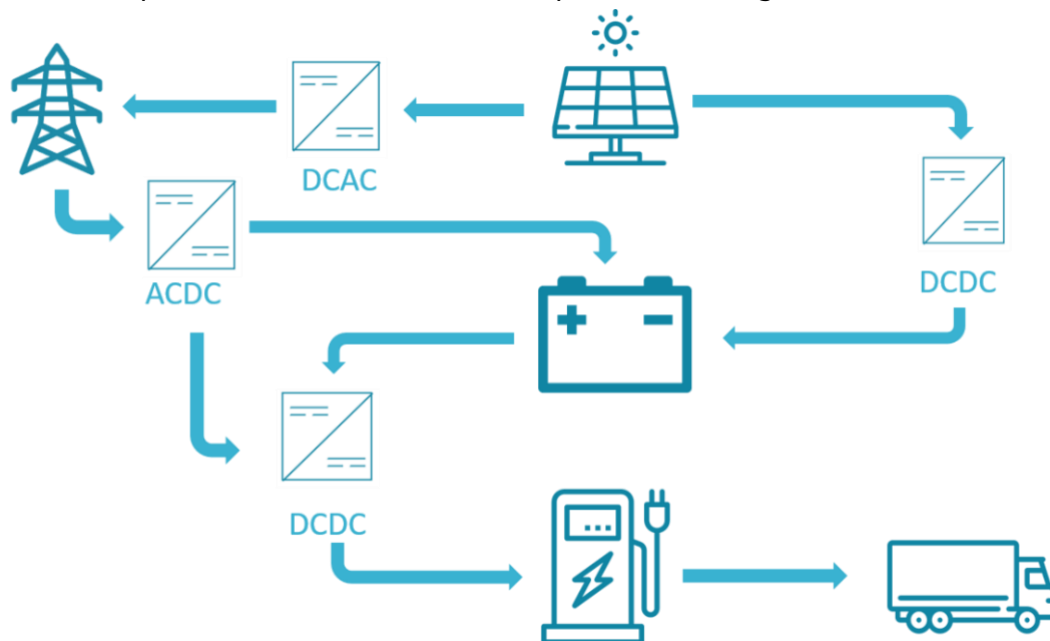


Figure 6.4: Technical solution infrastructure

CAPEX Customer

- PV modules
- Converter (Central Converter solution)
 - DC/DC - Converter (between PV-modules and battery storage, between battery storage and chargers)
 - DC/AC - Converter (between PV-modules and electrical grid transfer point)
 - AC/DC - Converter (between grid transfer point and battery storage or charger circuit)
- Battery (price based on price for 2nd life battery storage on KEM)
- Cables
- Energy management system
- Charger
- Transformer
- Installation costs

OPEX Customer

- Maintenance (Battery, Grid connection – for further maintenance no prices are found, so only battery and grid connection maintenance are included in the financial calculation)
- Imputed interest
- Depreciation of components
- Grid electricity energy costs

Highest Cost factors for depot solution – for all scenarios

PV-modules, Converter and Batteries, as well as battery installation and PV-module installation are the highest CAPEX cost factors for the customer. Further is battery maintenance a very high cost position in OPEX as well. These components have a strong influence on the initial investment of the customer. Therefore financial solutions must be available. Else the customer may not being able to afford the infrastructure necessary for the Electrical DTAG trucks is the risk.

Saving and Revenues Streams for the Customer

Calculated savings as part of the revenue streams is the release of refuelling diesel, since the solutions is based on electrical trucks. Another saving emerges because of the renewable energy gained on the depot, that is used to charge the trucks. The saving than includes all the electrical energy that is not requested from the electrical grid but used from the depot generation and storage. Further there is the electrical energy surplus – especially in summer – that can't be stored anymore. This surplus is sold to the local energy supplier and fed into the electrical grid.

6.4.2 Financing solutions

To decrease the customers initial invest to built up the depot infrastructure for renewable energy supply, there are three financing models useful. First two, Renting and Leasing solution, will be connected with each other. As third option the Pay per use – model is described.

Renting/Leasing model

In this financing model the Renting (batteries) and Leasing (PV-modules, converter) contract is signed by the customer and a DTAG key partner that provides the required component. DTAG position in this business relationship is, beside selling trucks to the customer, being a service

provider to the customer and a contact provider between customer and component supplier. The customer pays for the service and DTAG will get a mark up from the supplier for every successful contract DTAG arranged between the supplier and the customer. This model requires the key partner to offer a renting or rather leasing contract.

Pay per use model

If no renting or leasing solutions is possible a third option exist - the pay per use – model. Here the customer contracts with an investor, that pay instead of the customer the CAPEX of the depot decentralized energy solution. In this model the component suppliers get their full payment up front. The customer is only in debt to the investor. As financing option, a pay-per-use credit is possible for the customer. The customer then takes out financing from the bank at an interest rate based on the use of the asset. Second option to finance is by means of a special-purpose vehicle (SPV). A special purpose vehicle is a subsidiary created by a parent company for a variety of purposes. The SPV can be used to isolate financial risk, securitize assets, and perform separate financial transactions. The SPV is a structure that offers a solution that is in many ways similar to the approaches of original equipment manufacturers (OEMs) in the automotive and mechanical engineering sectors that have their own captive finance companies for sales financing. In this model, the manufacturer sells the asset to the SPV, receiving payment of the purchase price. The SPV becomes the owner of the asset, offers it to the user, and in return receives use-dependent cash flows.

6.4.3 Cost Structure and Revenue Stream for DTAG

Multiple revenue streams for DTAG have been identified. No matter what financial model from customer side will be chosen or will be offered from DTAG side, the revenue streams stay the same.

The first revenue stream is coming from the customers.

All operational expenses that come with the yearly maintenance of facilities as well as installation costs, DTAG would pass on to the customer. EConsultancy and DTAG initial capital expenses must be priced by DTAG. Project based pricing, hourly based pricing and value-based pricing could be considered for pricing approaches.

The second revenue stream is payed from the suppliers, consisting of a mark-up of the customers expenses. This income is therefore dependant on the customer's individual project scope. Assuming a mark-up of 10%, in the base scenario eActros 300 a revenue of 370.000 € (720.000 €) would be generated (PV + battery + converter)

6.5 Business

6.5.1 Key partners

DTAG needs key partners to ensure depot infrastructure components for decentralized energy solution are available and affordable for the customer. Contracts with between DTAG and component suppliers ensure quality standards and well-known technologies DTAG reliable can provide services for. Key partner for the following technologies are needed.

Technology Contract with DTAG

- Main supplier PV technology
- Main supplier VAWT technology
- Main supplier converter

- 2nd life batterie manufacturer
- Batterie manufacturer

Further for Renting-Leasing-solution it is necessary that key partners provide renting and leasing contracts for the customer. In case of Pay-per-Use model investors have to be available. Further if there are services DTAG does not want to provide on its own, contracts with different service providers are vital. Detailed research on possible key partners was done in subchapter *Key partner*.

6.5.2 Key activities

Key activity is to ensure reliability of all business relationships to ensure a sustainable business model. Therefore, DTAG has to observe revenue streams between the customer and the key suppliers or rather investors. Further the reliability of the infrastructure ensures operability of the truck fleet. DTAG should provide maintenance, high quality service and experts for the technical depot solution on its own, to make quick and reliable service possible. That includes the built up of know-how and know about regulations concerning the technical solution as well.

6.5.3 Key resources

Following up on the last paragraphs key resources DTAG has to build up for the depot decentralized energy supply solution are:

- Contracting and planning personnel
- Experts for maintenance
- Experts for service
- Experts for regulations
- Experts for technologies

6.6 Sustainability

Sustainability is the main goal for the transition towards electric trucks and building of charging depots. Therefore it is necessary to look at the eco-social costs and benefits of the proposed business model.

The main **eco-social costs** in the proposed business model are the necessary resources to produce the equipment. Batteries, PV cells and other necessary products contain many scarce resources such as rare metals. They are expensive and sometimes mined under critical working conditions. An option to reduce the impact the depots have is to use 2nd life batteries. This increases the usage of batteries and reduces the number of batteries which must be manufactured. An end-of-life treatment and recycling also reduces the environmental impact of the depots.

For DTAG a main **eco-social benefit** is the achievement of sustainability goals. Offering the corresponding charging opportunities for their customers has the potential to increase the number of sold electric trucks, therefore reducing the overall emissions of the sold fleet. This can also give DTAG an image as a company passionate about sustainability. The customer naturally can also reach their sustainability goals when adopting these depots. They can also act as a role model by establishing “lighthouse projects” and gain valuable experience early in the transition towards climate-neutral logistics, giving them an edge over their slower competitors. Another benefit is the increased independence through the use of self-generated electricity. Since the produced electricity is 100 % renewable it is also better than the current electricity mix in most electrical grids.

7 Appendix

Output for Den Haag 13 charge cycles of eActros300

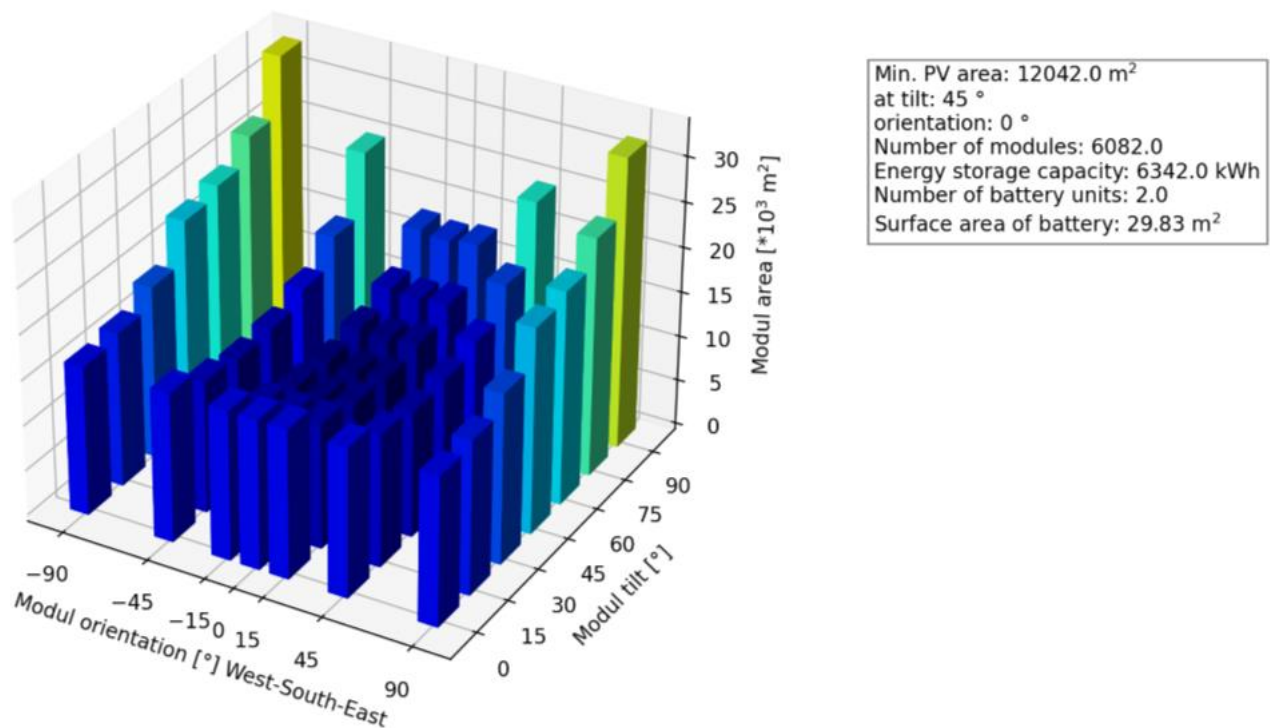


Figure 7.1: Area of needed PV modules according to tilt and orientation and output of optimal position and battery data

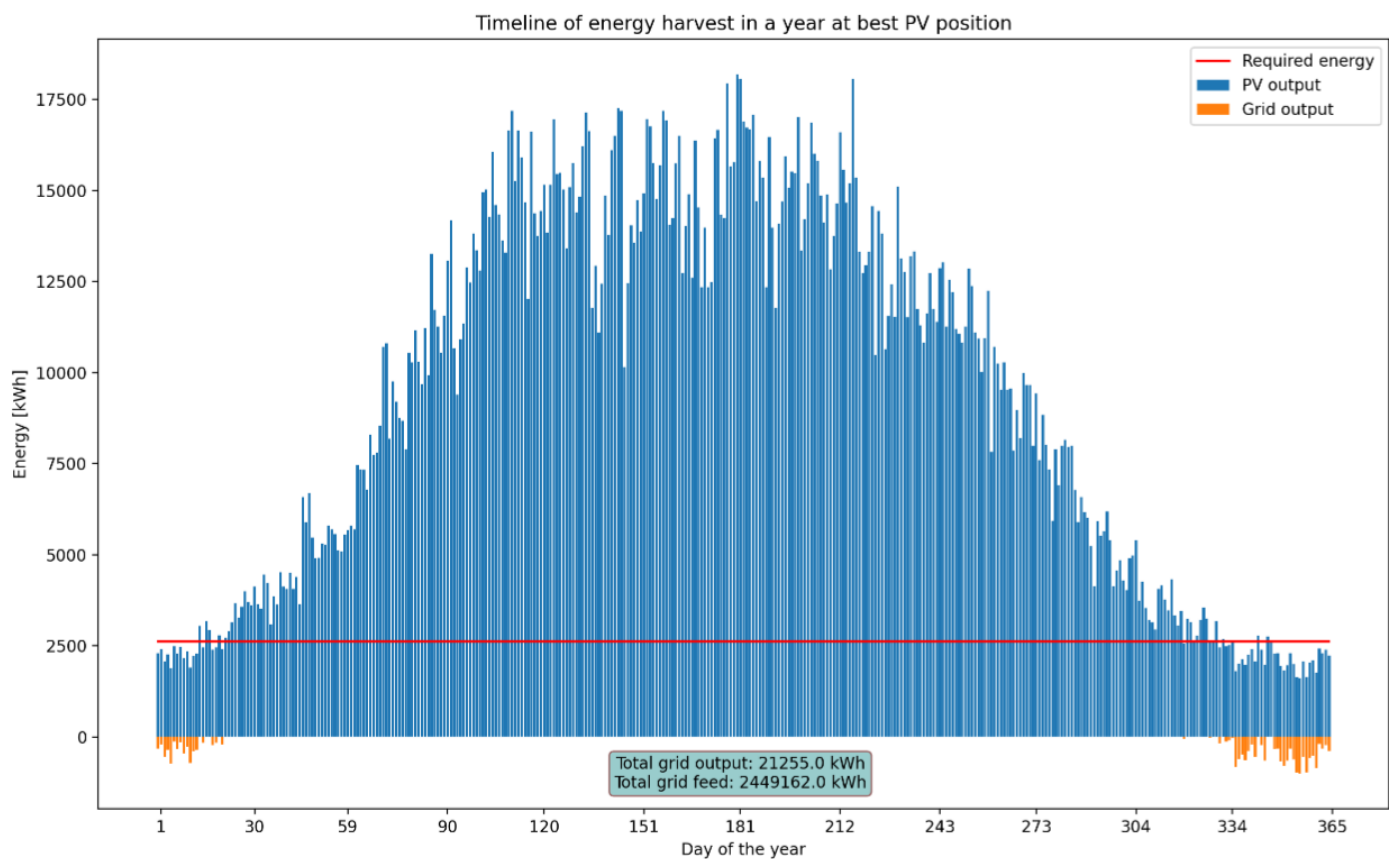


Figure 7.2: Power output of PV panels over a mean meteorological year, grid support and needed power, as well as the total grid output and feed-in

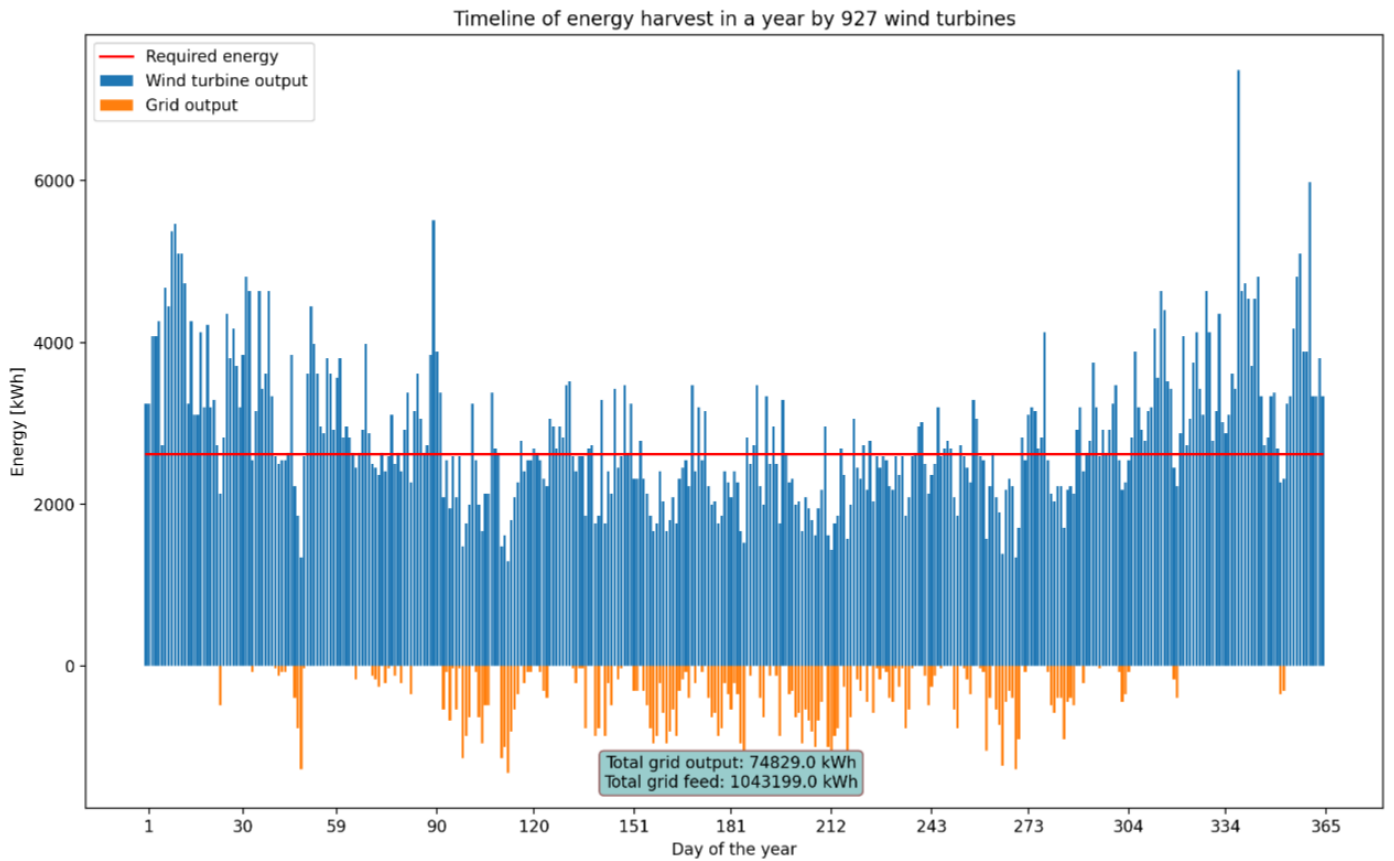


Figure 7.3: Number of needed wind turbines, power output over the mean meteorological year, grid support over the mean meteorological year and total grid feed-in and output

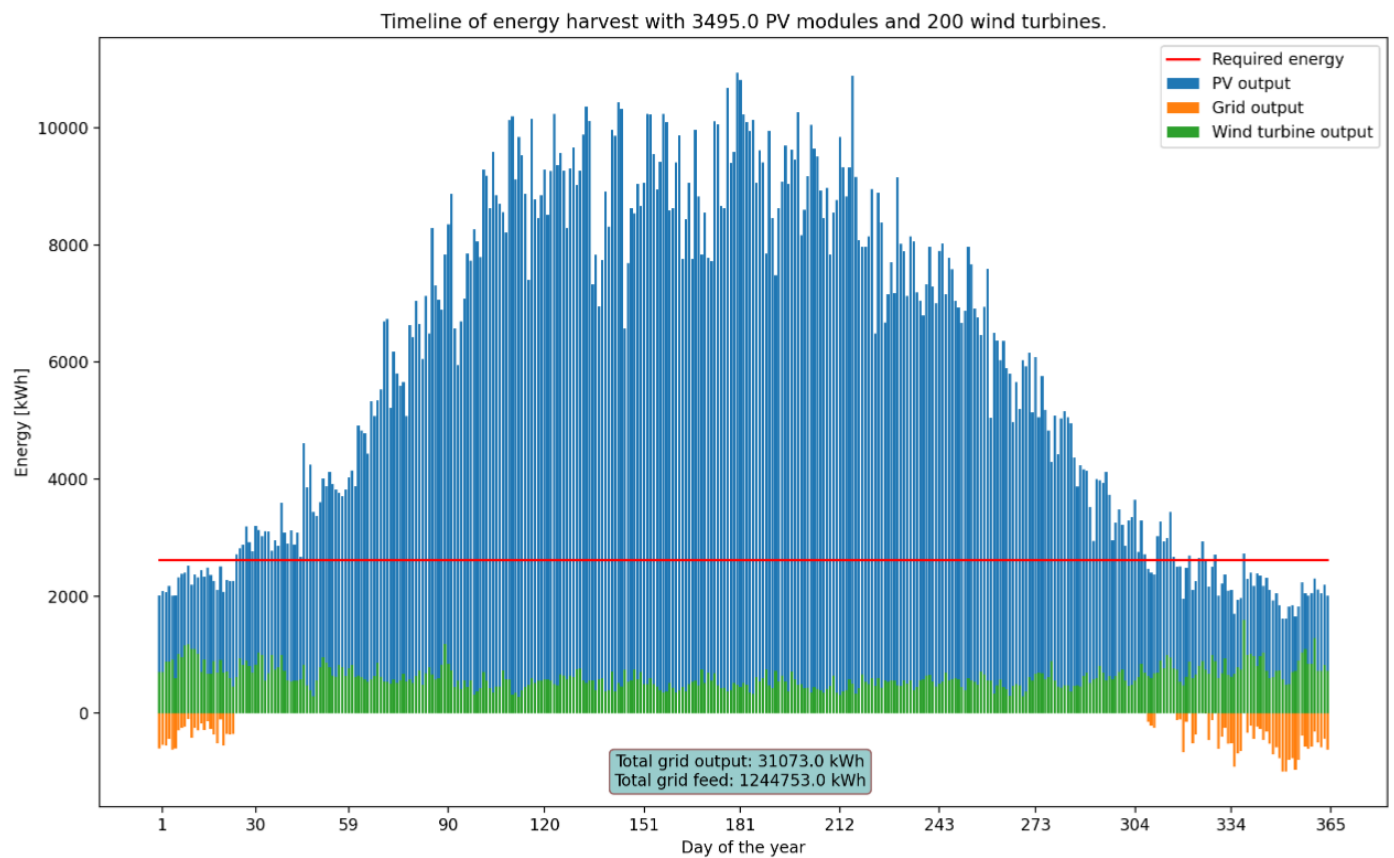


Figure 7.4: Combined PV and wind turbine power output, number of needed PV panels for a set maximum amount of wind turbines, required power, grid output over the mean meteorological year and total grid support and feed-in

Output for Den Haag 13 charge cycles of eActros600

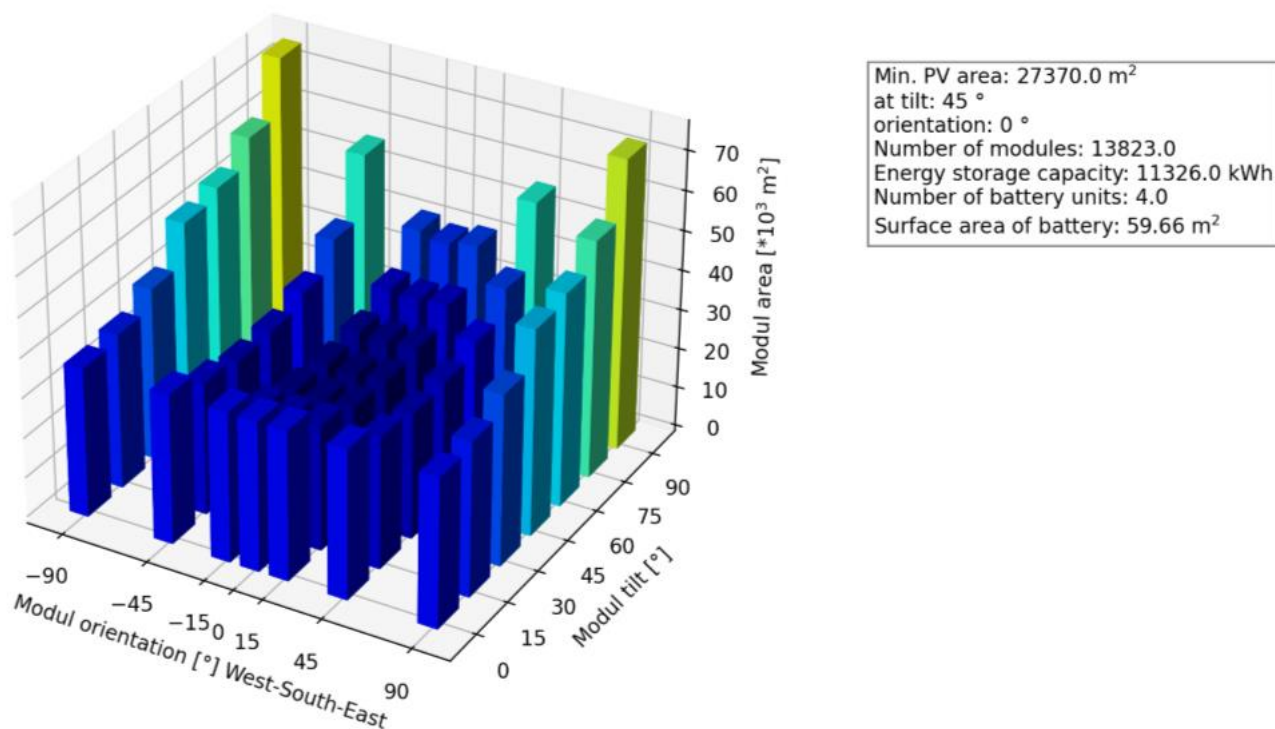


Figure 7.5: Area of needed PV modules according to tilt and orientation and output of optimal position and battery data

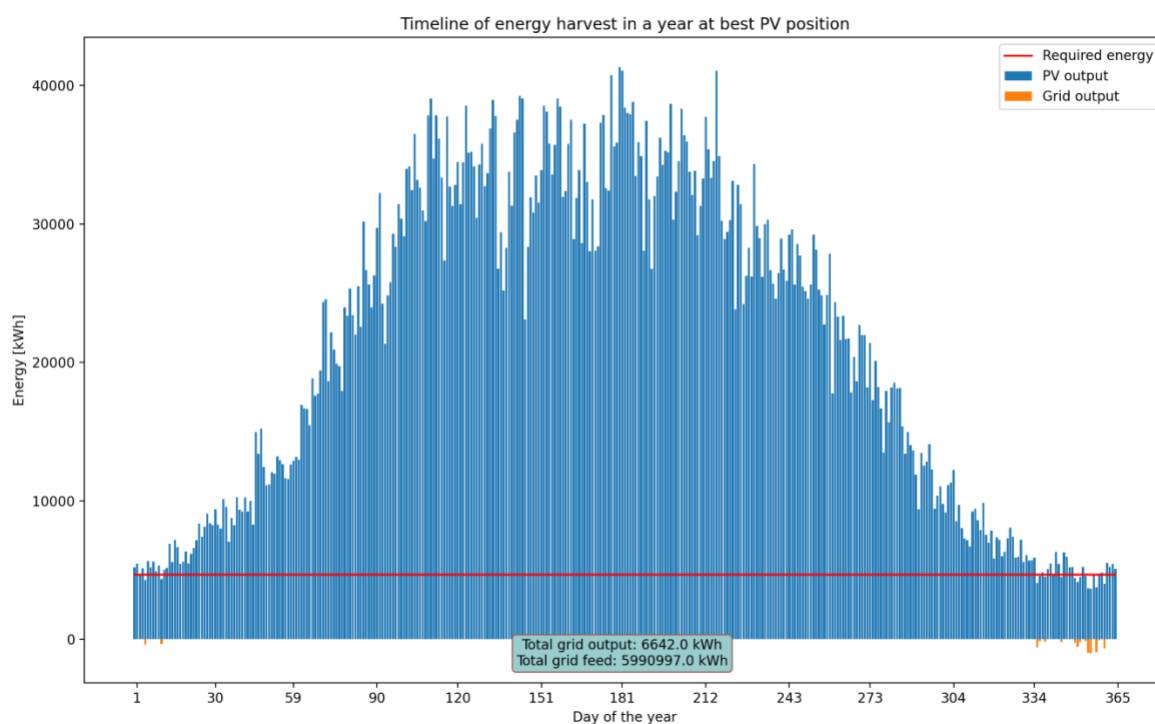


Figure 7.6: Power output of PV panels over a mean meteorological year, grid support and needed power, as well as the total grid output and feed-in

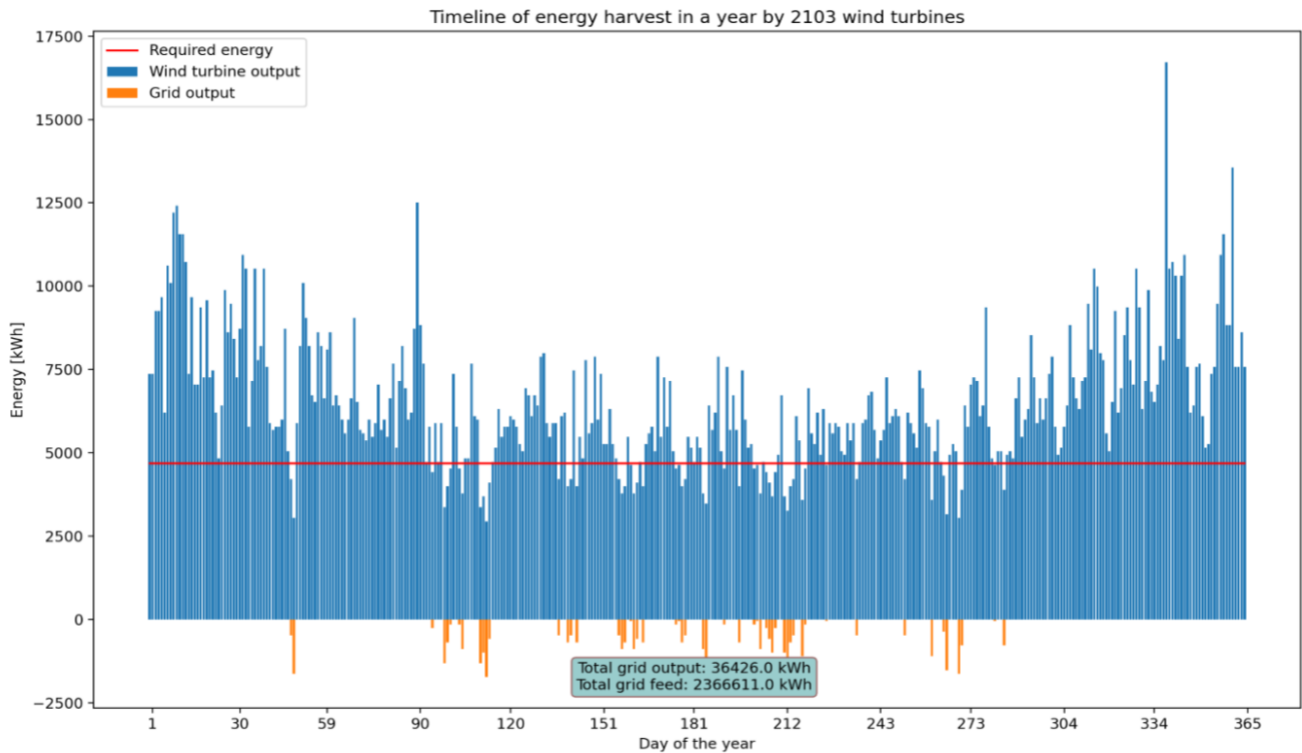


Figure 7.7: Number of needed wind turbines, power output over the mean meteorological year, grid support over the mean meteorological year and total grid feed-in and output

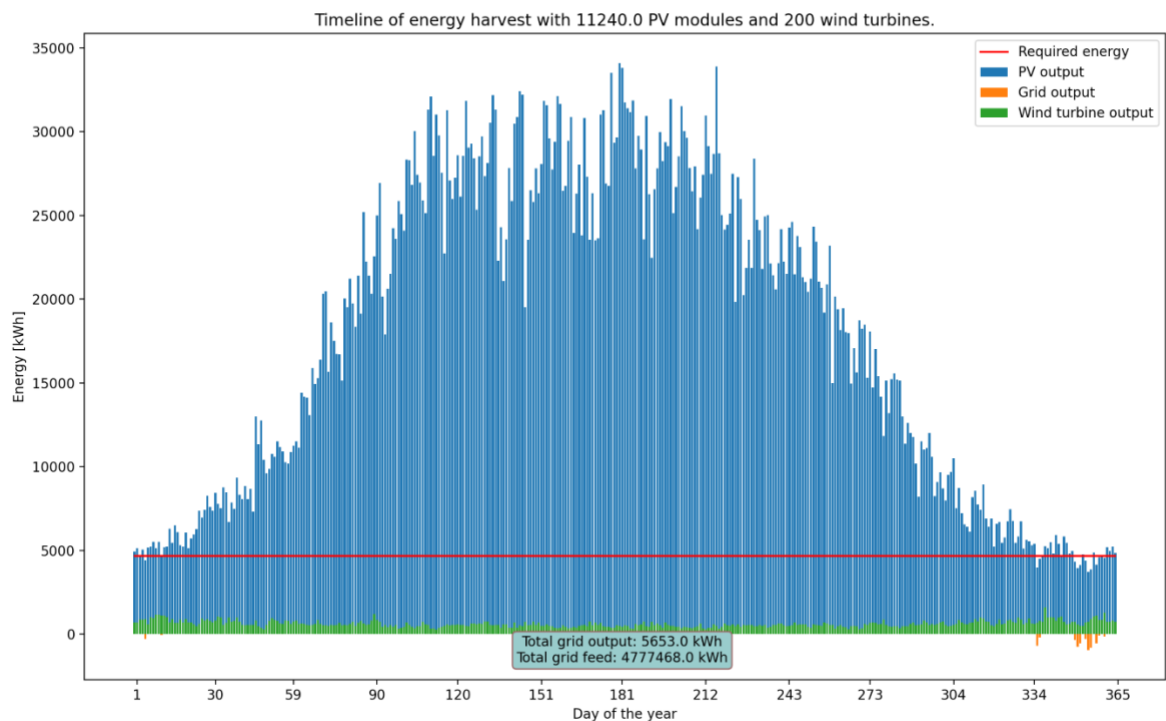


Figure 7.8: Combined PV and wind turbine power output, number of needed PV panels for a set maximum amount of wind turbines, required power, grid output over the mean meteorological year and total grid support and feed-in

Output for Stockholm 13 charge cycles of eActros300

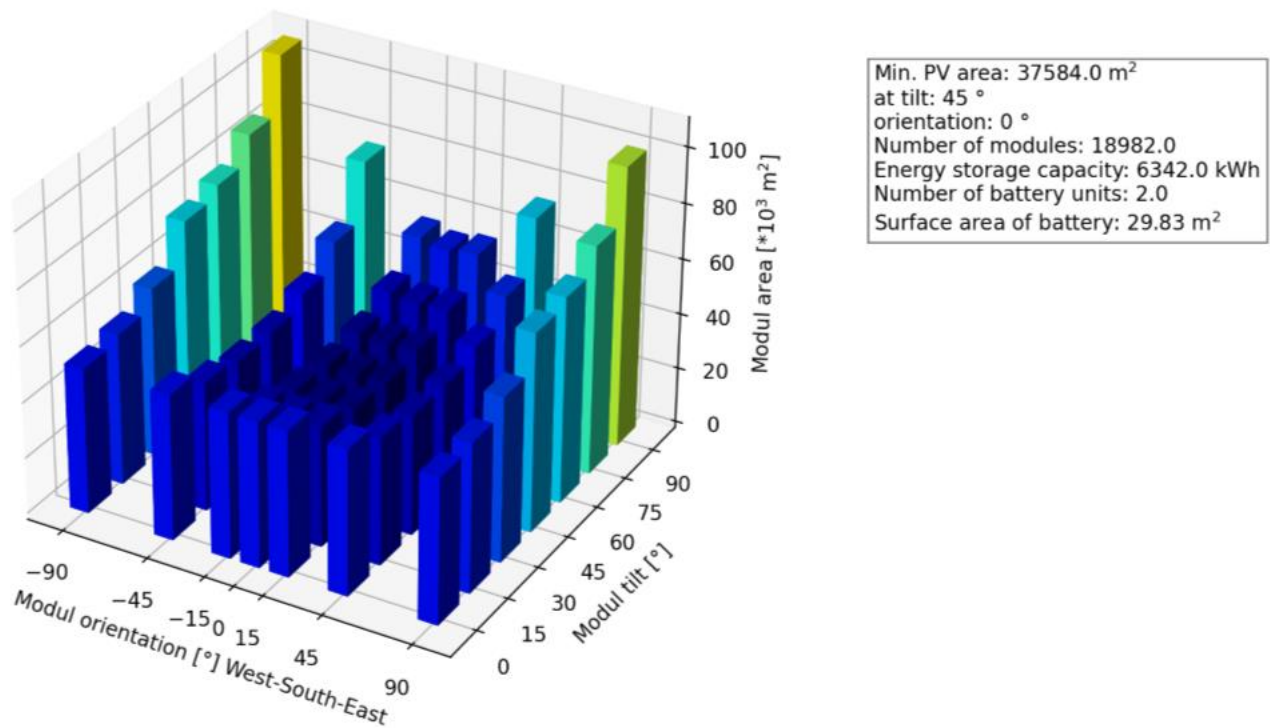


Figure 7.9: Area of needed PV modules according to tilt and orientation and output of optimal position and battery data

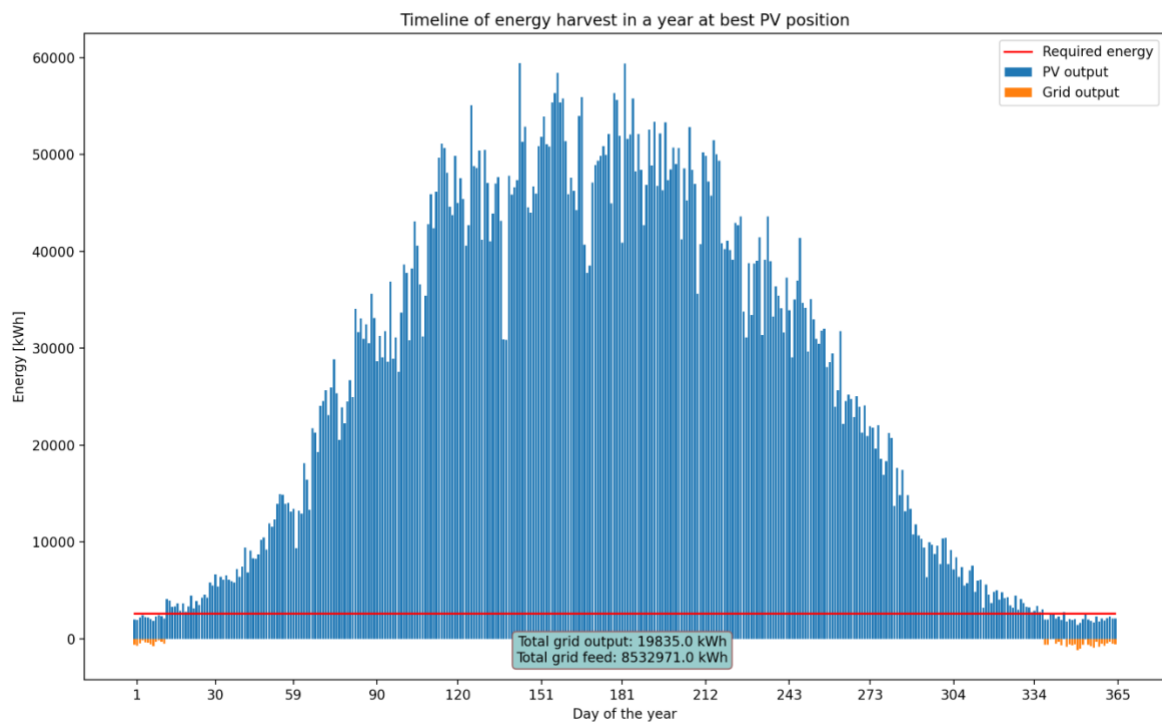


Figure 7.10: Power output of PV panels over a mean meteorological year, grid support and needed power, as well as the total grid output and feed-in

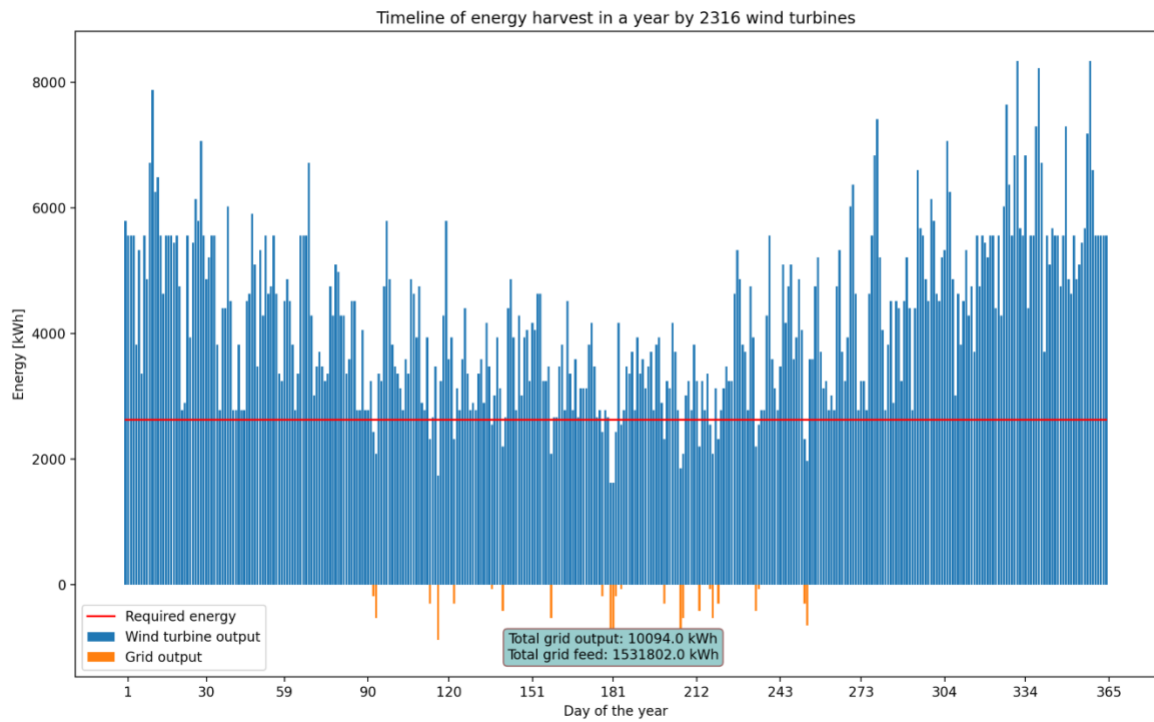


Figure 7.11: Number of needed wind turbines, power output over the mean meteorological year, grid support over the mean meteorological year and total grid feed-in and output

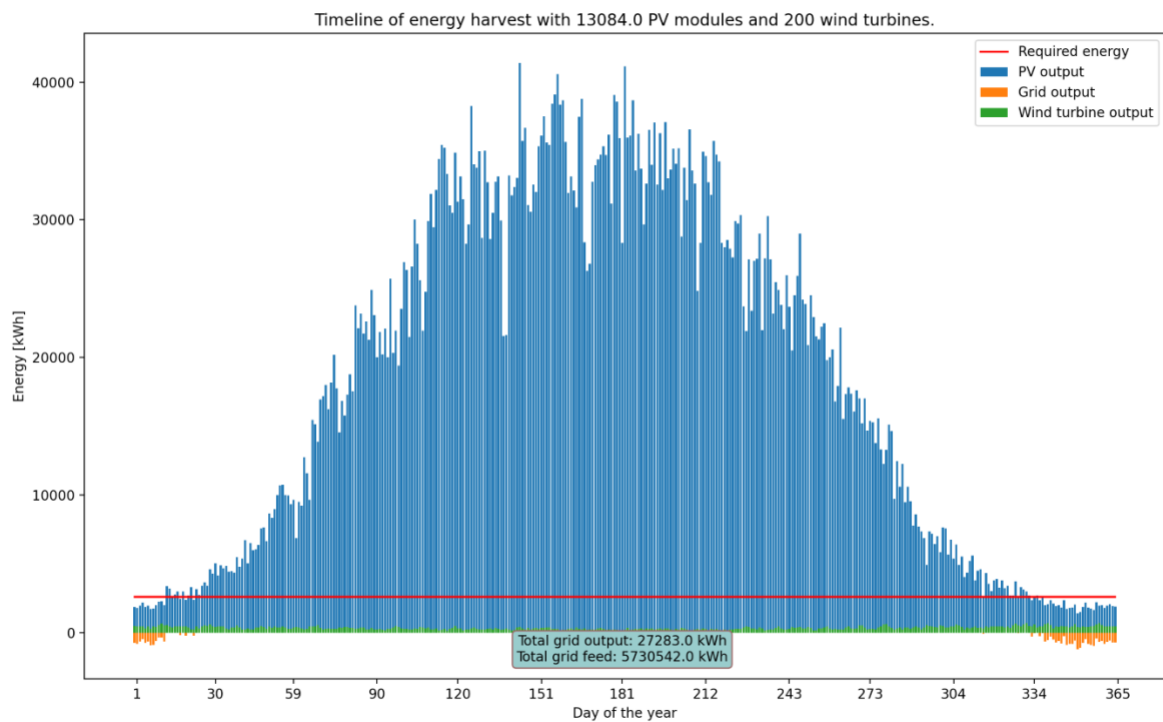


Figure 7.12: Combined PV and wind turbine power output, number of needed PV panels for a set maximum amount of wind turbines, required power, grid output over the mean meteorological year and total grid support and feed-in

Output for Stockholm 13 charge cycles of eActros600

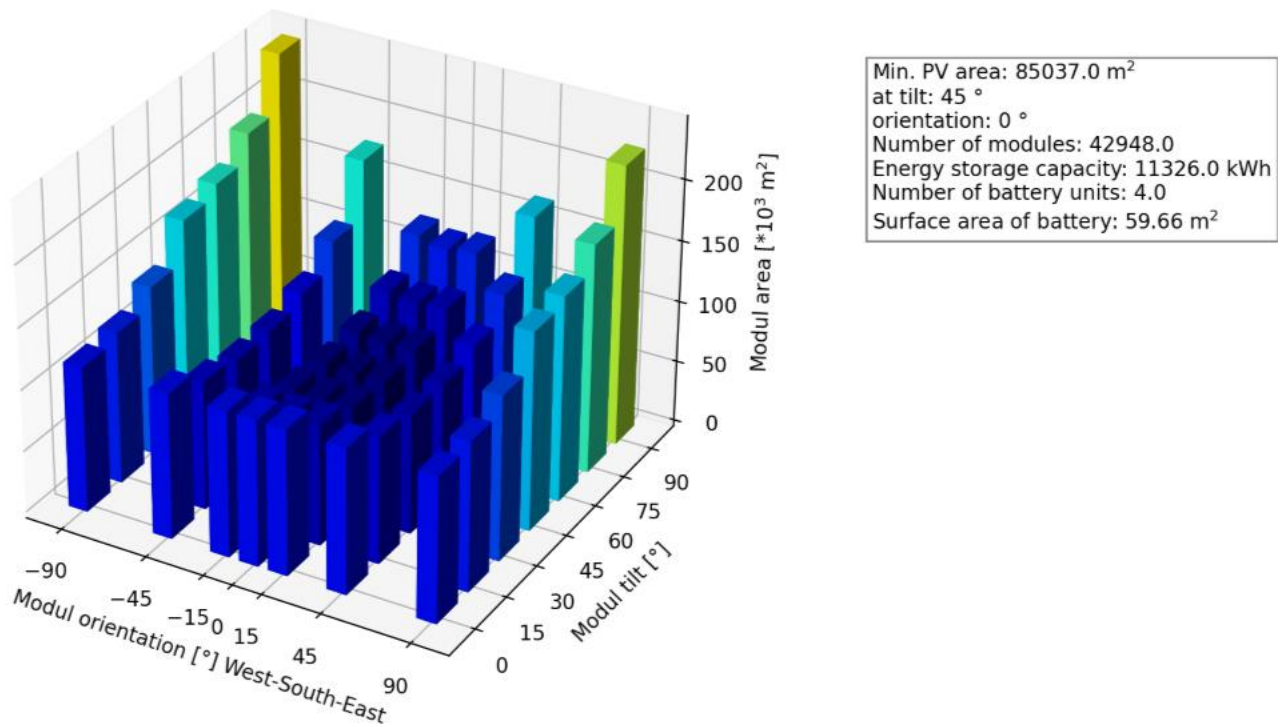


Figure 7.13: Area of needed PV modules according to tilt and orientation and output of optimal position and battery data

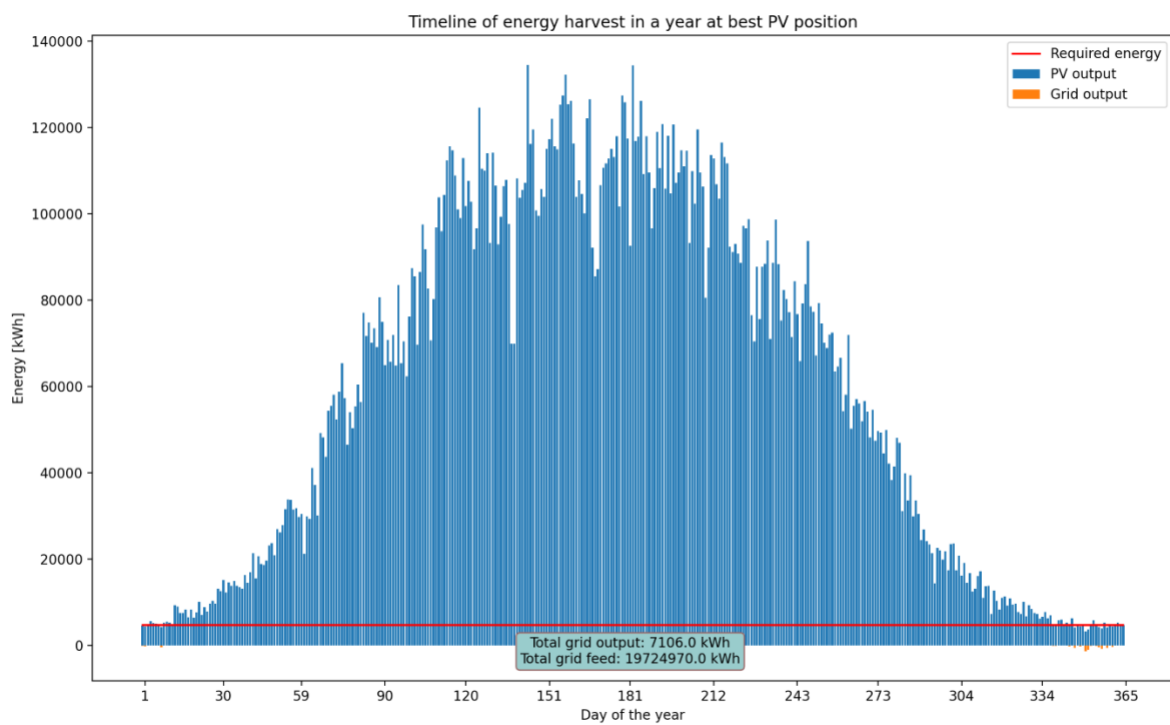


Figure 7.14: Power output of PV panels over a mean meteorological year, grid support and needed power, as well as the total grid output and feed-in

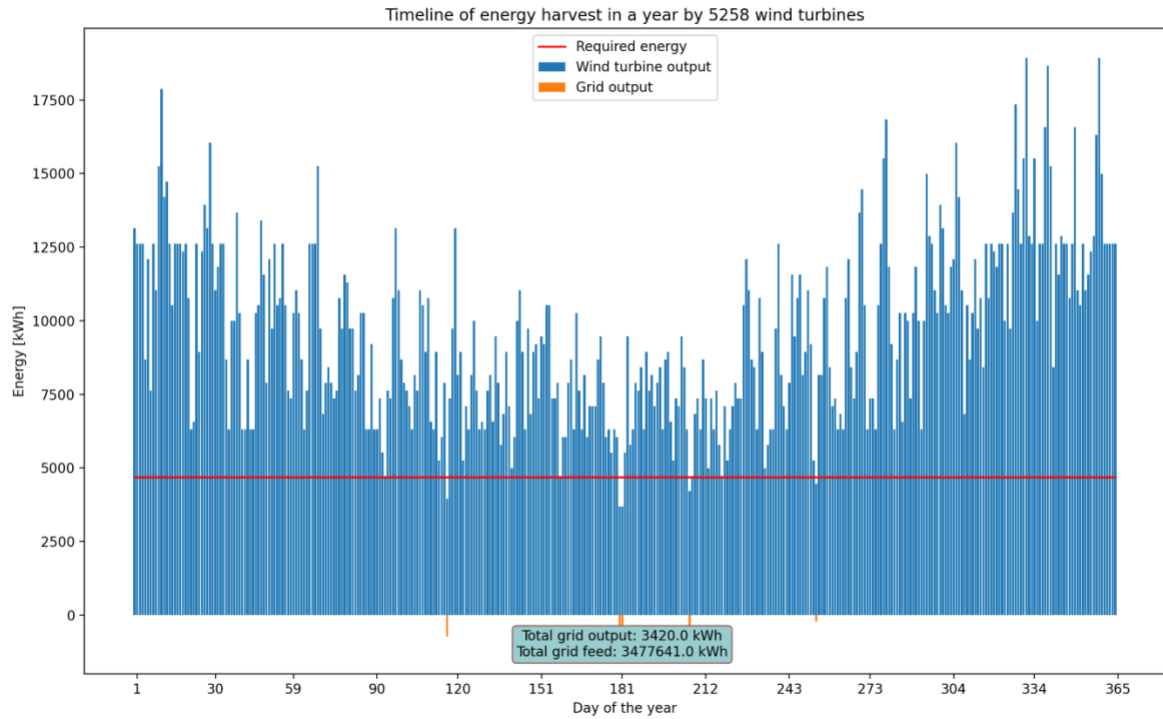


Figure 7.15: Number of needed wind turbines, power output over the mean meteorological year, grid support over the mean meteorological year and total grid feed-in and output

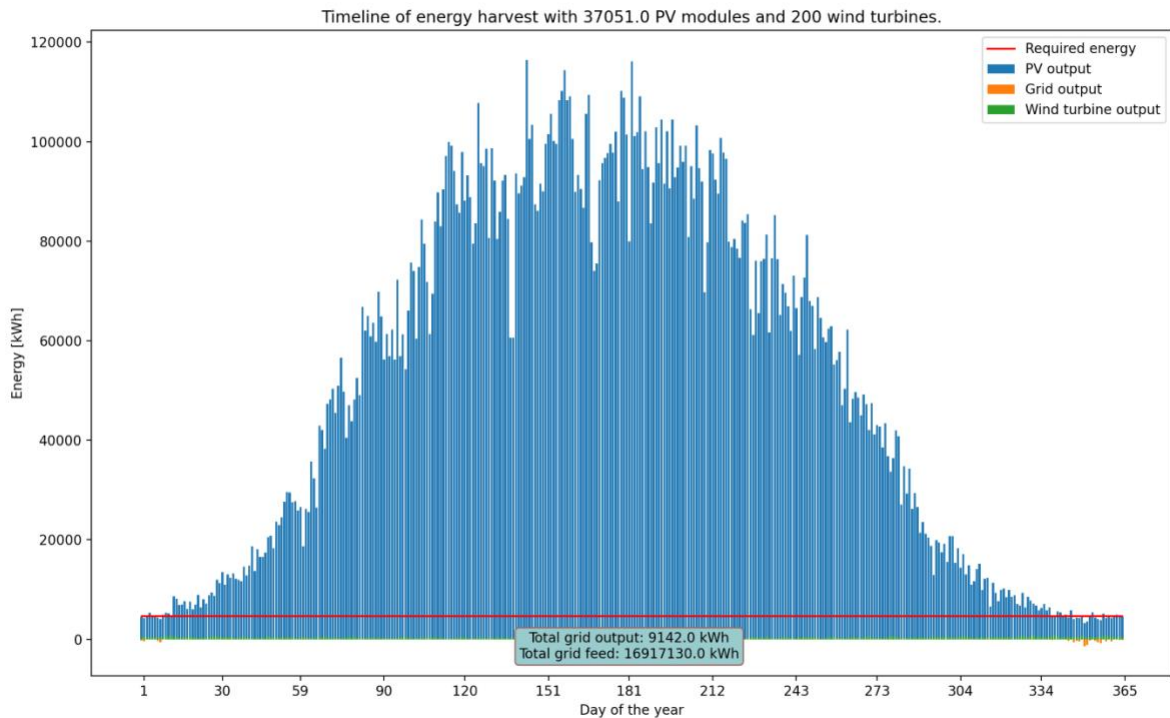


Figure 7.16: Combined PV and wind turbine power output, number of needed PV panels for a set maximum amount of wind turbines, required power, grid output over the mean meteorological year and total grid support and feed-in

Output for Stuttgart 13 charge cycles of eActros300

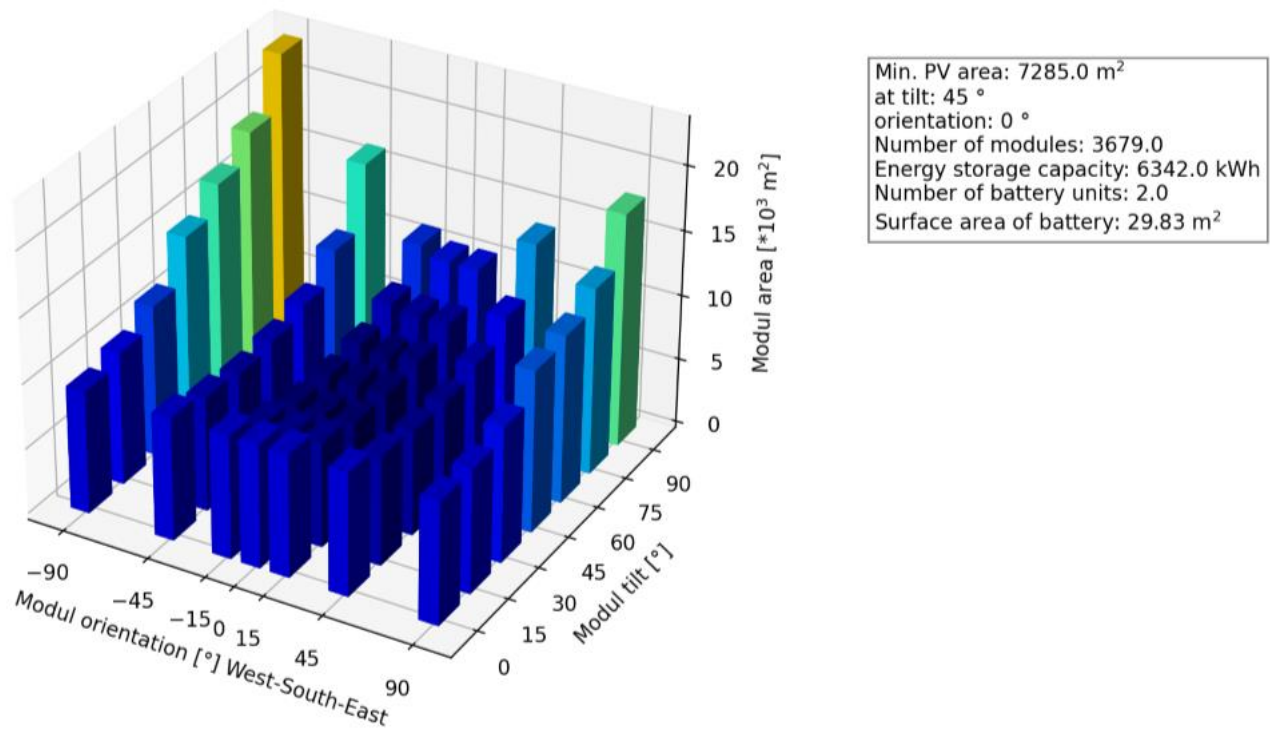


Figure 7.17: Area of needed PV modules according to tilt and orientation and output of optimal position and battery data

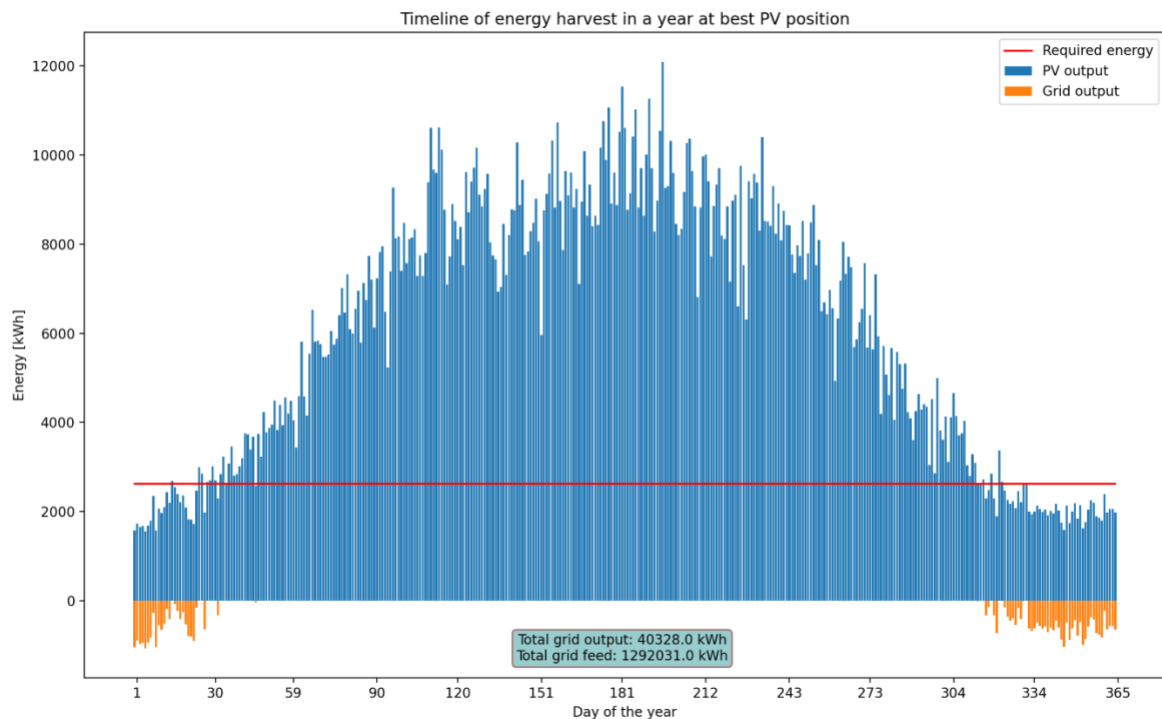


Figure 7.18: Power output of PV panels over a mean meteorological year, grid support and needed power, as well as the total grid output and feed-in

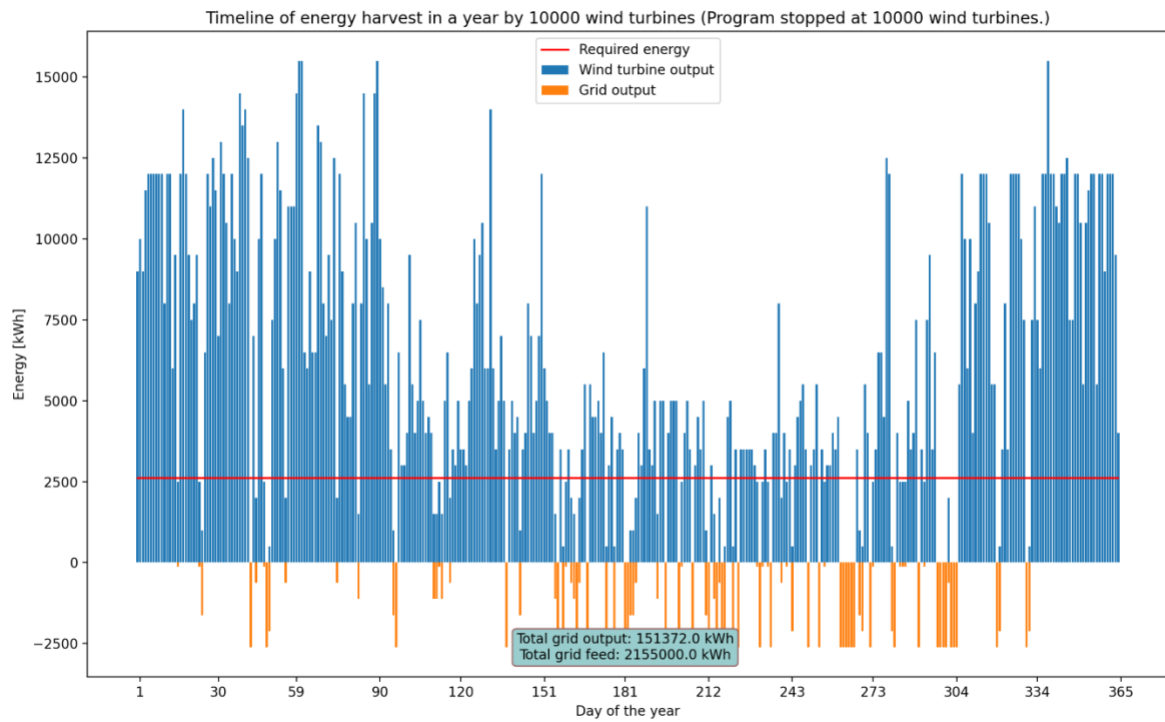


Figure 7.19: Number of needed wind turbines, power output over the mean meteorological year, grid support over the mean meteorological year and total grid feed-in and output

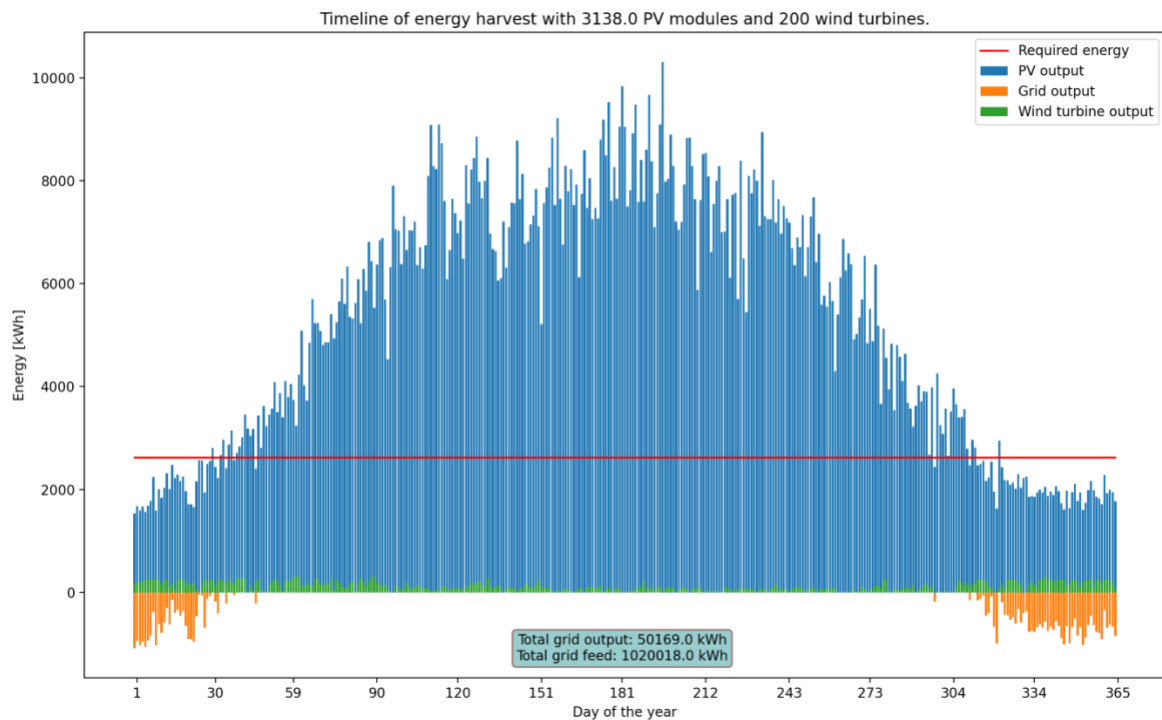


Figure 7.20: Combined PV and wind turbine power output, number of needed PV panels for a set maximum amount of wind turbines, required power, grid output over the mean meteorological year and total grid support and feed-in

Output for Stuttgart 13 charge cycles of eActros600

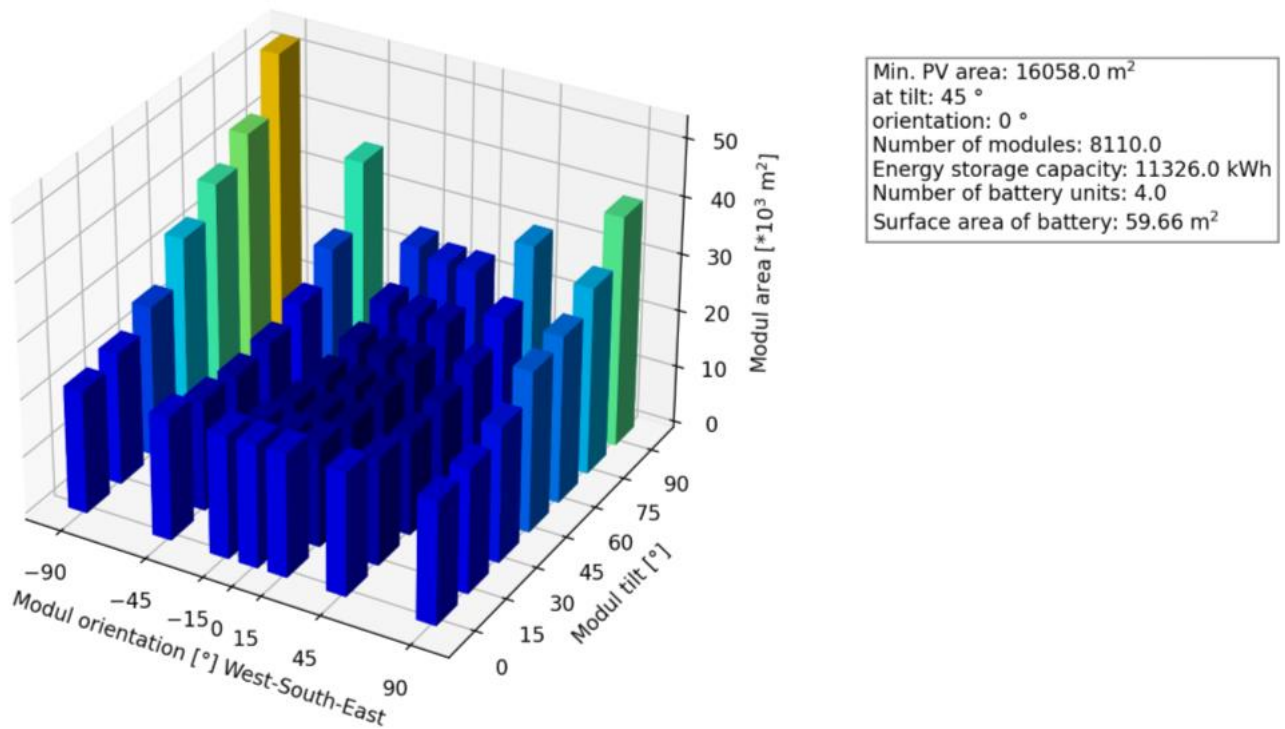


Figure 7.21: Area of needed PV modules according to tilt and orientation and output of optimal position and battery data

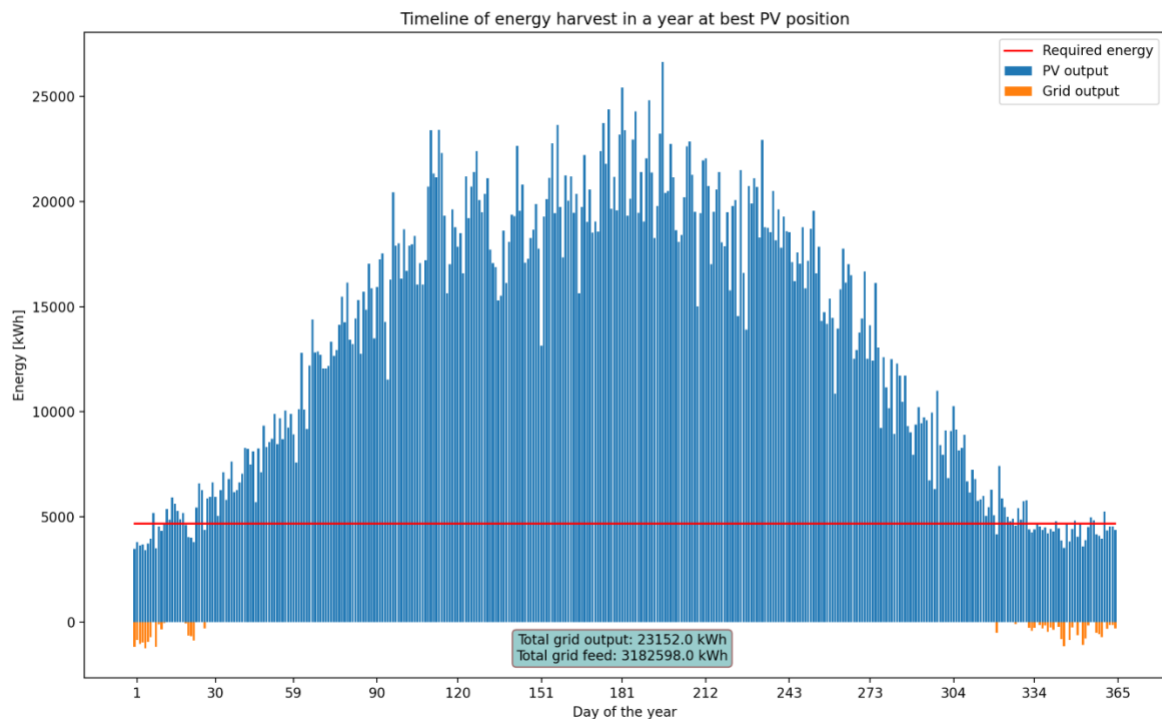


Figure 7.22: Power output of PV panels over a mean meteorological year, grid support and needed power, as well as the total grid output and feed-in

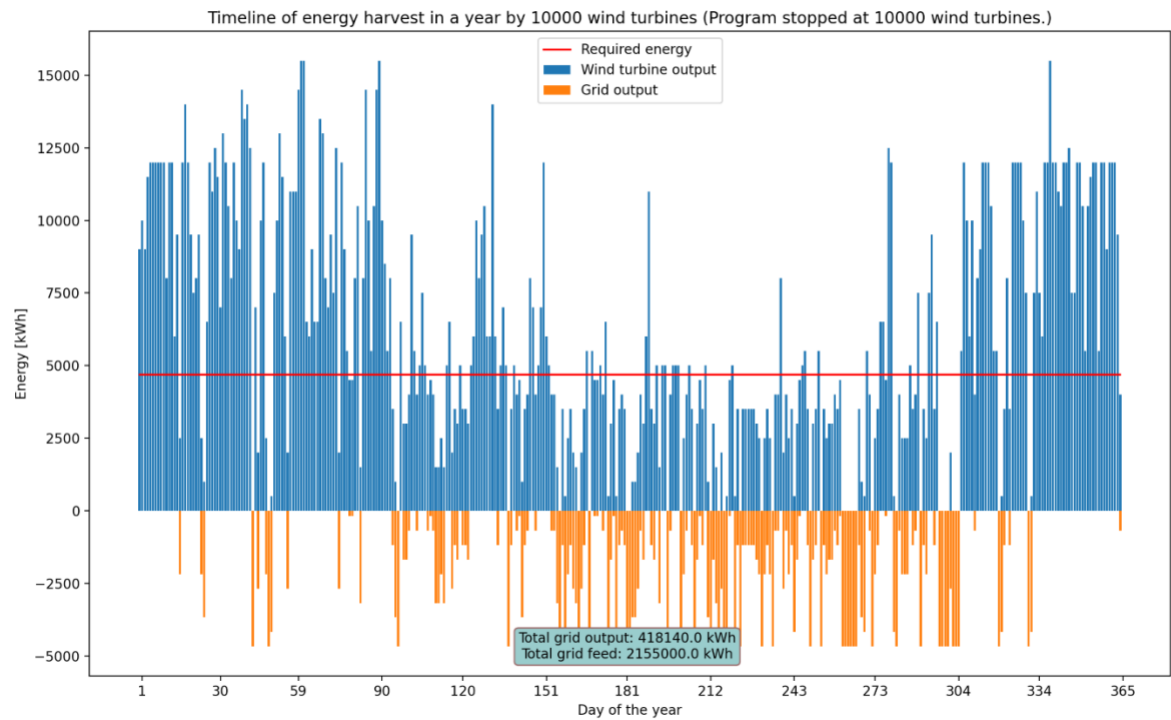


Figure 7.23: Number of needed wind turbines, power output over the mean meteorological year, grid support over the mean meteorological year and total grid feed-in and output

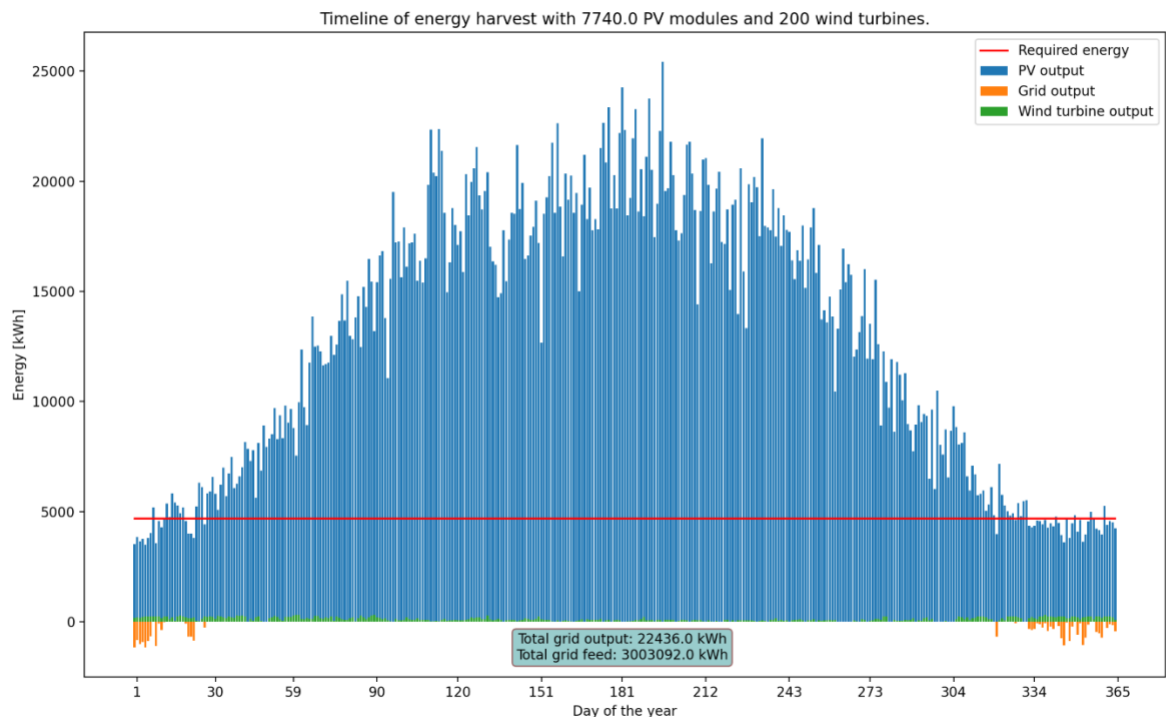


Figure 7.24: Combined PV and wind turbine power output, number of needed PV panels for a set maximum amount of wind turbines, required power, grid output over the mean meteorological year and total grid support and feed-in

Output for Stuttgart 40 charge cycles of eActros300

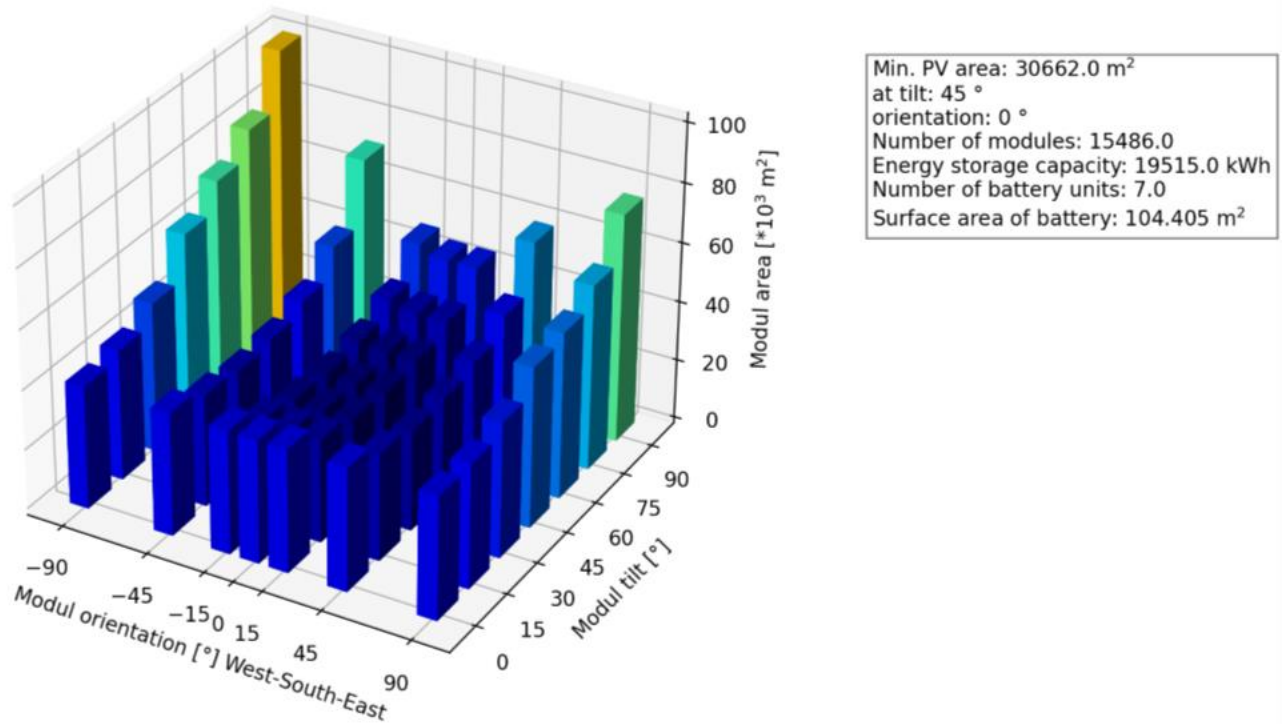


Figure 7.25: Area of needed PV modules according to tilt and orientation and output of optimal position and battery data

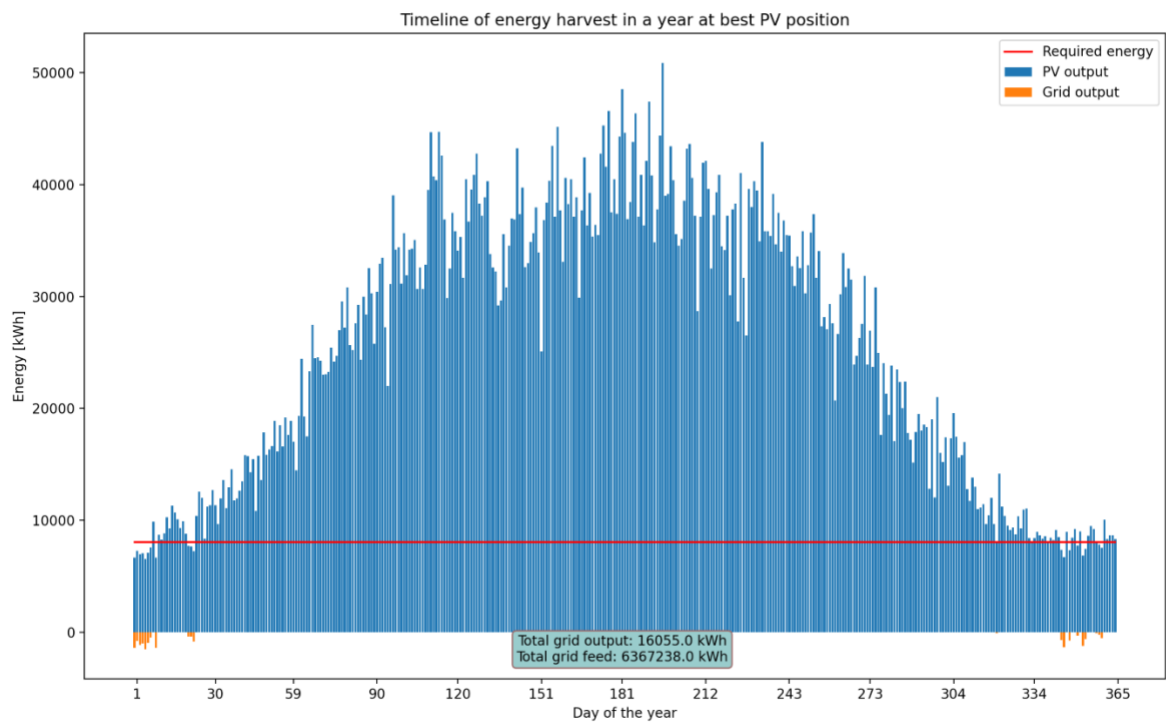


Figure 7.26: Power output of PV panels over a mean meteorological year, grid support and needed power, as well as the total grid output and feed-in

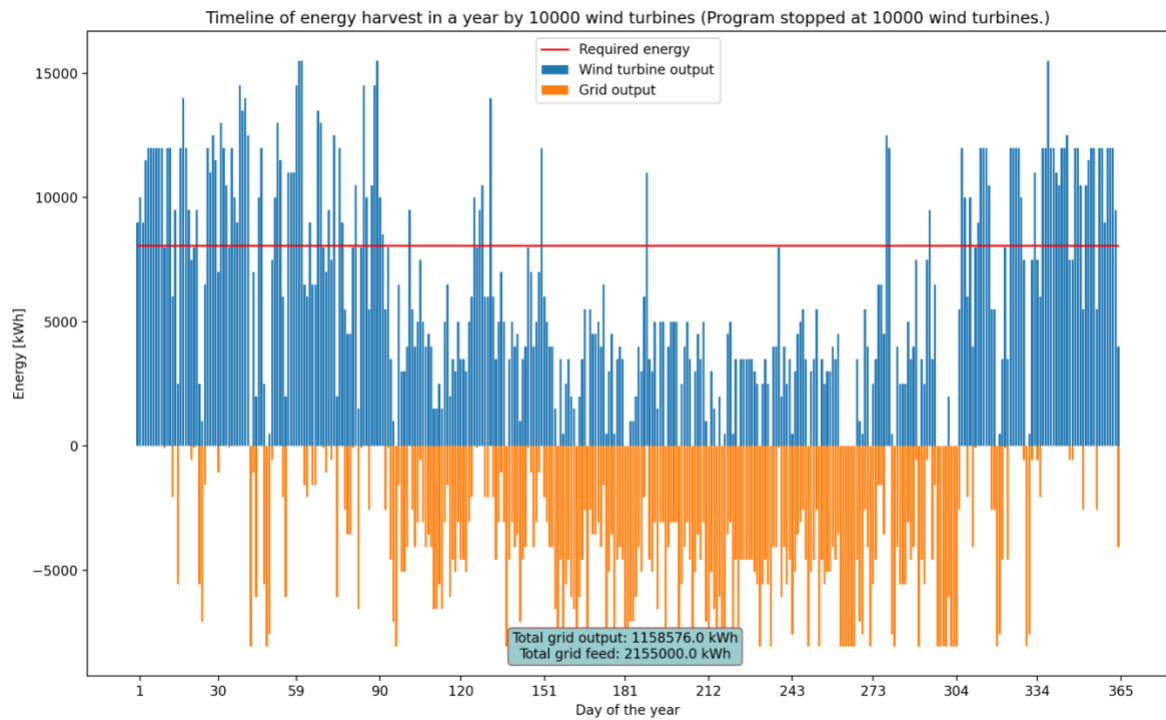


Figure 7.27: Number of needed wind turbines, power output over the mean meteorological year, grid support over the mean meteorological year and total grid feed-in and output

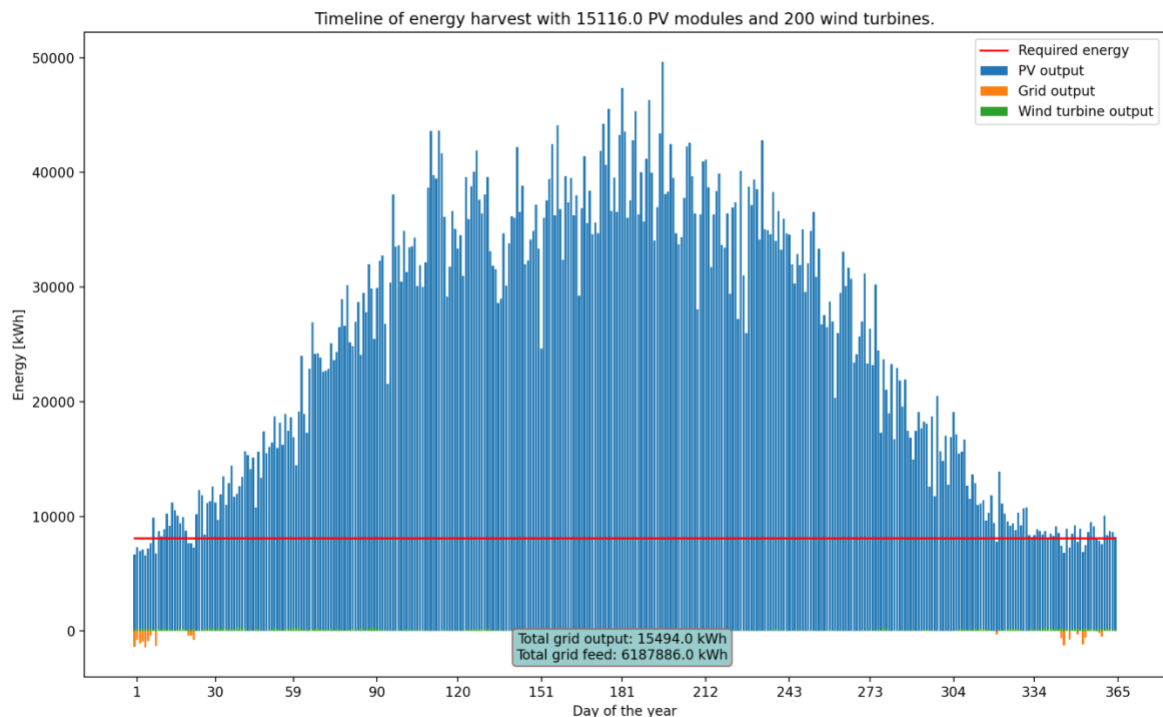


Figure 7.28: Combined PV and wind turbine power output, number of needed PV panels for a set maximum amount of wind turbines, required power, grid output over the mean meteorological year and total grid support and feed-in

Output for Stuttgart 40 charge cycles of eActros600

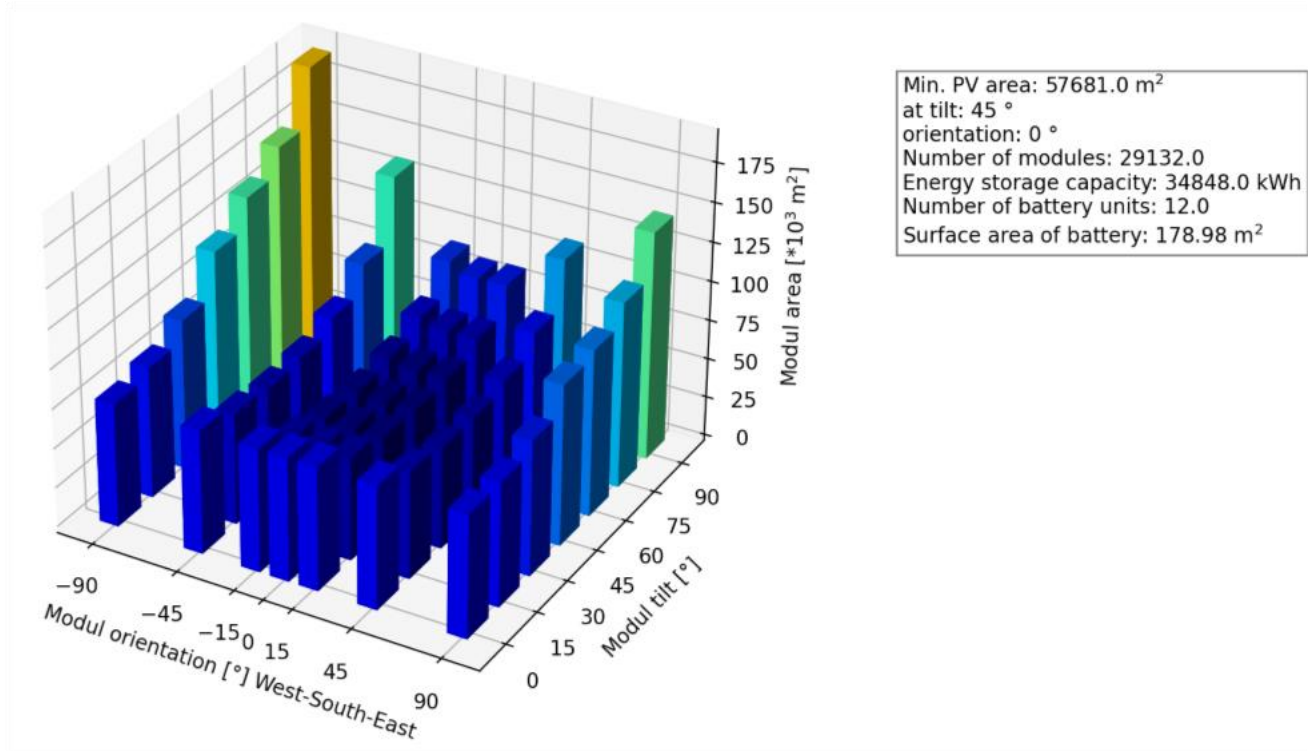


Figure 7.29: Area of needed PV modules according to tilt and orientation and output of optimal position and battery data

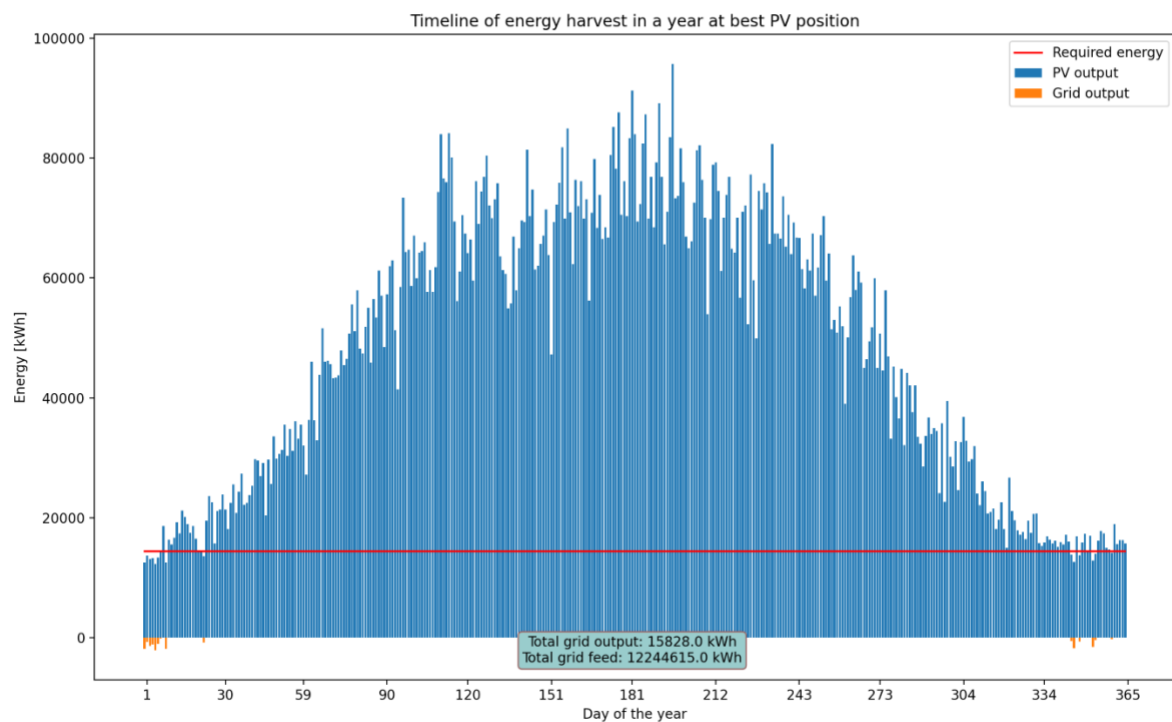


Figure 7.30: Power output of PV panels over a mean meteorological year, grid support and needed power, as well as the total grid output and feed-in

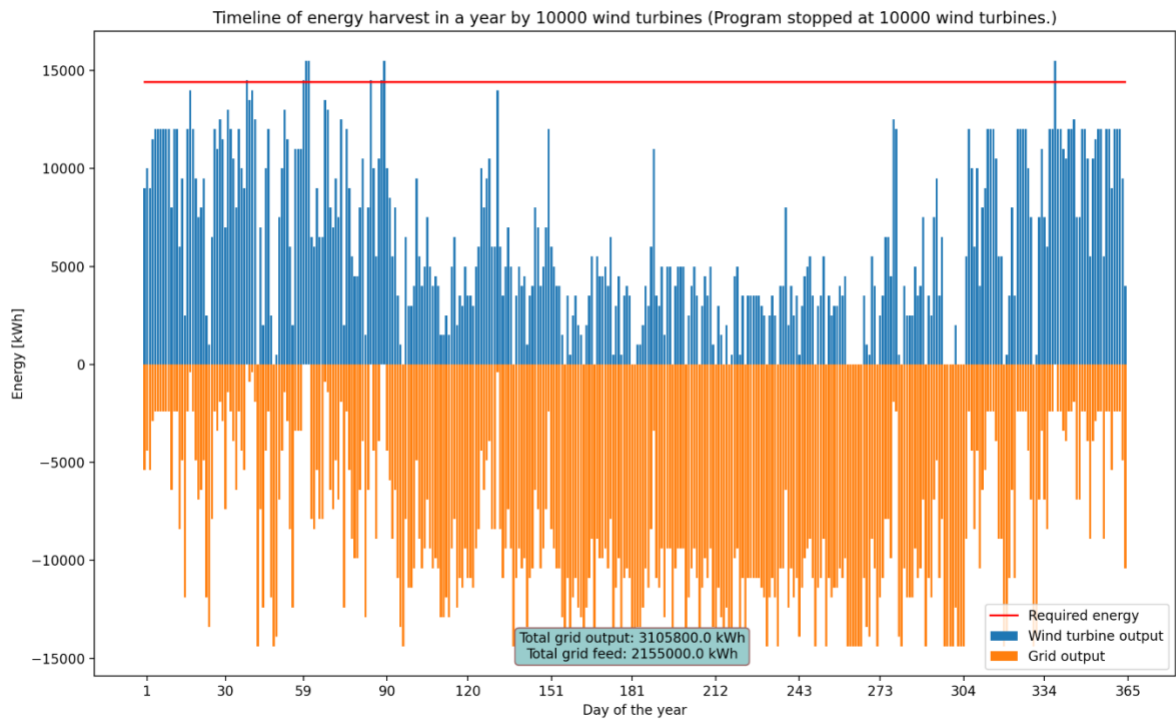


Figure 7.31: Number of needed wind turbines, power output over the mean meteorological year, grid support over the mean meteorological year and total grid feed-in and output

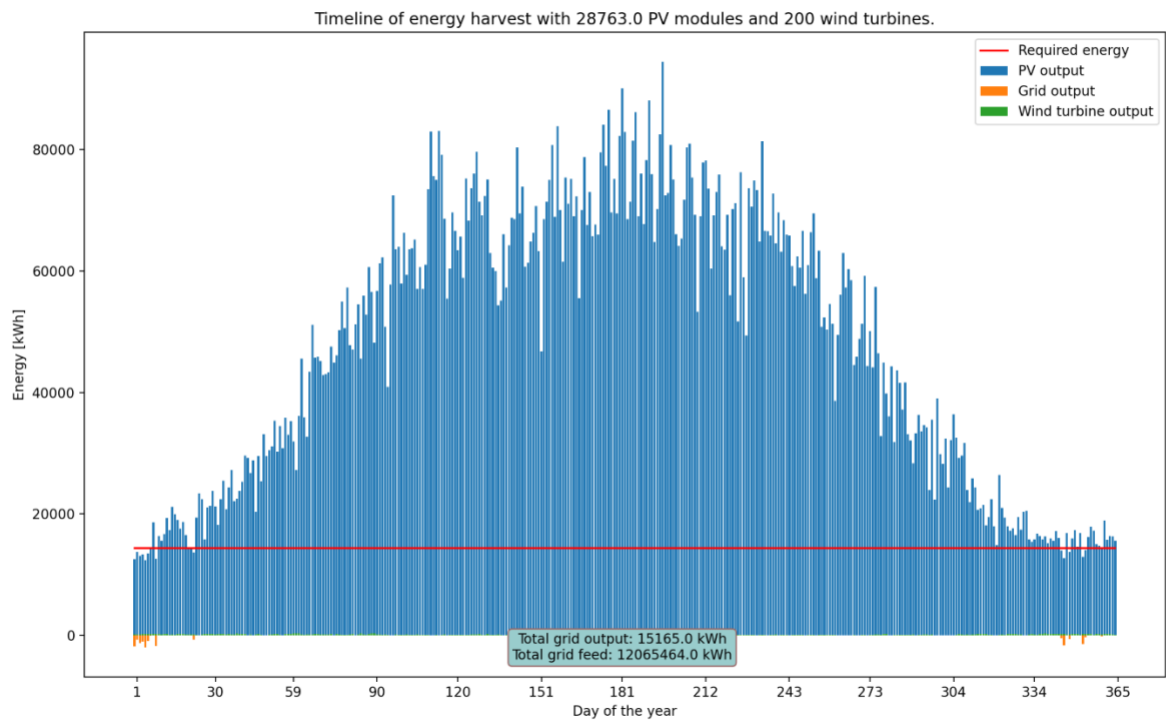


Figure 7.32: Combined PV and wind turbine power output, number of needed PV panels for a set maximum amount of wind turbines, required power, grid output over the mean meteorological year and total grid support and feed-in

Output for Stuttgart 20 charge cycles of eActros300

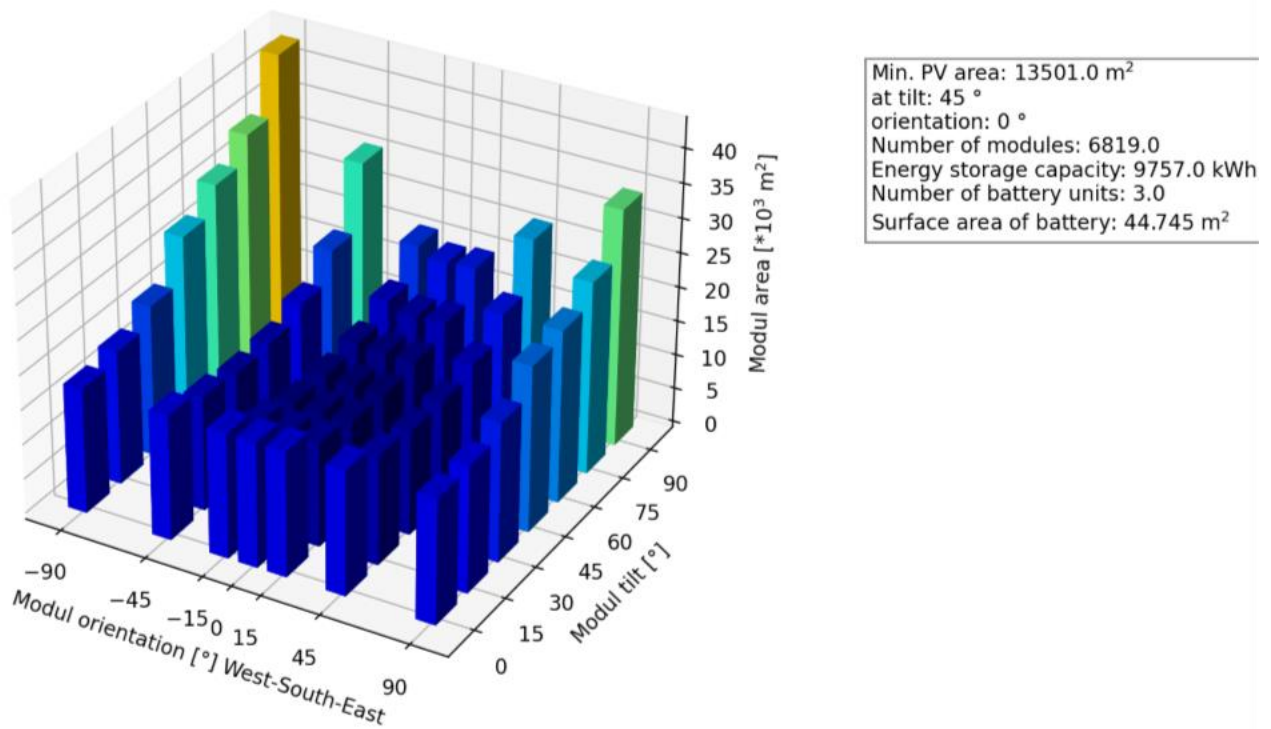


Figure 7.33: Area of needed PV modules according to tilt and orientation and output of optimal position and battery data

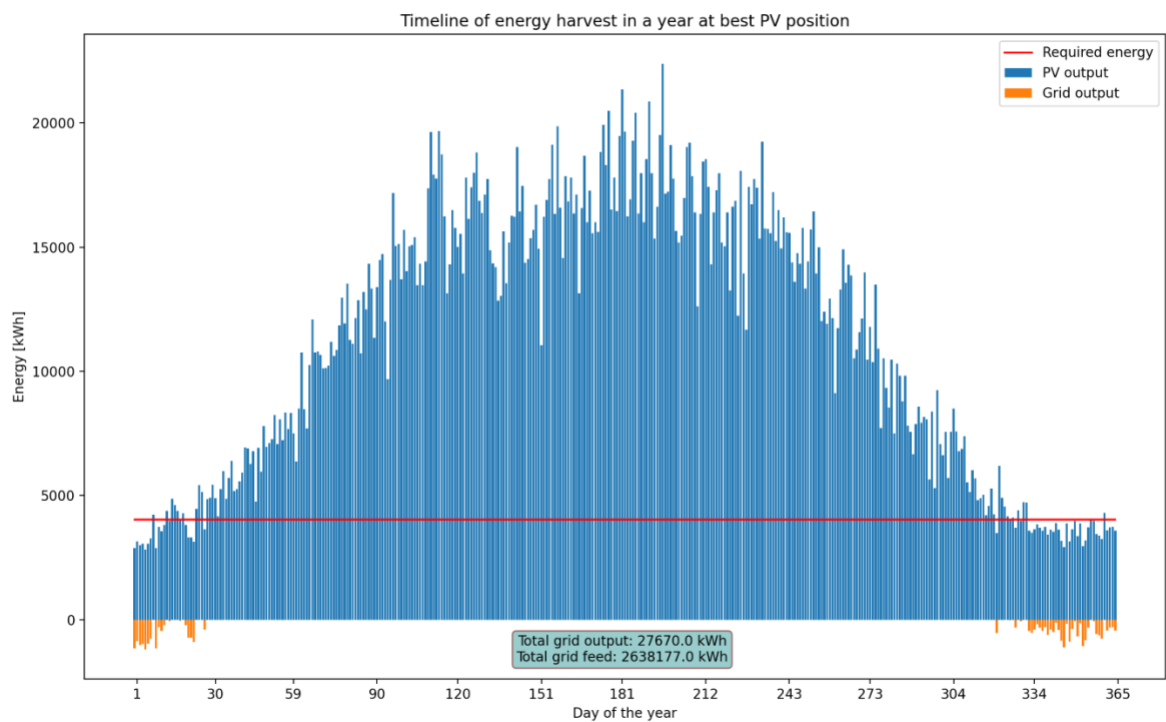


Figure 7.34: Power output of PV panels over a mean meteorological year, grid support and needed power, as well as the total grid output and feed-in

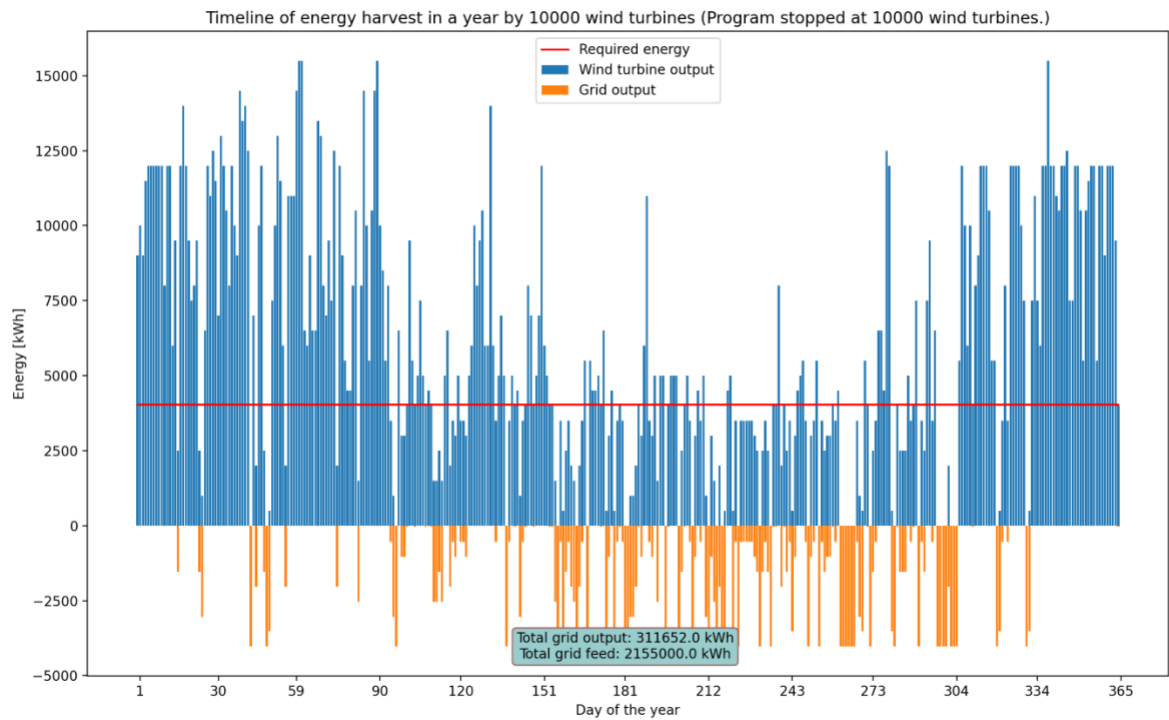


Figure 7.35: Number of needed wind turbines, power output over the mean meteorological year, grid support over the mean meteorological year and total grid feed-in and output

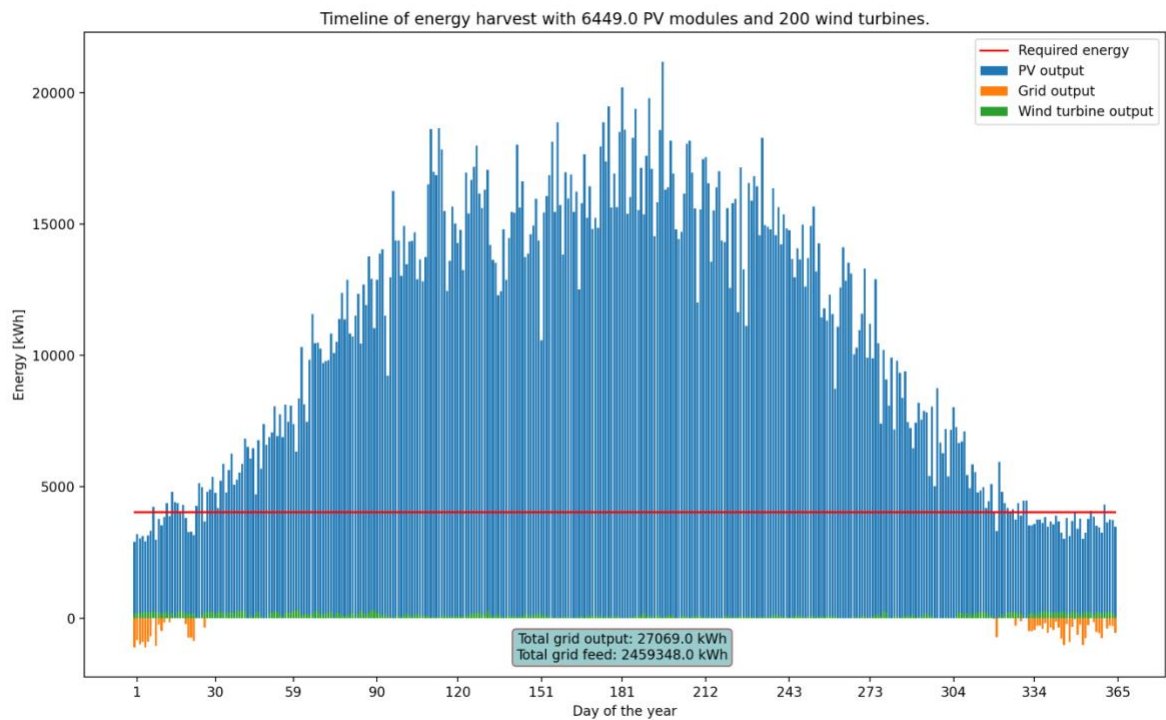


Figure 7.36: Combined PV and wind turbine power output, number of needed PV panels for a set maximum amount of wind turbines, required power, grid output over the mean meteorological year and total grid support and feed-in

Output for Stuttgart 20 charge cycles of eActros600

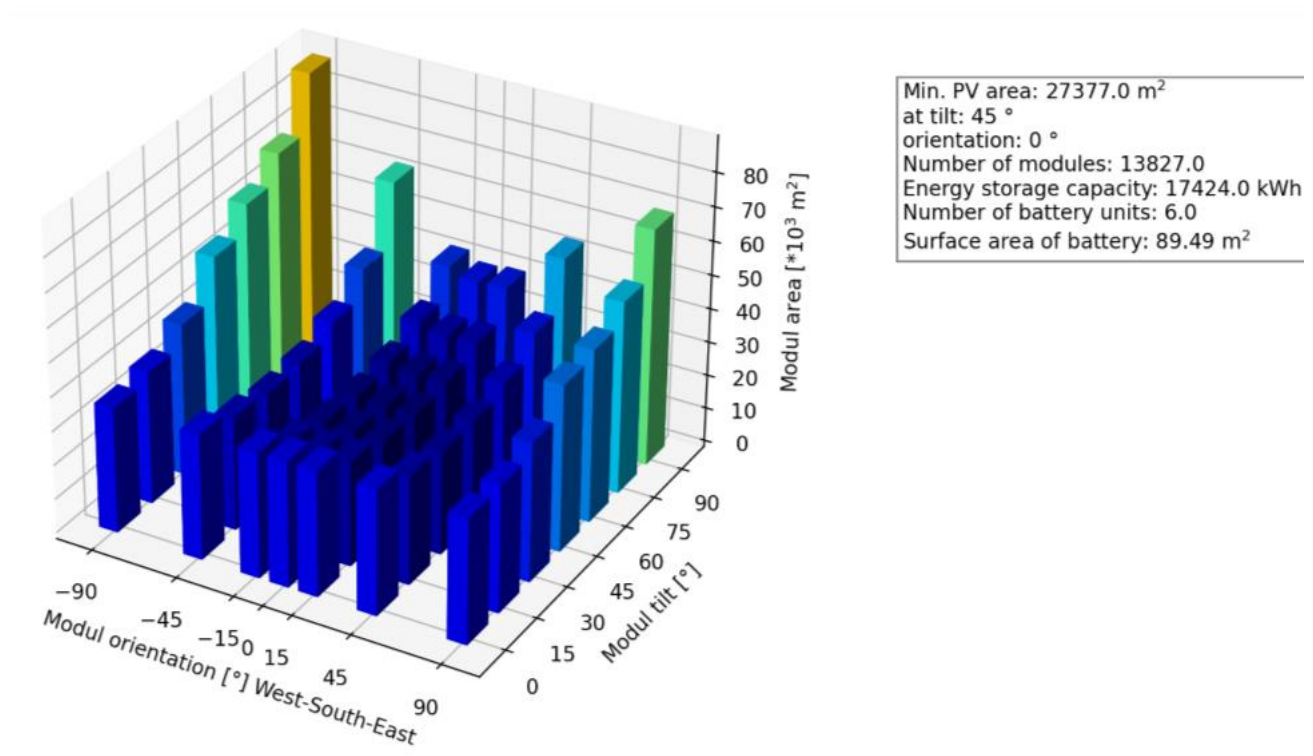


Figure 7.37: Area of needed PV modules according to tilt and orientation and output of optimal position and battery data

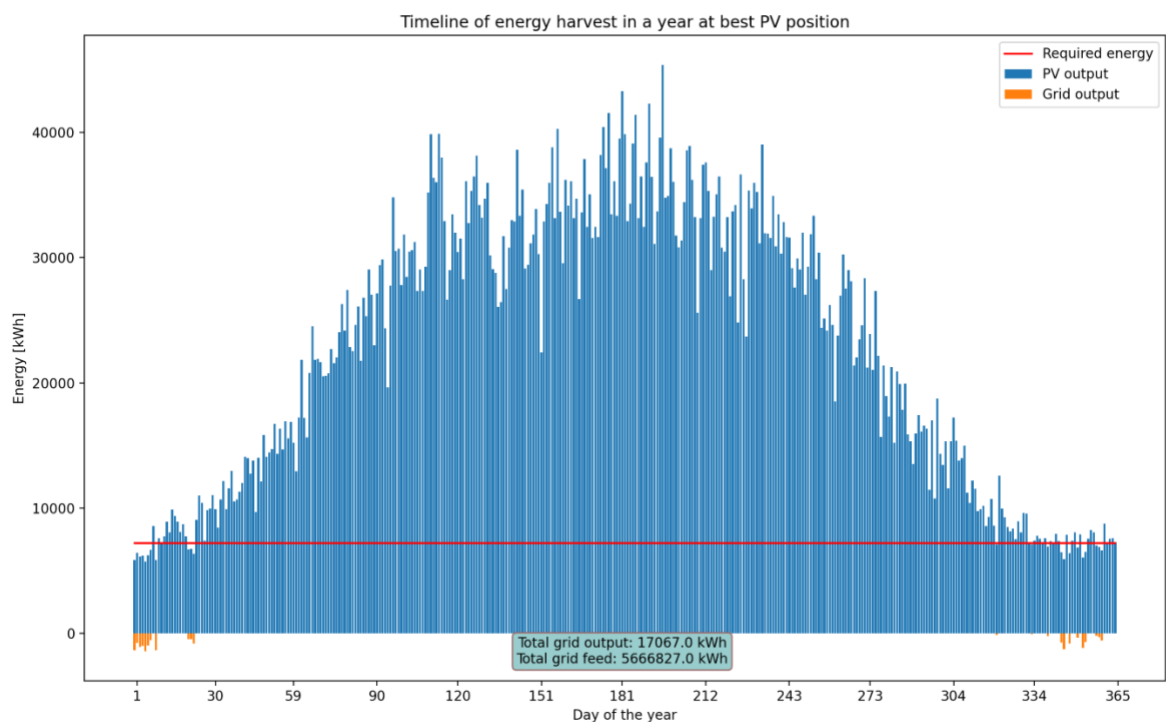


Figure 7.38: Power output of PV panels over a mean meteorological year, grid support and needed power, as well as the total grid output and feed-in

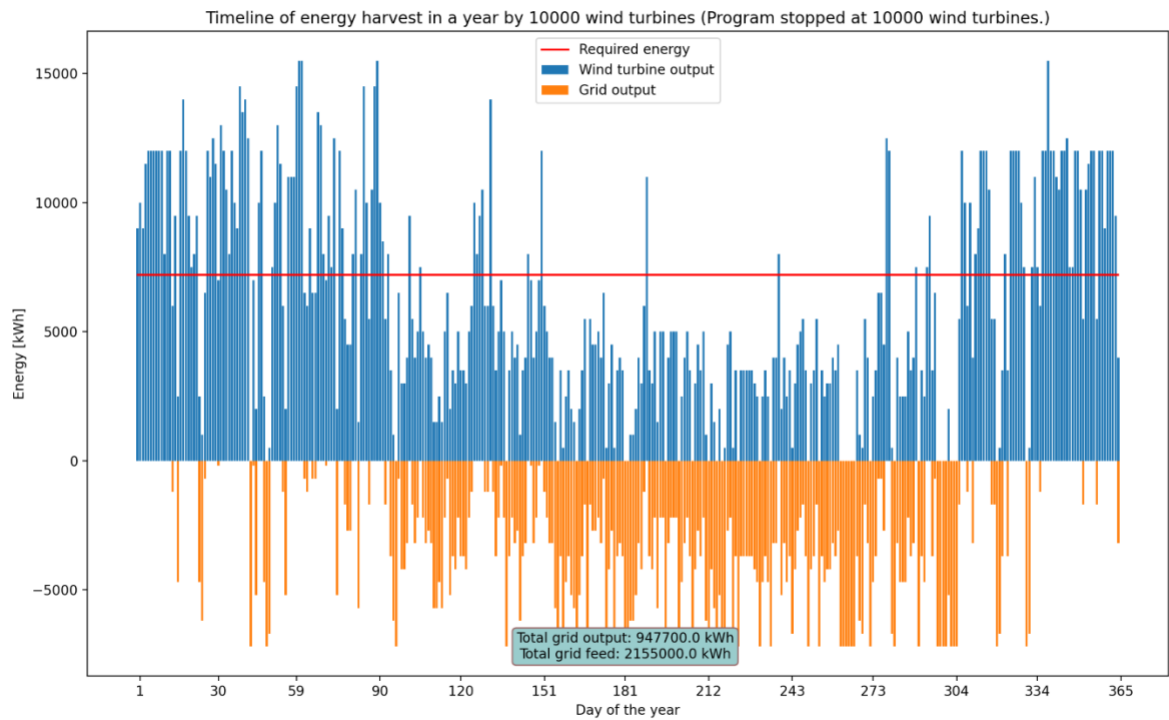


Figure 7.39: Number of needed wind turbines, power output over the mean meteorological year, grid support over the mean meteorological year and total grid feed-in and output

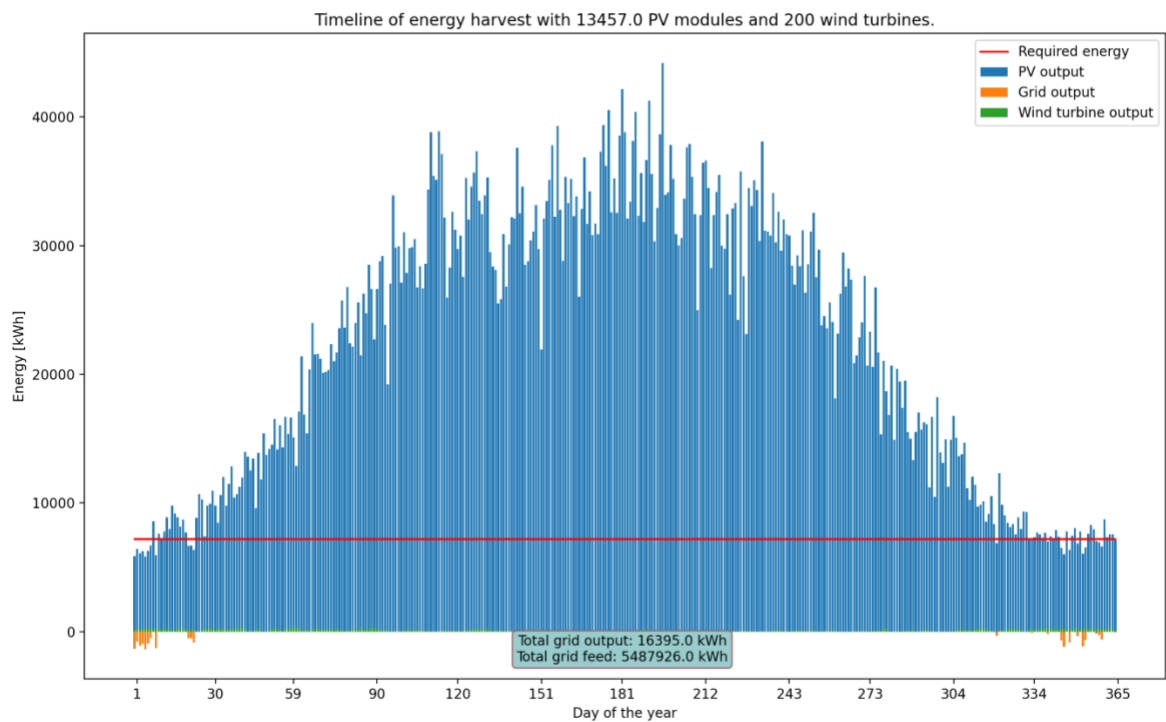


Figure 7.40: Combined PV and wind turbine power output, number of needed PV panels for a set maximum amount of wind turbines, required power, grid output over the mean meteorological year and total grid support and feed-in

Output for Madrid 13 charge cycles of eActros300

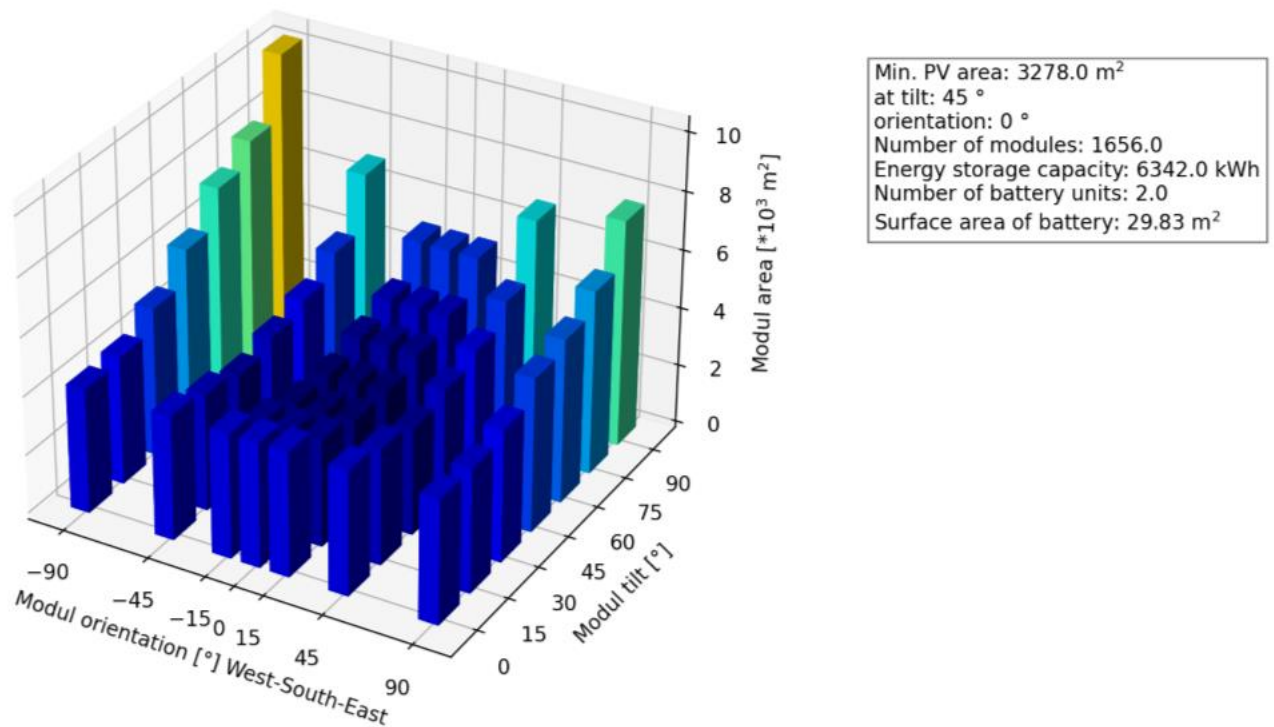


Figure 7.41: Area of needed PV modules according to tilt and orientation and output of optimal position and battery data

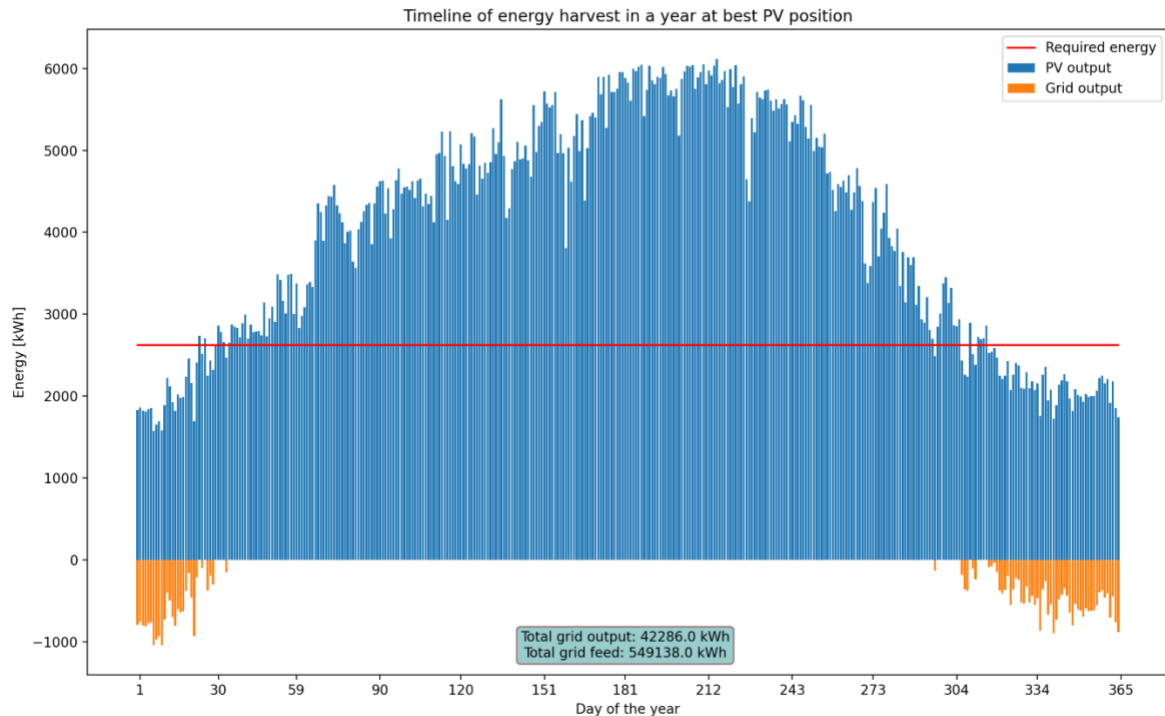


Figure 7.42: Power output of PV panels over a mean meteorological year, grid support and needed power, as well as the total grid output and feed-in

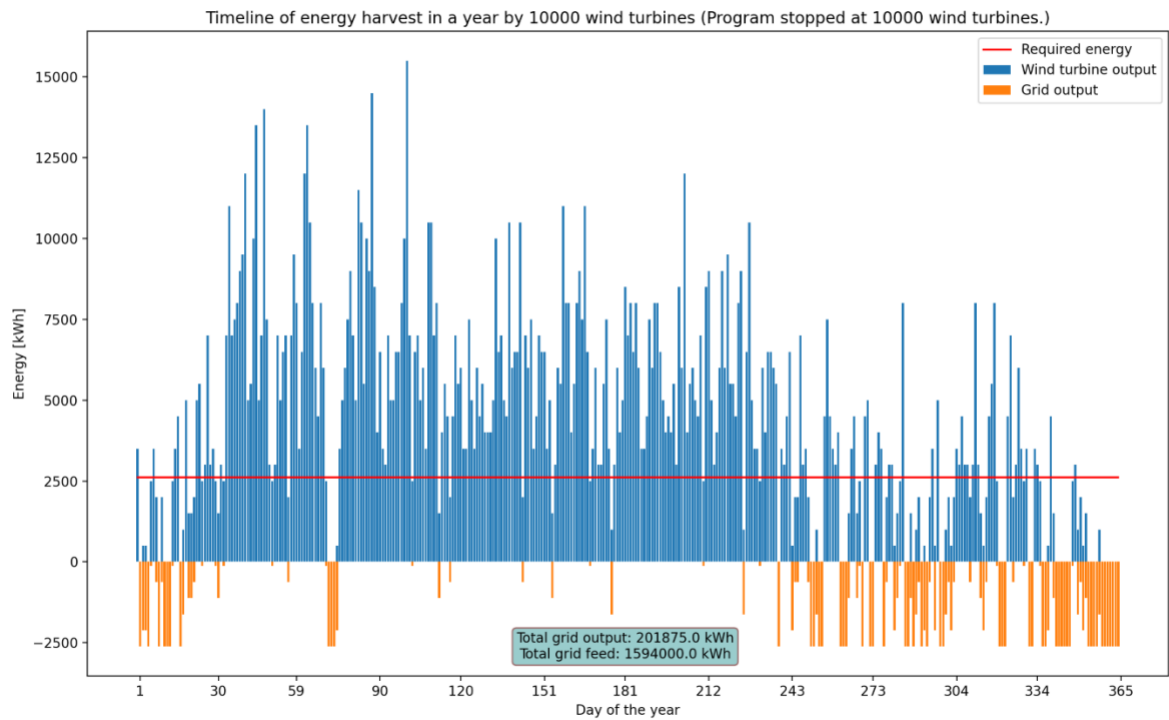


Figure 7.43: Number of needed wind turbines, power output over the mean meteorological year, grid support over the mean meteorological year and total grid feed-in and output

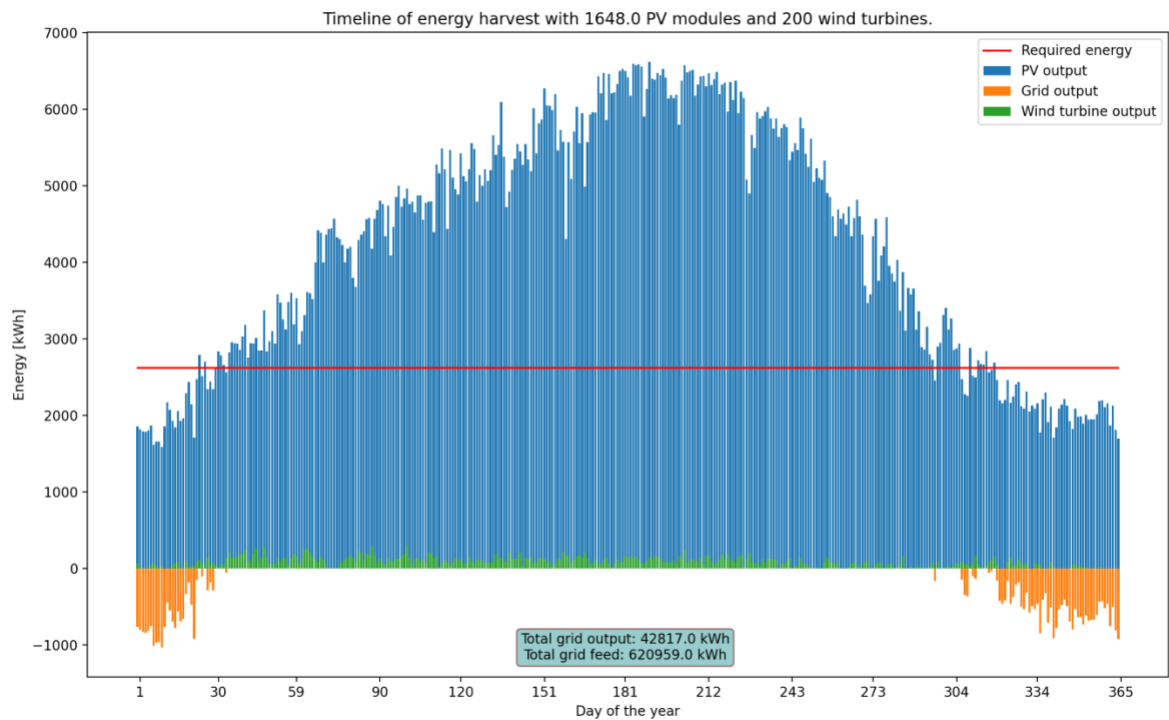


Figure 7.44: Combined PV and wind turbine power output, number of needed PV panels for a set maximum amount of wind turbines, required power, grid output over the mean meteorological year and total grid support and feed-in

Output for Madrid 13 charge cycles of eActros600

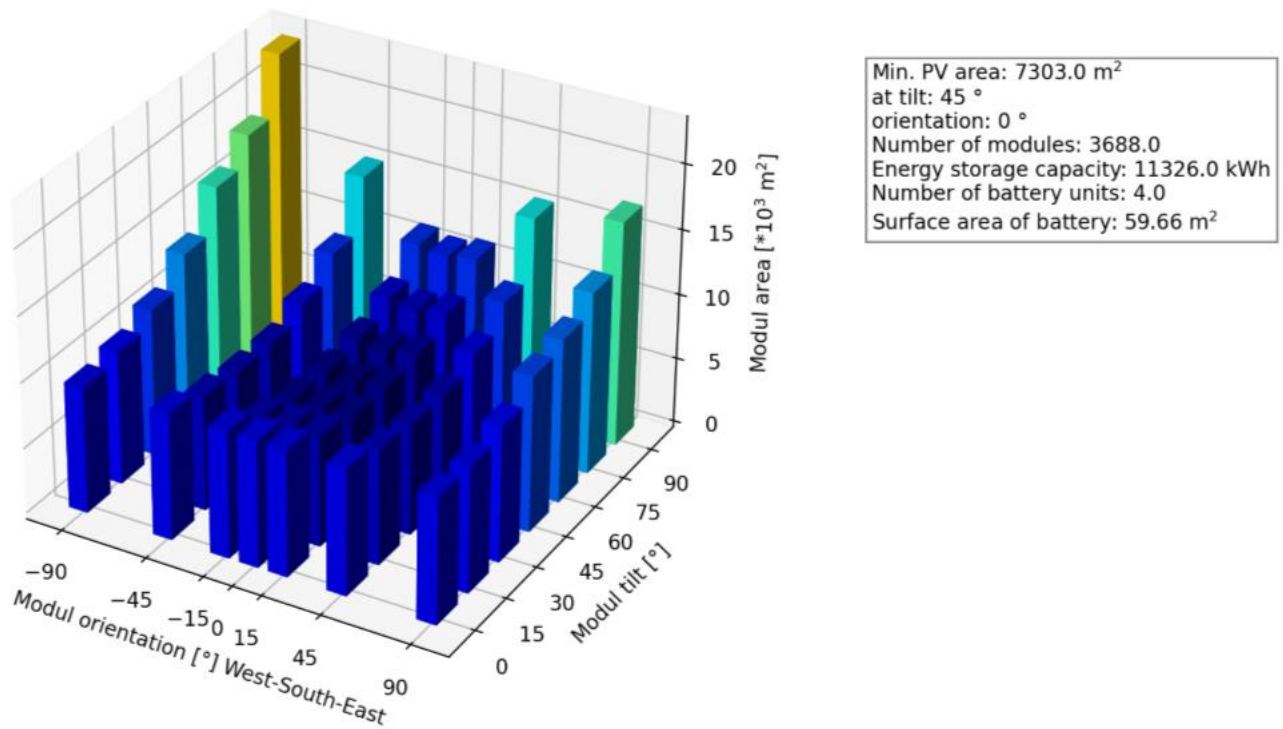


Figure 7.45: Area of needed PV modules according to tilt and orientation and output of optimal position and battery data

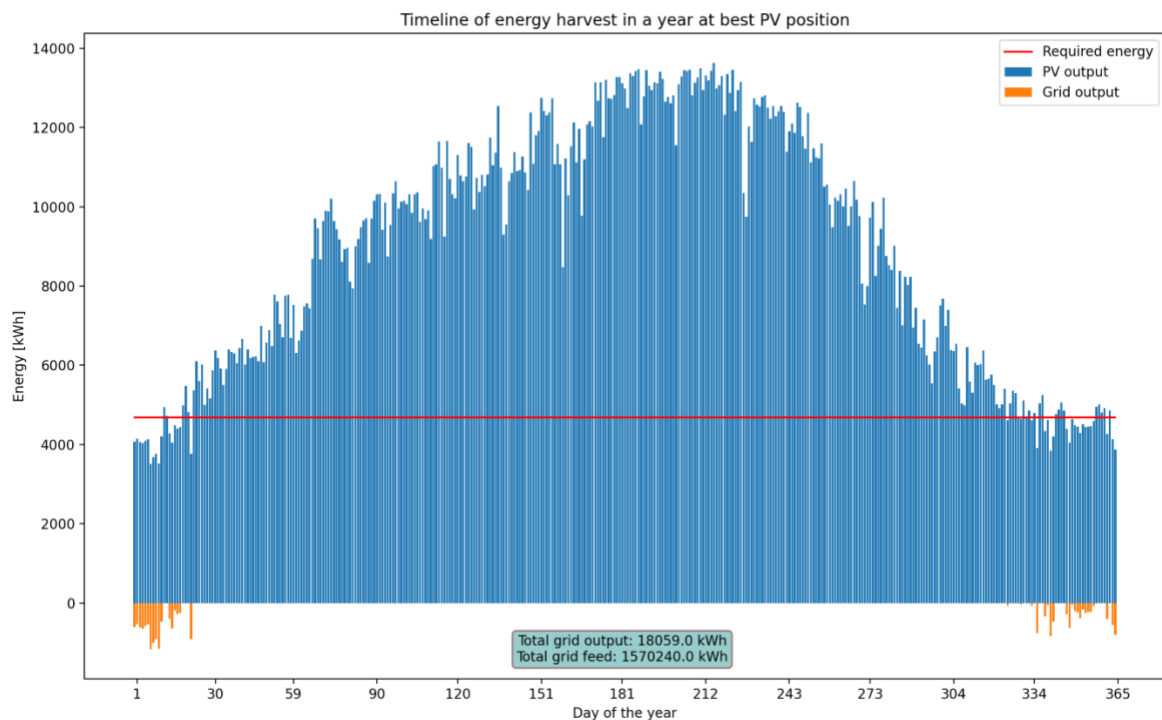


Figure 7.46: Power output of PV panels over a mean meteorological year, grid support and needed power, as well as the total grid output and feed-in

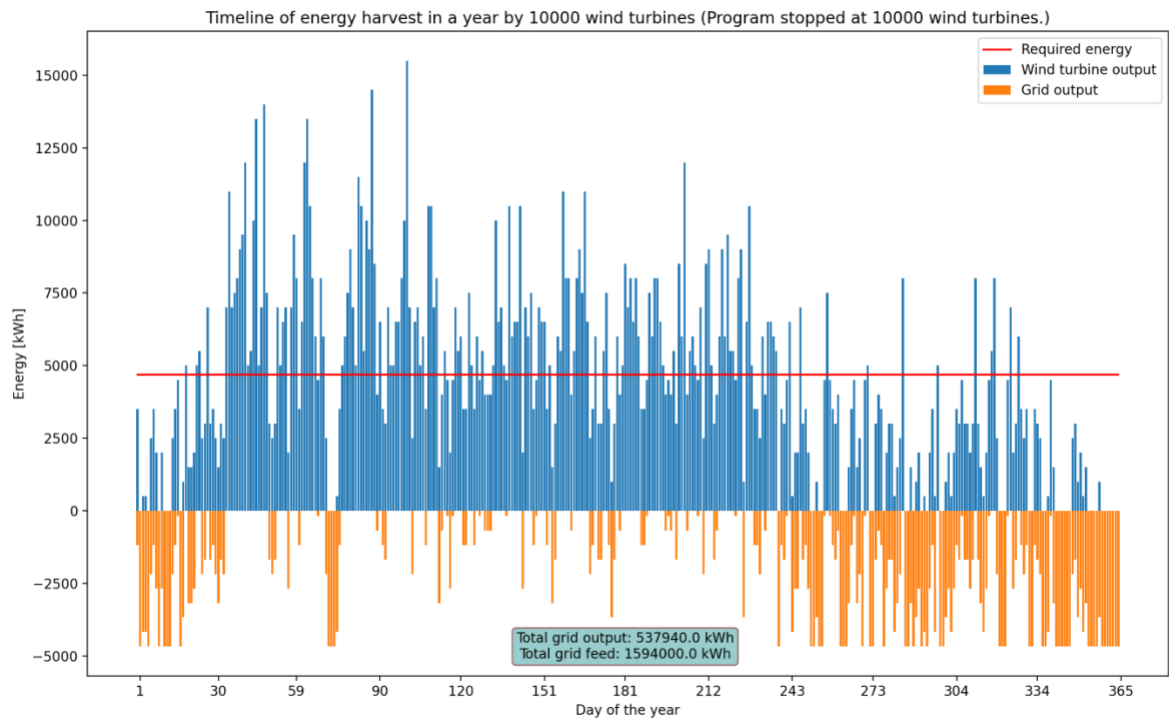


Figure 7.47: Number of needed wind turbines, power output over the mean meteorological year, grid support over the mean meteorological year and total grid feed-in and output

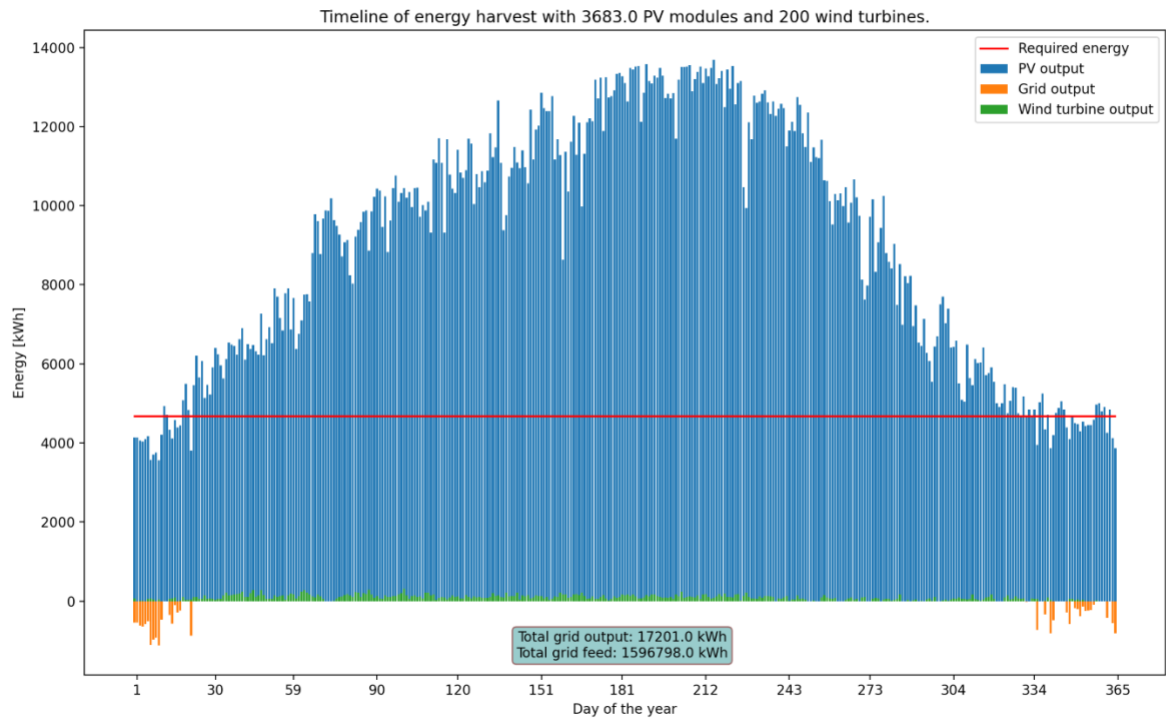


Figure 7.48: Combined PV and wind turbine power output, number of needed PV panels for a set maximum amount of wind turbines, required power, grid output over the mean meteorological year and total grid support and feed-in