60MW Multi-Rotor Vertical Axis Wind Turbine

Project Plan

Group 21

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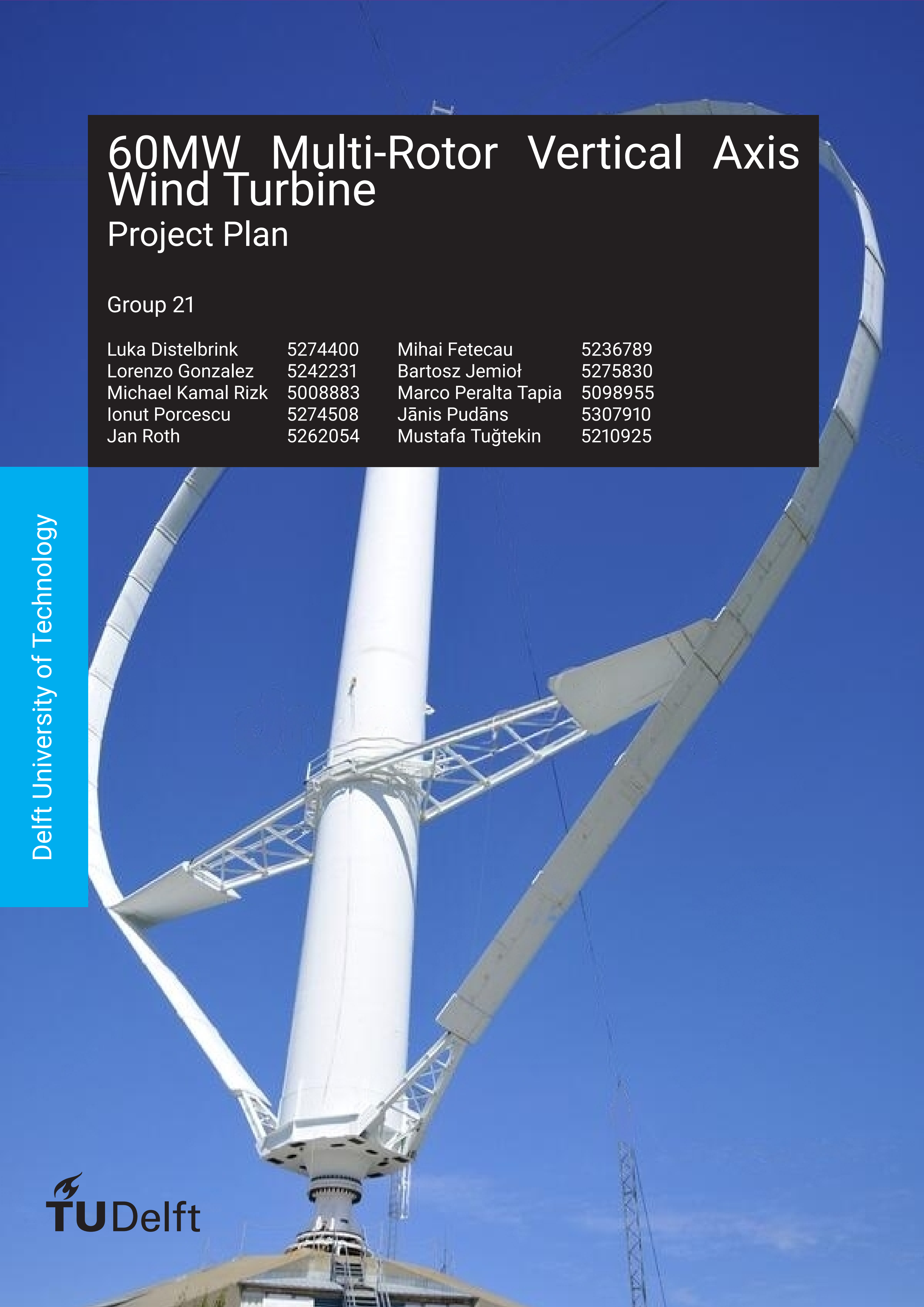
Delft University of Technology



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Report duration: April 24, 2023 – April 28, 2023
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Project coaches: Dr. Morgan Li, Stratos Koufis
Course: AE3200 Design Synthesis
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TU Delft

Contents

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Introduction

Wind turbines are becoming an increasingly common sight in today's countryside. In the future, they will become ever more present both on land and at sea in offshore wind farms. By 2050 the spatial requirement for offshore wind will exceed 250 000 km^2 [1]. That is equivalent to six times the land area of The Netherlands. This illustrates the need for larger and more space-efficient wind energy systems. Increasing the diameter of a traditional wind turbine presents the challenge of ever larger torques in the low-speed shaft and the gear box. A multi-rotor system with vertical axis wind turbines increases the energy density while reducing the torque [1]. This project investigates the commercial feasibility of such a design.

One of the main drivers of turbine development is the costs associated with them. Maintenance accounts for a large portion of costs during a lifetime of a wind turbine. Up-scaling of wind turbines decreases these costs by reducing the units deployed per megawatt. Up-scaling also aids in managing foundation and electrical interconnection requirements. Systems with multiple rotors, having only a single supporting structure, may maximize the benefits of minimizing maintenance costs and making wind energy more cost-effective. Smaller rotors and larger rotational frequencies allow for the oversizing of components, increasing reliability. Additionally, multi-rotor systems allow for better wake management systems due to a larger supporting structure on which it can be mounted.

Another big driver for this project is decreasing the environmental impact of wind turbines. As wind turbines are massive structures, placing them in natural environments, for example, offshore projects, cause massive changes to the local environment and thus provide negative impact to the area. Minimizing the negative impact of wind farms and increasing their sustainability is thus another goal of this project.

The scope of the Design Synthesis Exercise constitutes 10 students working full-time for 10 weeks. The project is mentored by the staff and professors of TU Delft. The goal of this project is to make a plan for the 10 weeks of the DSE: to become familiar with all design options and limitations and to do a trade-off. Based on this, make a detailed, optimized design, a proposal for a wind turbine that would be more sustainable, cheaper and efficient than any other wind energy alternative. The wind turbine should aid in solving the eminent challenges in moving to a green economy.

This paper constitutes the plan for the Design Syntheses Exercises. The design requirements are a scale of 60 MW (approx. 430x430 m^2), Multi Rotor System of Vertical Axis Wind Turbines, higher wind farm energy density above 16MW/km^2; 45% lower cost of energy; and improved Life Cycle Analysis performance in materials, energy and emissions.

[1] URL: https://www.dnv.com/research/download/oceans-future-thank-you.html [cited 28 April 2023]

2

Project description

2.1. Mission Need Statement

The mission need statement is given in this section. The need that underlines the whole project was brought to the group's attention by the tutor of the group. Given the direction taken by the Dutch government, which plans to achieve 21 GW of wind energy capacity by the year 2030 and between 38 GW and 72 GW by 2050, the opportunity to innovate the wind energy system is apparent [1]. The focus on sustainability and sea conservation, coupled with lower costs for energy, can be found within the mission statement.

Generating a means of producing energy with higher energy density, above 16MW/km2, at 45% lower cost of energy with improved Life Cycle Analysis performance of materials, energy, and emissions.

2.2. Project Objective Statement

The project objective statement as set by the tutor of the project is presented here. This statement will guide the team along the length of the entire project and help the team share the same image with regard to the desired outcome as provided by the client.

Design a 60 MW Multi Rotor System of Vertical Axis Wind Turbines that allows for wind farm energy density above 16 MW/km^2, 45% lower cost of energy and improved material and emission sustainability in 10 weeks by 10 students.

2.3. Description of system

This section presents the overview of the entire system. The system is a Multi-Rotor System of Vertical Axis Wind Turbine. The system input is the weather data from The Royal Netherlands Meteorological Institute (KNMI), the wind that passes through the system, the environment, and a maintenance center. The system outputs electrical power to the power grid TenneT through a transformer. The system will need to be connected to the TenneT grid. The system consists of:

- Yaw control system - responsible for aligning the structure with the wind to obtain the best performance.
- Sensors - responsible for gathering information needed to operate the wind turbines and yaw control system, to operate and schedule maintenance.
- Wake management - responsible for re-energizing the airflow that passes the wind turbines
- Lightning rod - responsible for directing lightning to the ground in case of a lightning strike
- Structure - responsible for taking the loads of and supporting wind turbines
- Wind turbines - responsible system for power generation

[1] URL: https://english.rvo.nl/information/offshore-wind-energy/offshore-wind-energy-plans-2030-2050 [cited 26 April 2023]

- Power center - responsible for power transfer from the individual generators to the transformer system.

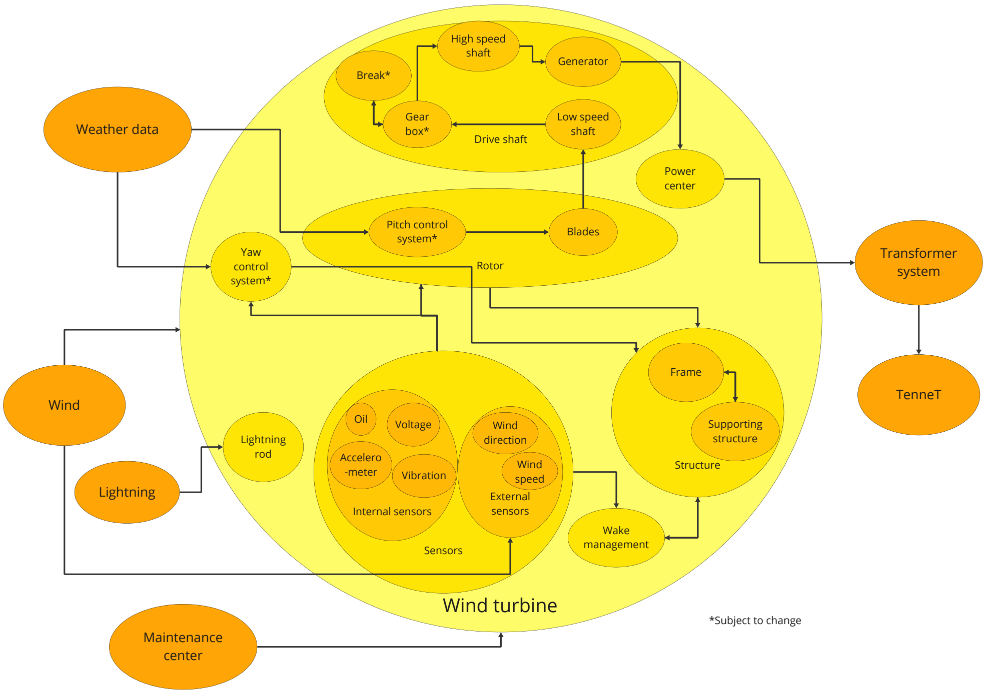


Figure 2.1: *System description diagram*

2.4. User requirements

The user requirements presented in this section have been either derived from the mission need statement as presented in section 2.1, or from private discussions conducted with the client, the sole user of our design expertise.

US.REQ.01 The system shall deliver at least 60 MW of power.

US.REQ.02 The system shall have an energy density equal to or greater than 16 MW/km^2.

US.REQ.03 The system shall have 45 % lower levelized cost of energy than traditional horizontal axis offshore wind turbines.

US.REQ.04 The system shall have multiple rotors.

US.REQ.05 The system shall have lower lifetime emissions than traditional horizontal axis offshore wind turbines.

US.REQ.06 The system shall have increased material recyclability than traditional horizontal axis offshore wind turbines.

US.REQ.07 The system shall have decreased rare metals use than comparable conventional offshore wind energy alternatives.

US.REQ.08 The system shall have a wake re-energizing management system.

US.REQ.09 The system shall be installed offshore.

US.REQ.10 The system shall have less impact on marine life than traditional horizontal axis offshore wind farms.

3

Project organisation

3.1. Team organisation

In this section, the team organisation overview is presented. Firstly, the team organisational approach is provided, followed by an organogram depicting the way specific people are assigned to their respective roles. Lastly, a list of basic rules along with specific corrective actions are presented in order to maintain the proper operation of the team.

3.1.1. Organisational approach

Technical vs Non-technical roles

The team has managed to divide the necessary team roles between technical roles and non-technical or organisational roles. The technical roles are aggregated into technical departments and require special engineering skills. The organisational roles concern all support duties that are required so that the team is able to meet the project's objectives in the scheduled period, within the available resource budgets and with the required quality by the tutor. In order to include all team members equitably across the technical and organisational fields, each team member holds one non-technical role and two technical roles. The duality of technical roles will ensure that all team members will have developed an extensive knowledge about at least two main aspects of the project.

Department division

After extensive talks with the client, it was determined that the project requires the establishment of four main departments, namely aerodynamics, structures, performance and sustainability. These departments will accommodate multiple people, who will share the same title and place in their hierarchy. This functional team organisation will be able to assure that human resources can flow freely between tasks within departments. All departments of engineering will be overseen by the chief engineer. Apart from these technical departments, two other organisational departments have been established, namely documentation and system engineering.

Workday breakdown

The workday begins at 9:00 and ends at 18:00. This includes four 10-minute briefing meetings, where all members of the group update each other on the progress on assigned tasks, as well as planning for the next tasks. The briefing meetings are scheduled in the very morning, before lunchtime, at the midpoint of the afternoon session and at the final of the day. Five additional minutes are allocated for each member to fill in their logbook. In total, one hour is allocated for breaks. This is divided into a 40 min lunch break and two 10 min coffee breaks. Status meetings are planned a minimum of once per week in consultation with the principal tutor.

Responsibility vs Accountability

It is important to mention the crucial difference between different activities in the decision making process. Four different attributes are identified for the decision making parties involved, namely responsible, accountable, consulted and informed. The responsible person is the person that performs the task, while the accountable person is the one that receives the consequences of the work and has ultimate decisive power. The consulted person is the one providing feedback or help. The informed person is only aware of the decision making process, but has no decisive power. Using accurate vocabulary is fundamental in keeping team responsibilities and obligations clear.

Maintaining a healthy working space

There are a few important factors in promoting a healthy working space for all team members. Attention to communication is important. Firstly, respect and appreciation of others' ideas and proposals gives confidence to discuss ideas. Team members that struggle with a task should have the possibility to ask for help/advice/resources/additional time by informing the project manager of the problem. Accountability for the task remains with the group member otherwise, so communicating issues is encouraged.

3.1.2. Organogram

In Figure 3.1, different technical and non-technical roles are assigned to each team members. Non-technical roles, displayed in yellow, concern the organisational and management aspects of the project, while the technical roles displayed in blue concern the different aspects of engineering design that each department will work on. The diagram shows some overlap between the engineering departments, as each team member has two technical roles and one non-technical role.

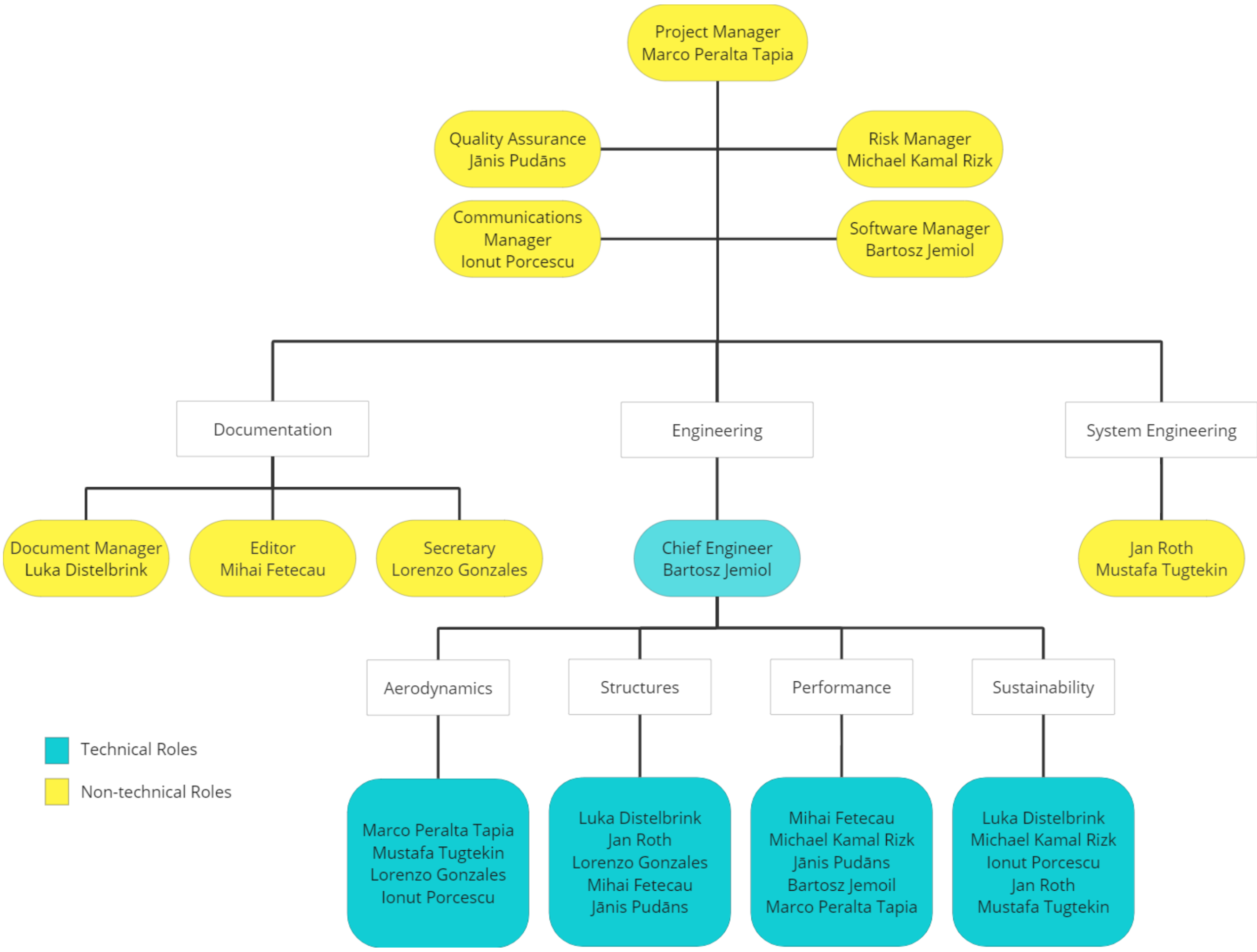


Figure 3.1: *Organogram specifying technical and non-technical roles for group members*

The responsibilities of each role are summarised here:

Project Manager Responsible for overseeing the group's task progress by following up during the briefings on the progress of each assigned task. This includes organising resources according to need (adding members to certain tasks, reorganising the Gantt chart, etc.). The project manager is responsible for establishing shared objectives and deadlines with the client, for leading the team and assuring the functional cohesion of the team, to plan the activities of the team and to ensure the delivery of the system in time, within budget and of the prescribed quality.

Quality Assurance Ensures the quality of the content of the reports and deliverables through inspection, proposes measures to maintain the desired quality during the design process and implements quality assurance practices.

Risk Manager Monitors risks that could affect project progress and provides mitigation and contingency plans to manage these risks. Oversees technical risk assessment and management plans.

Communication Manager Handles group communication with principal tutor, coaches, internal or external experts and third parties.

Software Manager Manages the use of software during the project and provides software solutions.

Document Manager Responsible for data organisation and archiving of group resources as well as submitting deliverables.

Editor Responsible for the formatting of all overleaf documents so that they are consistent and match the expected standard, and solving latex errors that may arise.

Secretary Responsible for taking minutes during the meeting with the client or other persons of contact and develop a summarized information form of what was discussed.

Systems Engineer Responsible for handling the communication at the interfaces between the engineering departments, for giving support to team members regarding system engineering standards and tools, and for identifying possible issues that arise from the inter-dependencies between departments.

Chief Engineer Responsible for leading and overseeing the day-to-day operation of the engineering departments to reach their respective goals, for giving technical support in design decision making and for setting project goals within the technical departments.

Aerodynamics Engineer Responsible for evaluating the aerodynamic performance of the turbines integrated into the system, while also assessing the aerodynamic loads that impinge on the structure of the system.

Structures Engineer Responsible for designing, verifying and validating the performance and safety of the load bearing elements of the system.

Performance Engineer Responsible for the electrical design of the system, the control and stability of the system, the operation and maintenance strategies to be implemented in the system design.

Sustainability Engineer Responsible for integrating the client's sustainability goals in the system design and analysing the sustainability risks and mitigation strategies involved in these risks.

3.1.3. Team rules

Conflicts technical/non-technical It may happen that conflicts arise during the project. Here, the types of conflicts are divided between technical and non-technical. The technical conflicts shall be mediated by the chief engineer. The chief engineer then chooses, based on his own skills and experience, to mediate the issue alone or to raise the problem to the attention of the entire group. For the non-technical conflicts, all issues should first be solved between the involved parties in their personal time outside of the project, keeping in mind that a professional attitude is required for all project participants. In the unlikely case that the conflict escalates and interferes with the quality of the project work, the project manager will intervene and mediate the conflict. If the project manager ultimately cannot make the parties involved reach a unilateral conclusion, the DSE staff will be informed and corrective action will be taken according to them.

Time management If a group member is more than 1 min late, they must buy cake for team members. Additionally, if a team member is consistently late, other group members should inform TAs. Finally, attendance to team briefings takes priority over completing a task.

Communication Communication with tutor/coaches should go through communications officer. Outside intervention should go through tutor first. Inter-department technical communications should involve the systems engineer.

3.2. Work flow diagram

Work flow diagram was made in order to present the relation of tasks that are to be done in order to complete the design. The diagram was split into four major stages: beginning project plan, project plan to base report, base report to midterm report, and midterm report to final report. The breakdown was done first on a very high, fully-sequential level, then on a more detailed level. At that point, could already be done in parallel.

3.3. Work breakdown diagram

While the work flow diagram mostly contains large-scale tasks and illustrates their relations, many blocks on it describe work items too large to be done by a single person in one day. To this end, a work breakdown diagram was made, where each task that was too extensive to be done by a single person in at most 8 hours (one working day) was further broken down into smaller and smaller pieces, until all could be done with the constraints.

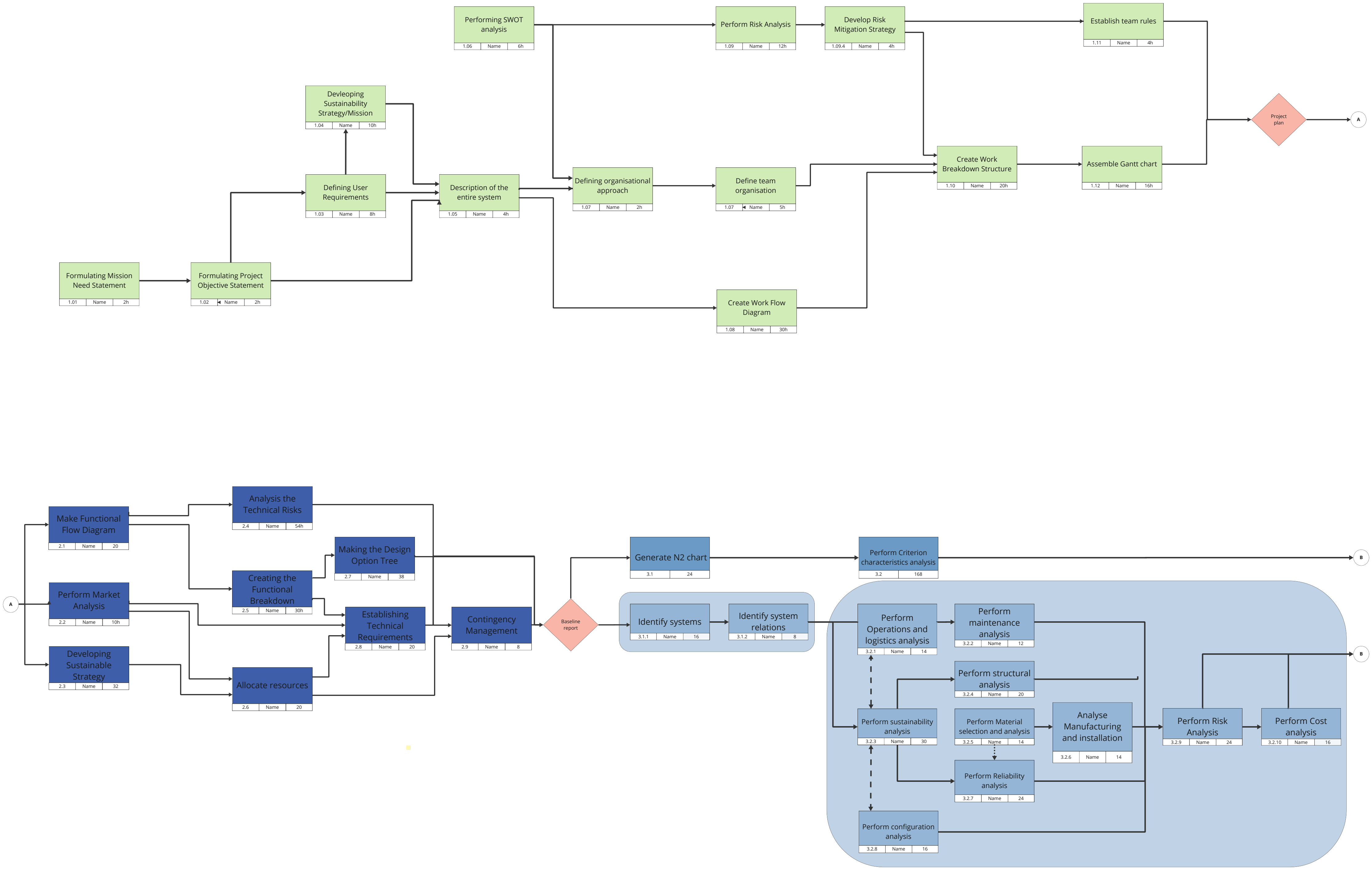
Just as before for the work flow diagram, the work breakdown was done in four main groups: beginning project plan, project plan to base report, base report to midterm report, and midterm report to final report. The breakdown up until midterm review was done in its entirety. For the period from midterm onwards, not all tasks were fully broken down, as the WBS will largely depend on the design selected later.

To aid with planning, the estimate for the number of man hours that the task is expected to take was made. The numbers for lower levels were then added together to make estimates for higher levels. The workflow diagram is intended as a guide, but should regularly be updated and revised during the course of the project in order to help with planning and to reflect the real state of the project.

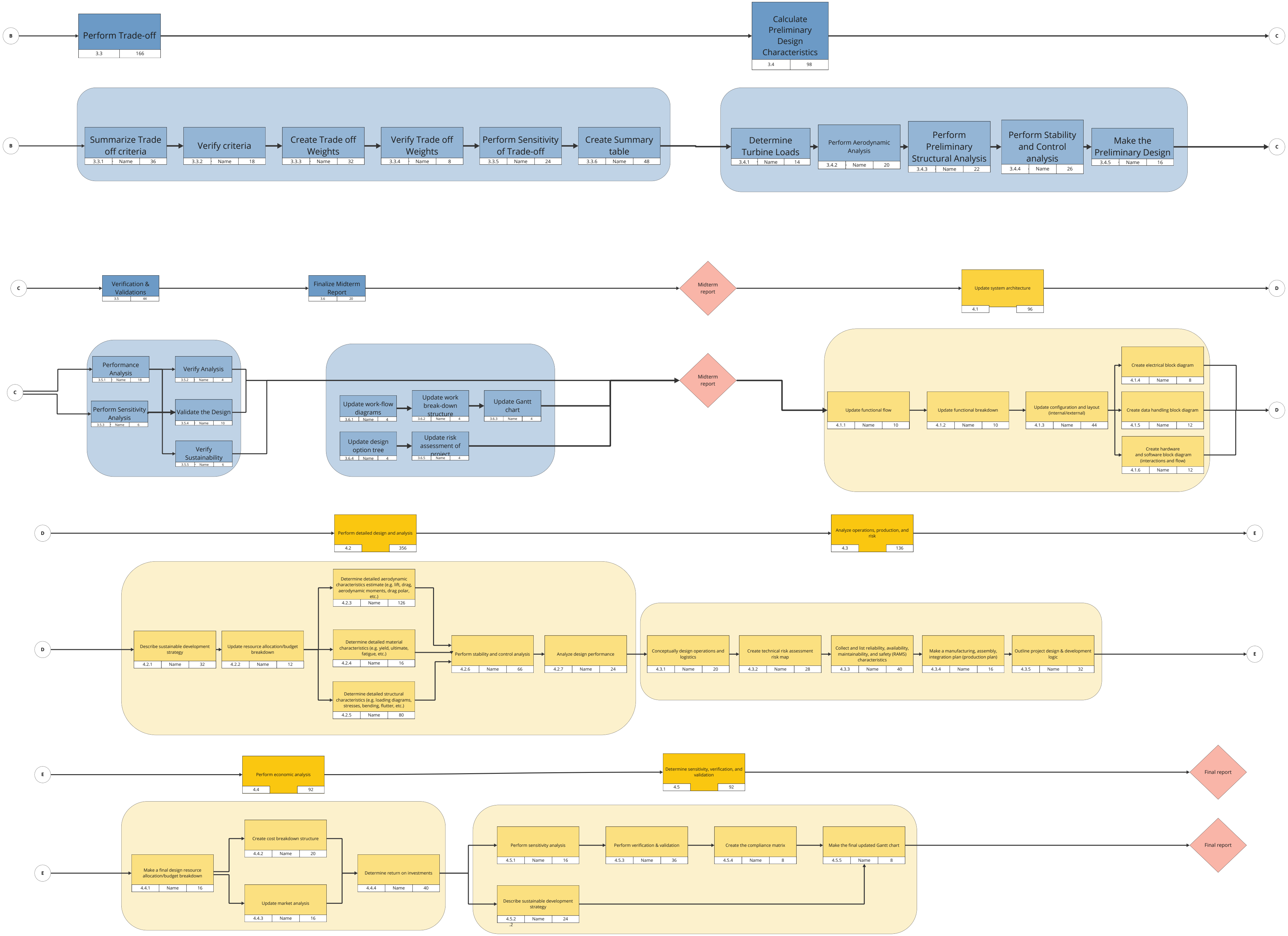
3.4. Gantt chart

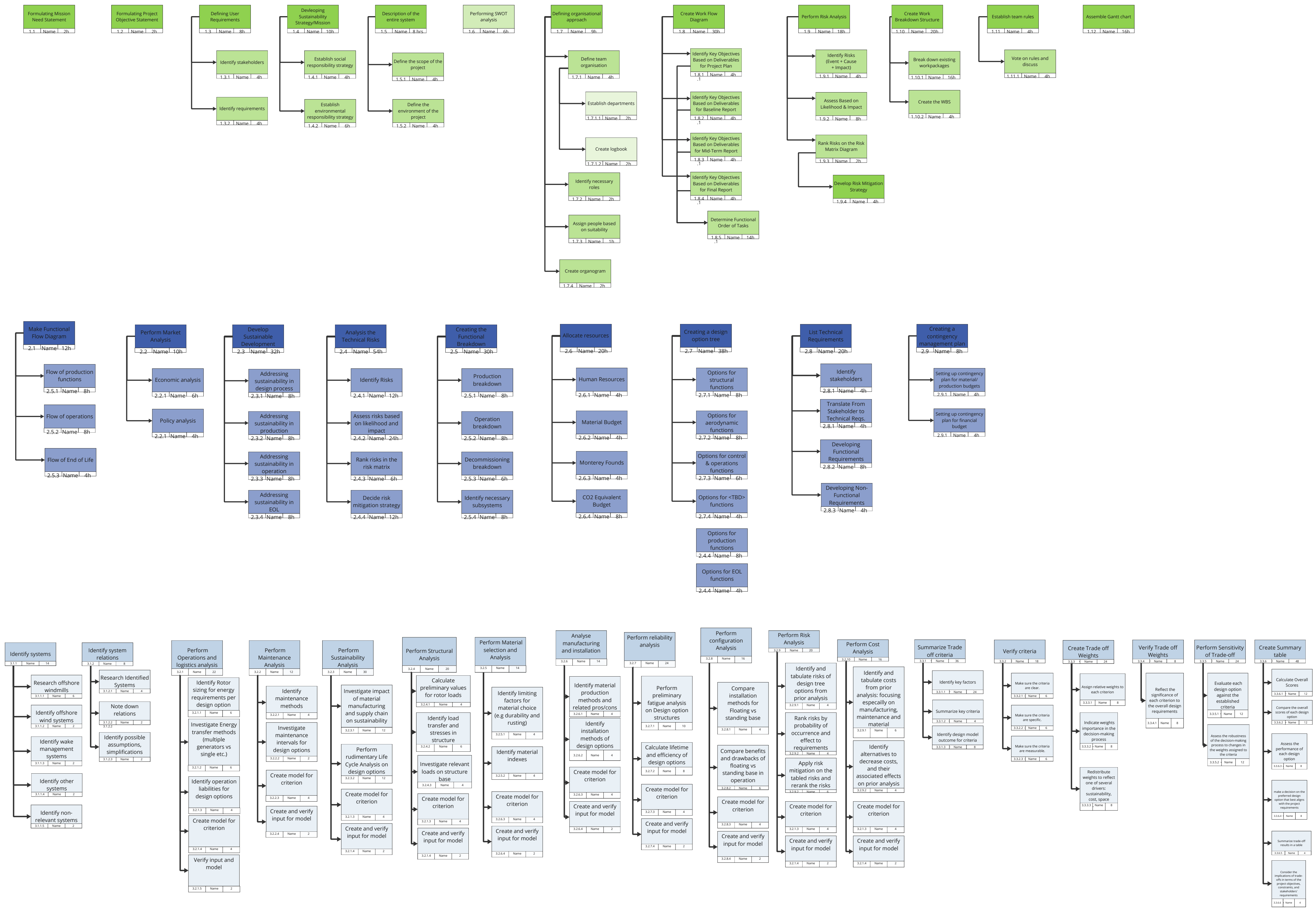
With the WFD and WBS done, a Gantt chart was made. The chart contains all tasks to be done from the beginning of work for the baseline report, up until the final report. The chart does not yet include information about the responsibilities of individual team members, as that was agreed to be determined later.

The Gantt chart will be used to follow progress during the course of the project. It is expected that the final chart will differ from the original state quite largely, however it serves as the best outline of how and when the tasks should be done.

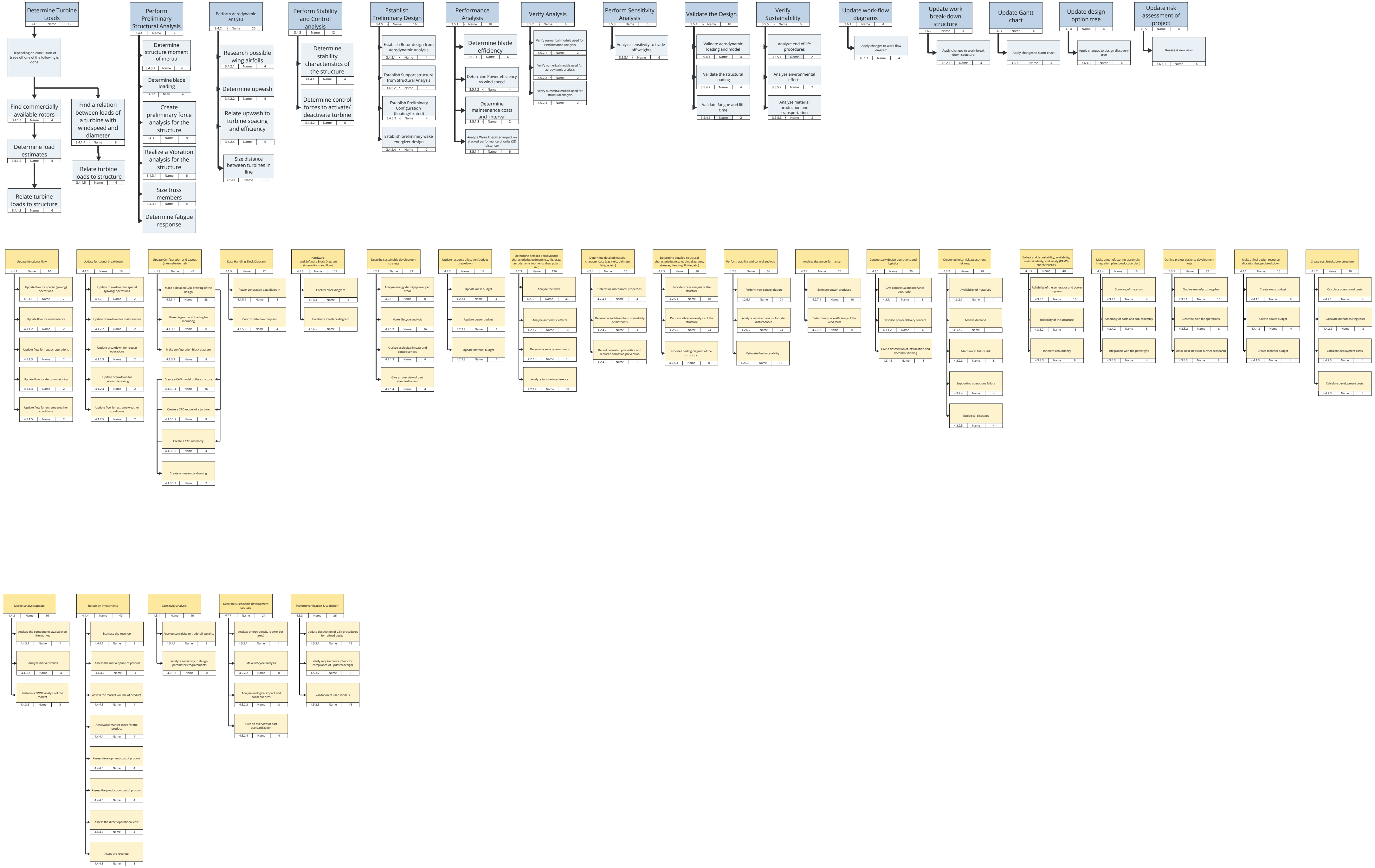


Formulating Mission Need Statement
1.01 Name 2h
Formulating Project Objective Statement
1.02 Name 2h
Defining User Requirements
1.03 Name 8h
Devleoping Sustainability Strategy/Mission
1.04 Name 10h
Description of the entire system
1.05 Name 4h
Performing SWOT analysis
1.06 Name 6h
Defining organisational approach
1.07 Name 2h
Define team organisation
1.07 Name 5h
Create Work Flow Diagram
1.08 Name 30h
Perform Risk Analysis
1.09 Name 12h
Develop Risk Mitigation Strategy
1.09.4 Name 4h
Create Work Breakdown Structure
1.10 Name 20h
Establish team rules
1.11 Name 4h
Assemble Gantt chart
1.12 Name 16h
Project plan
A
A
Make Functional Flow Diagram
2.1 Name 20
Perform Market Analysis
2.2 Name 10h
Developing Sustainable Strategy
2.3 Name 32
Analysis the Technical Risks
2.4 Name 54h
Creating the Functional Breakdown
2.5 Name 30h
Allocate resources
2.6 Name 20
Making the Design Option Tree
2.7 Name 38
Establishing Technical Requirements
2.8 Name 20
Contingency Management
2.9 Name 8
Baseline report
Generate N2 chart
3.1 24
Perform Criterion characteristics analysis
3.2 168
B
Identify systems
3.1.1 Name 16
Identify system relations
3.1.2 Name 8
Perform Operations and logistics analysis
3.2.1 Name 14
Perform maintenance analysis
3.2.2 Name 12
Perform structural analysis
3.2.4 Name 20
Perform sustainability analysis
3.2.3 Name 30
Perform Material selection and analysis
3.2.5 Name 14
Analyse Manufacturing and installation
3.2.6 Name 14
Perform Reliability analysis
3.2.7 Name 24
Perform configuration analysis
3.2.8 Name 16
Perform Risk Analysis
3.2.9 Name 24
Perform Cost analysis
3.2.10 Name 16
B


B
Perform Trade-off
3.3
166
Calculate Preliminary Design Characteristics
3.4
98
C
B
Summarize Trade off criteria
3.3.1
Name
36
Verify criteria
3.3.2
Name
18
Create Trade off Weights
3.3.3
Name
32
Verify trade off Weights
3.3.4
Name
8
Perform Sensitivity of Trade-off
3.3.5
Name
24
Create Summary table
3.3.6
Name
48
Determine Turbine Loads
3.4.1
Name
14
Perform Aerodynamic Analysis
3.4.2
Name
20
Perform Preliminary Structural Analysis
3.4.3
Name
22
Perform Stability and Control analysis
3.4.4
Name
26
Make the Preliminary Design
3.4.5
Name
16
C
C
Verification & Validations
3.5
44
Finalize Midterm Report
3.6
20
Midterm report
Update system architecture
4.1
96
D
C
Performance Analysis
3.5.1
Name
18
Verify Analysis
3.5.2
Name
4
Perform Sensitivity Analysis
3.5.3
Name
6
Validate the Design
3.5.4
Name
10
Verify Sustainability
3.5.5
Name
6
Update work-flow diagrams
3.6.1
Name
4
Update work break-down structure
3.6.2
Name
4
Update Gantt chart
3.6.3
Name
4
Update design option tree
3.6.4
Name
4
Update risk assessment of project
3.6.5
Name
4
Midterm report
Update functional flow
4.1.1
Name
10
Update functional breakdown
4.1.2
Name
10
Update configuration and layout (internal/external)
4.1.3
Name
44
Create electrical block diagram
4.1.4
Name
8
Create data handling block diagram
4.1.5
Name
12
Create hardware and software block diagram (interactions and flow)
4.1.6
Name
12
D
D
Perform detailed design and analysis
4.2
356
Analyze operations, production, and risk
4.3
136
E
D
Describe sustainable development strategy
4.2.1
Name
32
Update resource allocation/budget breakdown
4.2.2
Name
12
Determine detailed aerodynamic characteristics estimate (e.g. lift, drag, aerodynamic moments, drag polar, etc.)
4.2.3
Name
126
Determine detailed material characteristics (e.g. yield, ultimate, fatigue, etc.)
4.2.4
Name
16
Determine detailed structural characteristics (e.g. loading diagrams, stresses, bending, flutter, etc.)
4.2.5
Name
80
Perform stability and control analysis
4.2.6
Name
66
Analyze design performance
4.2.7
Name
24
Conceptually design operations and logistics
4.3.1
Name
20
Create technical risk assessment risk map
4.3.2
Name
28
Collect and list reliability, availability, maintainability, and safety (RAMS) characteristics
4.3.3
Name
40
Make a manufacturing, assembly, integration plan (production plan)
4.3.4
Name
16
Outline project design & development logic
4.3.5
Name
32
E
E
Perform economic analysis
4.4
92
Determine sensitivity, verification, and validation
4.5
92
Final report
E
Make a final design resource allocation/budget breakdown
4.4.1
Name
16
Create cost breakdown structure
4.4.2
Name
20
Update market analysis
4.4.3
Name
16
Determine return on investments
4.4.4
Name
40
Perform sensitivity analysis
4.5.1
Name
16
Perform verification & validation
4.5.3
Name
36
Create the compliance matrix
4.5.4
Name
8
Make the final updated Gantt chart
4.5.5
Name
8
Describe sustainable development strategy
4.5.2
Name
24
Final report

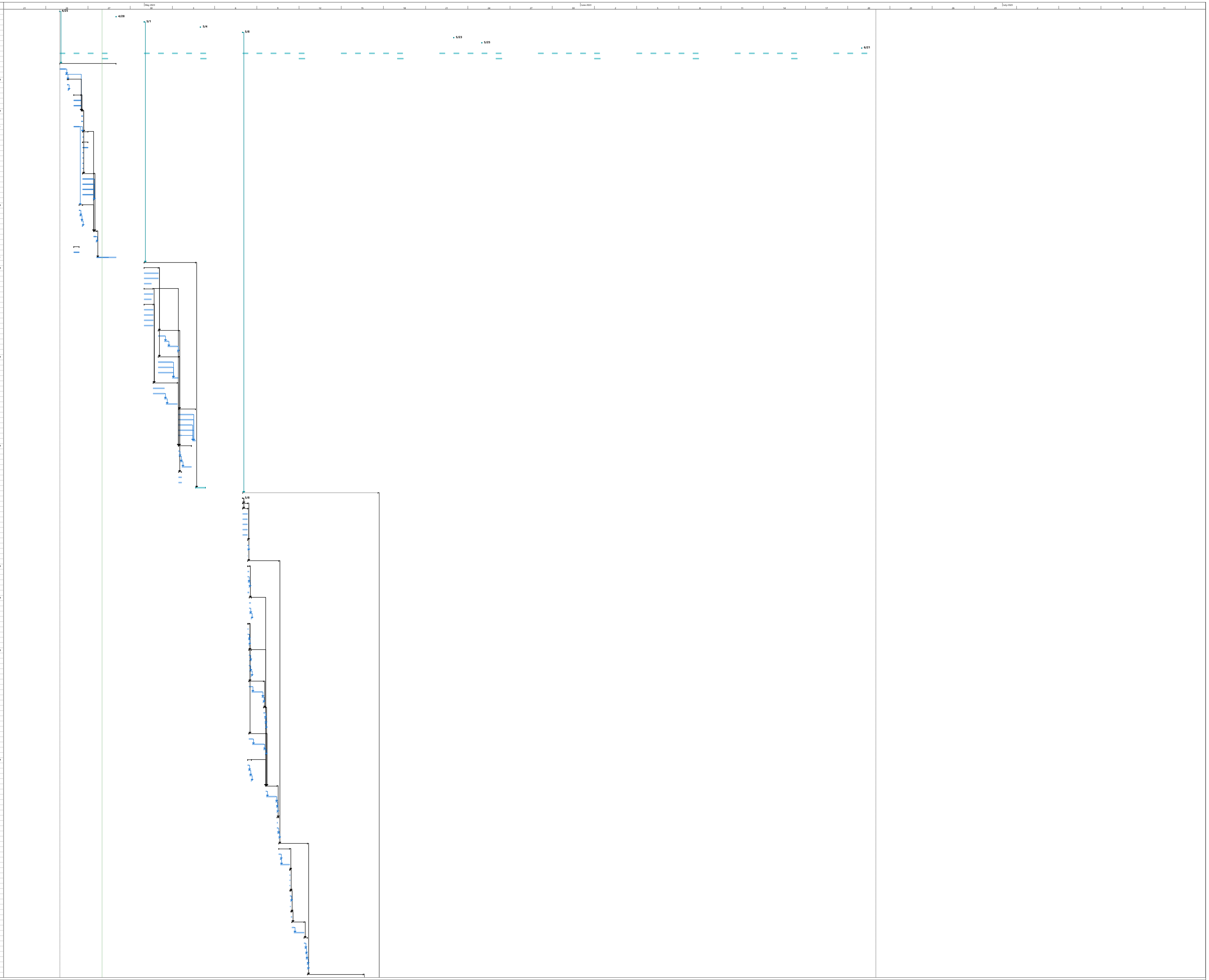


Formulating Mission Need Statement
1.1 Name 2h
Formulating Project Objective Statement
1.2 Name 2h
Defining User Requirements
1.3 Name 8h
Identify stakeholders
1.3.1 Name 4h
Identify requirements
1.3.2 Name 4h
Devleoping Sustainability Strategy/Mission
1.4 Name 10h
Establish social responsibility strategy
1.4.1 Name 4h
Establish environmental responsibility strategy
1.4.2 Name 6h
Description of the entire system
1.5 Name 8 hrs
Define the scope of the project
1.5.1 Name 4h
Define the environment of the project
1.5.2 Name 4h
Performing SWOT analysis
1.6 Name 6h
Defining organisational approach
1.7 Name 9h
Define team organisation
1.7.1 Name 4h
Establish departments
1.7.1.1 Name 2h
Create logbook
1.7.1.2 Name 2h
Identify necessary roles
1.7.2 Name 2h
Assign people based on suitability
1.7.3 Name 1h
Create organogram
1.7.4 Name 2h
Create Work Flow Diagram
1.8 Name 30h
Identify Key Objectives Based on Deliverables for Project Plan
1.8.1.1 Name 4h
Identify Key Objectives Based on Deliverables for Baseline Report
1.8.2.1 Name 4h
Identify Key Objectives Based on Deliverables for Mid-Term Report
1.8.3.1 Name 4h
Identify Key Objectives Based on Deliverables for Final Report
1.8.4.1 Name 4h
Determine Functional Order of Tasks
1.8.5.1 Name 14h
Perform Risk Analysis
1.9 Name 18h
Identify Risks (Event + Cause + Impact)
1.9.1 Name 4h
Assess Based on Likelihood & Impact
1.9.2 Name 8h
Rank Risks on the Risk Matrix Diagram
1.9.3 Name 2h
Develop Risk Mitigation Strategy
1.9.4 Name 4h
Create Work Breakdown Structure
1.10 Name 20h
Break down existing workpackages
1.10.1 Name 16h
Create the WBS
1.10.2 Name 4h
Establish team rules
1.11 Name 4h
Vote on rules and discuss
1.11.1 Name 4h
Assemble Gantt chart
1.12 Name 16h
Make Functional Flow Diagram
2.1 Name 12h
Flow of production functions
2.5.1 Name 8h
Flow of operations
2.5.2 Name 8h
Flow of End of Life
2.5.3 Name 4h
Perform Market Analysis
2.2 Name 10h
Economic analysis
2.2.1 Name 6h
Policy analysis
2.2.1 Name 4h
Develop Sustainable Development
2.3 Name 32h
Addressing sustainability in design process
2.3.1 Name 8h
Addressing sustainability in production
2.3.2 Name 8h
Addressing sustainability in operation
2.3.3 Name 8h
Addressing sustainability in EOL
2.3.4 Name 8h
Analysis the Technical Risks
2.4 Name 54h
Identify Risks
2.4.1 Name 12h
Assess risks based on likelihood and impact
2.4.2 Name 24h
Rank risks in the risk matrix
2.4.3 Name 6h
Decide risk mitigation strategy
2.4.4 Name 12h
Creating the Functional Breakdown
2.5 Name 30h
Production breakdown
2.5.1 Name 8h
Operation breakdown
2.5.2 Name 8h
Decommissioning breakdown
2.5.3 Name 6h
Identify necessary subsystems
2.5.4 Name 8h
Allocate resources
2.6 Name 20h
Human Resources
2.6.1 Name 4h
Material Budget
2.6.2 Name 4h
Monterey Founds
2.6.3 Name 4h
CO2 Equivalent Budget
2.6.4 Name 8h
Creating a design option tree
2.7 Name 38h
Options for structural functions
2.7.1 Name 8h
Options for aerodynamic functions
2.7.2 Name 8h
Options for control & operations functions
2.7.3 Name 6h
Options for <TBD> functions
2.7.4 Name 4h
Options for production functions
2.4.4 Name 8h
Options for EOL functions
2.4.4 Name 4h
List Technical Requirements
2.8 Name 20h
Identify stakeholders
2.8.1 Name 4h
Translate From Stakeholder to Technical Reqs.
2.8.1 Name 4h
Developing Functional Requirements
2.8.2 Name 8h
Developing Non-Functional Requirements
2.8.3 Name 4h
Creating a contingency management plan
2.9 Name 8h
Setting up contingency plan for material/ production budgets
2.9.1 Name 4h
Setting up contingency plan for financial budget
2.9.1 Name 4h
Identify systems
Research offshore windmills
Identify offshore wind systems
Identify wake management systems
Identify other systems
Identify non-relevant systems
Identify system relations
Research Identified Systems
Note down relations
Identify possible assumptions, simplifications
Perform Operations and logistics analysis
Identify Rotor sizing for energy requirements per design option
Investigate Energy transfer methods (multiple generators vs single etc.)
Identify operation liabilities for design options
Create model for criterion
Verify input and model
Perform Maintenance Analysis
Identify maintenance methods
Investigate maintenance intervals for design options
Create model for criterion
Create and verify input for model
Perform Sustainability Analysis
Investigate impact of material manufacturing and supply chain on sustainability
Perform rudimentary Life Cycle Analysis on design options
Create model for criterion
Create and verify input for model
Perform Structural Analysis
Calculate preliminary values for rotor loads
Identify load transfer and stresses in structure
Investigate relevant loads on structure base
Create model for criterion
Create and verify input for model
Perform Material selection and Analysis
Identify limiting factors for material choice (e.g durability and rusting)
Identify material indexes
Create model for criterion
Create and verify input for model
Analyse manufacturing and installation
Identify material production methods and related pros/cons
Identify installation methods of design options
Create model for criterion
Create and verify input for model
Perform reliability analysis
Perform preliminary fatigue analysis on Design option structures
Calculate lifetime and efficiency of design options
Create model for criterion
Create and verify input for model
Perform configuration Analysis
Compare installation methods for Floating vs standing base
Compare benefits and drawbacks of floating vs standing base in operation
Create model for criterion
Create and verify input for model
Perform Risk Analysis
Identify and tabulate risks of design tree options from prior analysis
Rank risks by probability of occurrence and effect to requirements
Apply risk mitigation on the tabled risks and rerank the risks
Create model for criterion
Create and verify input for model
Perform Cost Analysis
Identify and tabulate costs from prior analysis: focusing especially on manufacturing, maintenance and material
Identify alternatives to decrease costs, and their associated effects on prior analysis
Create model for criterion
Create and verify input for model
Summarize Trade off criteria
Identify key factors
Summarize key criteria
Identify design model outcome for criteria
Verify criteria
Make sure the criteria are clear.
Make sure the criteria are specific.
Make sure the criteria are measurable.
Create Trade off Weights
Assign relative weights to each criterion
Indicate weights importance in the decision-making process
Redistribute weights to reflect one of several drivers: sustainability, cost, space
Verify Trade off Weights
Reflect the significance of each criterion to the overall design requirements
Perform Sensitivity of Trade-off
Evaluate each design option against the established criteria
Assess the robustness of the decision-making process to changes in the weights assigned to the criteria
Create Summary table
Calculate Overall Scores
Compare the overall scores of each design option
Assess the performance of each design option
make a decision on the preferred design option that best aligns with the project requirements
Summarize trade-off results in a table
Consider the implications of trade-offs in terms of the project objectives, constraints, and stakeholders' requirements



Determine Turbine Loads 3.4.1 Name 12
Depending on conclusion of trade off one of the following is done
Find commercially available rotors 3.4.1.1 Name 4
Determine load estimates 3.4.1.2 Name 4
Relate turbine loads to structure 3.4.1.3 Name 4
Find a relation between loads of a turbine with windspeed and diameter 3.4.1.4 Name 8
Relate turbine loads to structure 3.4.1.5 Name 4
Perform Preliminary Structural Analysis 3.4.4 Name 36
Determine structure moment of inertia 3.4.3.1 Name 6
Determine blade loading 3.4.3.2 Name 4
Create preliminary force analysis for the structure 3.4.3.3 Name 8
Realize a Vibration analysis for the structure 3.4.3.4 Name 6
Size truss members 3.4.3.5 Name 4
Determine fatigue response
Perform Aerodynamic Analysis 3.4.2 Name 20
Research possible wing airfoils 3.4.2.1 Name 4
Determine upwash 3.4.2.2 Name 4
Relate upwash to turbine spacing and efficiency 3.4.2.4 Name 6
Size distance between turbines in line 3.4.2.5 Name 6
Perform Stability and Control analysis 3.4.3 Name 12
Determine stability characteristics of the structure 3.4.4.1 Name 4
Determine control forces to activate/ deactivate turbine 3.4.4.2 Name 8
Establish Preliminary Design 3.4.5 Name 16
Establish Rotor design from Aerodynamic Analysis 3.4.5.1 Name 4
Establish Support structure from Structural Analysis 3.4.5.2 Name 6
Establish Preliminary Configuration (floating/fixated) 3.4.5.3 Name 4
Establish preliminary wake energizer design 3.4.5.4 Name 2
Performance Analysis 3.5.1 Name 18
Determine blade efficiency 3.5.1.1 Name 6
Determine Power efficiency vs wind speed 3.5.1.2 Name 4
Determine maintenance costs and interval 3.5.1.3 Name 2
Analyze Wake Energizer impact on stacked performance of units (2D distance) 3.5.1.4 Name 6
Verify Analysis 3.5.2 Name 6
Verify numerical models used for Performance Analysis 3.5.2.1 Name 2
Verify numerical models used for aerodynamic analysis 3.5.2.2 Name 2
Verify numerical models used for structural analysis 3.5.2.3 Name 2
Perform Sensitivity Analysis 3.5.3 Name 6
Analyze sensitivity to trade-off weights 3.5.3.1 Name 6
Validate the Design 3.5.4 Name 10
Validate aerodynamic loading and model 3.5.4.1 Name 4
Validate the structural loading 3.5.4.2 Name 4
Validate fatigue and life time 3.5.4.3 Name 2
Verify Sustainability 3.5.5 Name 6
Analyze end of life procedures 3.5.5.1 Name 2
Analyze environmental effects 3.5.5.2 Name 2
Analyze material production and transportation 3.5.5.3 Name 2
Update work-flow diagrams 3.6.1 Name 4
Apply changes to work flow diagram 3.6.1.1 Name 4
Update work break-down structure 3.6.2 Name 4
Apply changes to work-break down structure 3.6.2.1 Name 4
Update Gantt chart 3.6.3 Name 4
Apply changes to Gantt chart 3.6.3.1 Name 4
Update design option tree 3.6.4 Name 4
Apply changes to design discovery tree 3.6.4.1 Name 4
Update risk assessment of project 3.6.5 Name 4
Reassess new risks 3.6.5.1 Name 4
Update functional flow 4.1.1 Name 10
Update flow for special (pawing) operations 4.1.1.1 Name 2
Update flow for maintenance 4.1.1.2 Name 2
Update flow for regular operations 4.1.1.3 Name 2
Update flow for decommissioning 4.1.1.4 Name 2
Update flow for extreme weather conditions 4.1.1.5 Name 2
Update functional breakdown 4.1.2 Name 10
Update breakdown for special (pawing) operations 4.1.2.1 Name 2
Update breakdown for maintenance 4.1.2.2 Name 2
Update breakdown for regular operations 4.1.2.3 Name 2
Update breakdown for decommissioning 4.1.2.4 Name 2
Update flow for extreme weather conditions 4.1.2.5 Name 2
Update Configuration and Layout (internal/external) 4.1.3 Name 44
Make a detailed CAD drawing of the design 4.1.3.1 Name 28
Make diagram and loading for mounting 4.1.3.2 Name 8
Make configuration block diagram 4.1.3.3 Name 8
Create a CAD model of the structure 4.1.3.1.1 Name 16
Create a CAD model of a turbine 4.1.3.1.2 Name 8
Create a CAD assembly 4.1.3.1.3 Name 4
Create an assembly drawing 4.1.3.1.4 Name 2
Data Handling Block Diagram 4.1.5 Name 12
Power generation data diagram 4.1.5.1 Name 8
Control data flow diagram 4.1.5.2 Name 4
Hardware and Software Block Diagram (interactions and flow) 4.1.6 Name 12
Control block diagram 4.1.6.1 Name 4
Hardware interface diagram 4.1.6.2 Name 8
Describe sustainable development strategy 4.2.1 Name 32
Analyze energy density (power per area) 4.2.1.1 Name 8
Make lifecycle analysis 4.2.1.2 Name 16
Analyze ecological impact and consequences 4.2.1.3 Name 4
Give an overview of part standardization 4.2.1.4 Name 4
Update resource allocation/budget breakdown 4.2.2 Name 12
Update mass budget 4.2.2.1 Name 4
Update power budget 4.2.2.2 Name 4
Update material budget 4.2.2.3 Name 4
Determine detailed aerodynamic characteristics estimate (e.g. lift, drag, aerodynamic moments, drag polar, etc.) 4.2.3 Name 126
Analyze the wake 4.2.3.1 Name 48
Analyze aeroelastic effects 4.2.3.2 Name 32
Determine aerodynamic loads 4.2.3.3 Name 16
Analyze turbine interference 4.2.3.4 Name 32
Determine detailed material characteristics (e.g. yield, ultimate, fatigue, etc.) 4.2.4 Name 16
Determine mechanical properties 4.2.4.1 Name 4
Determine and describe sustainability of materials 4.2.4.2 Name 4
Report corrosion properties, and required corrosion prevention 4.2.4.3 Name 8
Determine detailed structural characteristics (e.g. loading diagrams, stresses, bending, flutter, etc.) 4.2.5 Name 80
Provide stress analysis of the structure 4.2.5.1 Name 48
Perform vibration analysis of the structure 4.2.5.2 Name 24
Provide Loading diagram of the structure 4.2.5.3 Name 8
Perform stability and control analysis 4.2.6 Name 44
Perform yaw control design 4.2.6.1 Name 24
Analyze required control for tidal disturbances 4.2.6.2 Name 24
Estimate floating stability 4.2.6.3 Name 12
Analyze design performance 4.2.7 Name 24
Estimate power produced 4.2.7.1 Name 16
Determine space efficiency of the wind farm 4.2.7.2 Name 8
Conceptually design operations and logistics 4.3.1 Name 20
Give conceptual maintenance description 4.3.1.1 Name 8
Describe power delivery concept 4.3.1.2 Name 4
Give a description of installation and decommissioning 4.3.1.3 Name 8
Create technical risk assessment risk map 4.3.2 Name 28
Availability of materials 4.3.2.1 Name 4
Market demand 4.3.2.2 Name 8
Mechanical failure risk 4.3.2.3 Name 8
Supporting operations failure 4.3.2.4 Name 4
Ecological disasters 4.3.2.5 Name 4
Collect and list reliability, availability, maintainability, and safety (RAMS) characteristics 4.3.3 Name 40
Reliability of the generator and power system 4.3.3.1 Name 16
Reliability of the structure 4.3.3.2 Name 16
Inherent redundancy 4.3.3.3 Name 8
Make a manufacturing, assembly, integration plan (production plan) 4.3.4 Name 16
Sourcing of materials 4.3.4.1 Name 4
Assembly of parts and sub-assembly 4.3.4.2 Name 8
Integration with the power grid 4.3.4.3 Name 4
Outline project design & development logic 4.3.5 Name 32
Outline manufacturing plan 4.3.5.1 Name 16
Describe plan for operations 4.3.5.2 Name 8
Detail next steps for further research 4.3.5.3 Name 8
Make a final design resource allocation/budget breakdown 4.4.1 Name 16
Create mass budget 4.4.1.1 Name 8
Create power budget 4.4.1.2 Name 4
Create material budget 4.4.1.3 Name 4
Create cost breakdown structure 4.4.2 Name 20
Calculate operational costs 4.4.2.1 Name 4
Calculate manufacturing costs 4.4.2.2 Name 8
Calculate deployment costs 4.4.2.3 Name 4
Calculate development costs 4.4.2.3 Name 4
Market analysis update 4.4.3 Name 16
Analyze the components available on the market 4.4.3.1 Name 4
Analyze market trends 4.4.3.2 Name 4
Perform a SWOT analysis of the market 4.4.3.3 Name 8
Return on investments 4.4.4 Name 40
Estimate the revenue 4.4.4.1 Name 8
Assess the market price of product 4.4.4.2 Name 4
Assess the market volume of product 4.4.4.3 Name 4
Achievable market share for the product 4.4.4.4 Name 4
Assess development cost of product 4.4.4.5 Name 4
Assess the production cost of product 4.4.4.6 Name 4
Assess the direct operational cost 4.4.4.7 Name 4
Asses the revenue 4.4.4.8 Name 8
Sensitivity analysis 4.5.1 Name 16
Analyze sensitivity to trade-off weights 4.5.1.1 Name 8
Analyze sensitivity to design parameters/requirements 4.5.1.2 Name 8
Describe sustainable development strategy 4.5.2 Name 24
Analyze energy density (power per area) 4.5.2.1 Name 4
Make lifecycle analysis 4.5.2.2 Name 8
Analyze ecological impact and consequences 4.5.2.3 Name 8
Give an overview of part standardization 4.5.2.4 Name 4
Perform verification & validation 4.5.3 Name 36
Update description of V&V procedures for refined design 4.5.3.1 Name 8
Verify requirements (check for compliance of updated design) 4.5.3.2 Name 8
Validation of used models 4.5.3.3 Name 16

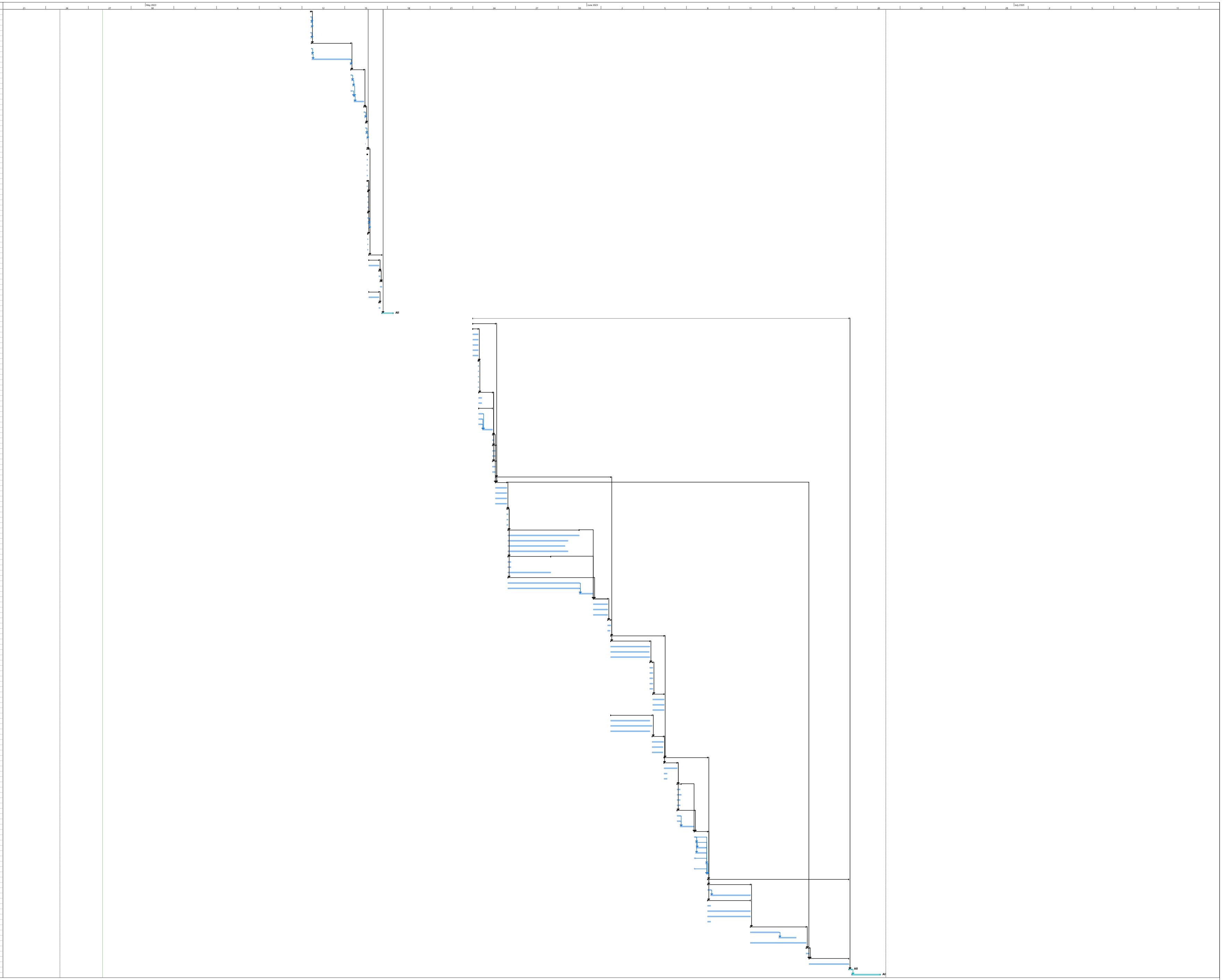
ID	% Compl	Task Name	Duration	Start	Finish	Predeces	Resource Names
1	0%	Project begins	0 days	Tue 4/25/23	Tue 4/25/23		
2	0%	Project plan draft submition	0 days	Fri 4/28/23	Fri 4/28/23		
3	0%	Baseline start	0 days	Mon 5/1/23	Mon 5/1/23		
4	0%	Baseline Review submititon	0 days	Thu 5/4/23	Thu 5/4/23		
5	0%	Begin Midterm	0 days	Mon 5/8/23	Mon 5/8/23		
6	0%	Midterm report deadline	0 days	Tue 5/23/23	Tue 5/23/23		
7	0%	Final phase begins	0 days	Thu 5/25/23	Thu 5/25/23		
8	0%	Final report deadline	0 days	Wed 6/21/23	Wed 6/21/23		
9	0%	**Time dedicated to quick team meetings and organisation**	41.13 days	Tue 4/25/23	Wed 6/21/23		
52	0%	**Weekly meeting with Professor and Mentors**	35.25 days	Fri 4/28/23	Fri 6/16/23		
61	91%	**Project plan phase**	4 days	Tue 4/25/23	Fri 4/28/23	1	
62	100%	Formulating mission need statemenet	2 hrs	Tue 4/25/23	Tue 4/25/23		One person
63	100%	Formulating project objective statement	2 hrs	Tue 4/25/23	Tue 4/25/23	62	One person
64	100%	**Defining User Requirements**	0.25 days	Tue 4/25/23	Tue 4/25/23	63	Three people
65	100%	Identify stakeholders	1 hr	Tue 4/25/23	Tue 4/25/23		
66	100%	Identify requirements	1 hr	Tue 4/25/23	Tue 4/25/23	65	
67	100%	**Developing Sutainability Mission**	0.5 days	Wed 4/26/23	Wed 4/26/23		Two people
68	100%	Establish social responsibility	4 hrs	Wed 4/26/23	Wed 4/26/23		
69	100%	Establish enviromental responsiblities	4 hrs	Wed 4/26/23	Wed 4/26/23		
70	100%	**Describie the entire system**	0.25 days	Wed 4/26/23	Wed 4/26/23	63,64,67	Three people
71	100%	Define the environment of the project	2 hrs	Wed 4/26/23	Wed 4/26/23		
72	100%	Define the scope of the project	2 hrs	Wed 4/26/23	Wed 4/26/23		
73	100%	Perform SWOT analysis	1 hr	Wed 4/26/23	Wed 4/26/23		Three people
74	93%	**Definine organistaional approach**	0.25 days	Wed 4/26/23	Wed 4/26/23	70,73	All
75	100%	Identify necessary roles	1 hr	Wed 4/26/23	Wed 4/26/23		
76	100%	**Define team organisation**	0.25 days	Wed 4/26/23	Wed 4/26/23		
77	100%	Create logbook	2 hrs	Wed 4/26/23	Wed 4/26/23		
78	100%	Establish departments	1 hr	Wed 4/26/23	Wed 4/26/23		
79	100%	Identify necessary roles	1 hr	Wed 4/26/23	Wed 4/26/23		
80	100%	Assign people based on suitability	1 hr	Wed 4/26/23	Wed 4/26/23		
81	50%	Create organogram	1 hr	Wed 4/26/23	Wed 4/26/23		
82	100%	**Create work flow diagram**	0.5 days	Wed 4/26/23	Thu 4/27/23	70	All
83	100%	Identify key objectives based on deliverables for project plan	3 hrs	Wed 4/26/23	Thu 4/27/23		
84	100%	Identify key objectives based on deliverables for baseline report	3 hrs	Wed 4/26/23	Thu 4/27/23		
85	100%	Identify key objectives based on deliverables for mid-term report	3 hrs	Wed 4/26/23	Thu 4/27/23		
86	100%	identify key objectives based on deliverables for fianl report	3 hrs	Wed 4/26/23	Thu 4/27/23		
87	100%	Determine functional order of tasks	1 hr	Thu 4/27/23	Thu 4/27/23	84,86,85	
88	100%	**Perform Project Risk Analysis**	0.63 days	Wed 4/26/23	Wed 4/26/23	73	Three people
89	100%	Identify risks (event + cause + impact)	1 hr	Wed 4/26/23	Wed 4/26/23		
90	100%	Assess Based on likelihood & impact	2 hrs	Wed 4/26/23	Wed 4/26/23	89	
91	100%	Rank risks on the risk matrix diagram	1 hr	Wed 4/26/23	Wed 4/26/23	90	
92	100%	Develop risk mitigation strategy	1 hr	Wed 4/26/23	Wed 4/26/23	91	
93	100%	**Create work breakdown structure**	0.5 days	Thu 4/27/23	Thu 4/27/23	88,74,82	All
94	100%	Break down exisiting workpackages	3 hrs	Thu 4/27/23	Thu 4/27/23		
95	100%	Create the WBS	1 hr	Thu 4/27/23	Thu 4/27/23	94	
96	100%	**Establish team rules**	0.13 days	Wed 4/26/23	Wed 4/26/23		All
97	100%	Vote on rules and discuss	1 hr	Wed 4/26/23	Wed 4/26/23		
98	50%	Assemble Gantt chart	10 hrs	Thu 4/27/23	Fri 4/28/23	93	Three people
99	0%	**Baseline report phase**	3.83 days	Mon 5/1/23	Thu 5/4/23	3	
100	0%	**Make functional flow diagram**	1 day	Mon 5/1/23	Mon 5/1/23		Three people
101	0%	Flow of production functions	8 hrs	Mon 5/1/23	Mon 5/1/23		
102	0%	Flow of operations	8 hrs	Mon 5/1/23	Mon 5/1/23		
103	0%	Flow of End of Life	4 hrs	Mon 5/1/23	Mon 5/1/23		
104	0%	**Perform market analysis**	0.75 days	Mon 5/1/23	Mon 5/1/23		Two people
105	0%	Economic analysis	6 hrs	Mon 5/1/23	Mon 5/1/23		
106	0%	Policy analysis	4 hrs	Mon 5/1/23	Mon 5/1/23		
107	0%	**Develop sustainable strategy**	0.8 days	Mon 5/1/23	Mon 5/1/23		Five people
108	0%	Addressing sustainabillity in design process	6.4 hrs	Mon 5/1/23	Mon 5/1/23		
109	0%	Addressing sustainabillity in production	6.4 hrs	Mon 5/1/23	Mon 5/1/23		
110	0%	Addressing sustainabillity in operation	6.4 hrs	Mon 5/1/23	Mon 5/1/23		
111	0%	Addressing sustainabillity in EOL	6.4 hrs	Mon 5/1/23	Mon 5/1/23		
112	0%	**Analyse the technical risks**	1.35 days	Tue 5/2/23	Wed 5/3/23	100	Five people
113	0%	Identify Risks	2.4 hrs	Tue 5/2/23	Tue 5/2/23		
114	0%	Assess risks based on likelihood and impact	4.8 hrs	Tue 5/2/23	Tue 5/2/23	113	
115	0%	Rank risks in the risk matrix	1.2 hrs	Tue 5/2/23	Wed 5/3/23	114	
116	0%	Decide risk mitigation strartegy	2.4 hrs	Wed 5/3/23	Wed 5/3/23	115	
117	0%	**Create the functional breakdown**	1.33 days	Tue 5/2/23	Wed 5/3/23	100	Three people
118	0%	Production breakdown	8 hrs	Tue 5/2/23	Tue 5/2/23		
119	0%	Operation breakdown	8 hrs	Tue 5/2/23	Tue 5/2/23		
120	0%	Decommission breakdown	8 hrs	Tue 5/2/23	Tue 5/2/23		
121	0%	Identify necessary subsystems	2.6 hrs	Wed 5/3/23	Wed 5/3/23	118,119,	
122	0%	**Allocate resources**	1.25 days	Mon 5/1/23	Wed 5/3/23	104,107	One person
123	0%	Human Resources	4 hrs	Mon 5/1/23	Tue 5/2/23		
124	0%	Material Budget	4 hrs	Mon 5/1/23	Tue 5/2/23		
125	0%	Monetary funds	2 hrs	Tue 5/2/23	Tue 5/2/23	124	
126	0%	CO2 equivalent budget	4 hrs	Tue 5/2/23	Wed 5/3/23	125	
127	0%	**Make the design option tree**	1.5 days	Wed 5/3/23	Thu 5/4/23	117	Five people
128	0%	Options for structal functions	8 hrs	Wed 5/3/23	Thu 5/4/23		
129	0%	Options for aeordynamic functions	8 hrs	Wed 5/3/23	Thu 5/4/23		
130	0%	Options for control & operations functions	6 hrs	Wed 5/3/23	Thu 5/4/23		
131	0%	Options for production functions	8 hrs	Wed 5/3/23	Thu 5/4/23		
132	0%	Options for EOL functions	4 hrs	Wed 5/3/23	Wed 5/3/23		
133	0%	Options for other functions	4 hrs	Thu 5/4/23	Thu 5/4/23	128,129,	
134	0%	**Establishing technical requirements**	0.75 days	Wed 5/3/23	Thu 5/4/23	117,122,	Three people
135	0%	Identify stakeholders	0.66 hrs	Wed 5/3/23	Wed 5/3/23		
136	0%	Translate from stakeholder to technical requirements	1.33 hrs	Wed 5/3/23	Wed 5/3/23	135	
137	0%	Developing functional requirements	2.66 hrs	Wed 5/3/23	Wed 5/3/23	136	
138	0%	Developing non-functional requirements	1.33 hrs	Wed 5/3/23	Thu 5/4/23	137	
139	0%	**Create a contingency plan**	0.5 days	Wed 5/3/23	Wed 5/3/23	112	Two people
140	0%	Set up contingency plan for material/production budgets	4 hrs	Wed 5/3/23	Wed 5/3/23		
141	0%	up contingency plan for financial budget	4 hrs	Wed 5/3/23	Wed 5/3/23		
142	0%	Baseline Review	2 hrs	Thu 5/4/23	Fri 5/5/23	99	
143	0%	**Baseline to midterm**	7.72 days	Mon 5/8/23	Wed 5/17/23	5	
1	0%	Begin Midterm	0 days	Mon 5/8/23	Mon 5/8/23		
2	0%	**Generate N2 chart**	0.08 days	Mon 5/8/23	Mon 5/8/23	1	
3	0%	**Identify systems**	0.04 days	Mon 5/8/23	Mon 5/8/23	1	Five people
4	0%	Research off shore windmills	0.3 hrs	Mon 5/8/23	Mon 5/8/23		
5	0%	Identify offshore wind systems	0.1 hrs	Mon 5/8/23	Mon 5/8/23		
6	0%	Identify wake management systems	0.1 hrs	Mon 5/8/23	Mon 5/8/23		
7	0%	Identify other systems	0.1 hrs	Mon 5/8/23	Mon 5/8/23		
8	0%	Identify non relevant systems	0.1 hrs	Mon 5/8/23	Mon 5/8/23		
9	0%	**Identify systems relations**	0.04 days	Mon 5/8/23	Mon 5/8/23	3	Five people
10	0%	Research identified systems	0.2 hrs	Mon 5/8/23	Mon 5/8/23		
11	0%	Note down relations	0.1 hrs	Mon 5/8/23	Mon 5/8/23	10	
12	0%	Identify possible assumptions, simplifications	0.1 hrs	Mon 5/8/23	Mon 5/8/23		
13	0%	**Perform criteria characteristics analysis**	2.5 days	Mon 5/8/23	Wed 5/10/23	2	
14	0%	**Perform operations and logistics analysis**	0.33 days	Mon 5/8/23	Mon 5/8/23		Three people
15	0%	Investigate energy transfer methods	2 hrs	Mon 5/8/23	Mon 5/8/23		
16	0%	Identify operation liabilities for design options	0.66 hrs	Mon 5/8/23	Mon 5/8/23		
17	0%	Create model for criterion	1.33 hrs	Mon 5/8/23	Mon 5/8/23	16	
18	0%	Verify input and model	0.66 hrs	Mon 5/8/23	Mon 5/8/23	17	
19	0%	Identify rotor sizing for energy requirements per design option	2 hrs	Mon 5/8/23	Mon 5/8/23		
20	0%	**Perform maintenance analysis**	0.33 days	Mon 5/8/23	Mon 5/8/23	14	Three people
21	0%	Identify maintenance methods	1.33 hrs	Mon 5/8/23	Mon 5/8/23		
22	0%	Investigate maintenance intervals for design options	0.66 hrs	Mon 5/8/23	Mon 5/8/23		
23	0%	Create model for criterion	1.33 hrs	Mon 5/8/23	Mon 5/8/23	22	
24	0%	Verify input and model	0.66 hrs	Mon 5/8/23	Mon 5/8/23	23	
25	0%	**Perform sustainability analysis**	0.25 days	Mon 5/8/23	Mon 5/8/23		Six people
26	0%	Investigate impact of material manufacturing and supply chain on sustainability	1 hr	Mon 5/8/23	Mon 5/8/23		
27	0%	Perform rudimentary Life cycle analysis on design options	1 hr	Mon 5/8/23	Mon 5/8/23		
28	0%	Create model for criterion	0.66 hrs	Mon 5/8/23	Mon 5/8/23	27	
29	0%	Verify input and model	0.33 hrs	Mon 5/8/23	Mon 5/8/23	28	
30	0%	**Perform structural analysis**	0.42 days	Mon 5/8/23	Mon 5/8/23	25	Three people
31	0%	Calculate preliminary values for rotor loads	1.33 hrs	Mon 5/8/23	Mon 5/8/23		
32	0%	Identify load transfer and stresses in the structure	2 hrs	Mon 5/8/23	Mon 5/8/23	31	
33	0%	Investigate relevant loads on structure base	1.33 hrs	Mon 5/8/23	Mon 5/8/23		
34	0%	Create model for criterion	1.33 hrs	Mon 5/8/23	Mon 5/8/23	33	
35	0%	Verify input and model	0.66 hrs	Mon 5/8/23	Mon 5/8/23	34	
36	0%	**Perform material selection and analysis**	1.13 days	Mon 5/8/23	Tue 5/9/23	25	Two people
37	0%	Identify limiting factors for material choice	4 hrs	Mon 5/8/23	Mon 5/8/23		
38	0%	Identify material indices	2 hrs	Mon 5/8/23	Tue 5/9/23	37	
39	0%	Create model for criterion	2 hrs	Tue 5/9/23	Tue 5/9/23	38	
40	0%	Verify input and model	1 hr	Tue 5/9/23	Tue 5/9/23	39	
41	0%	**Analyse manufacturing and installation**	0.29 days	Tue 5/9/23	Tue 5/9/23	36	Six people
42	0%	Identify material production methods and related pros/cons	0.66 hrs	Tue 5/9/23	Tue 5/9/23		
43	0%	Identify installation methods of design options	0.66 hrs	Tue 5/9/23	Tue 5/9/23	42	
44	0%	Create model for criterion	0.66 hrs	Tue 5/9/23	Tue 5/9/23	43	
45	0%	Verify input and model	0.33 hrs	Tue 5/9/23	Tue 5/9/23	44	
46	0%	**Perform reliability analysis**	1.5 days	Mon 5/8/23	Tue 5/9/23	25	Two people
47	0%	Perform preliminary fatigue analysis on design option structures	5 hrs	Mon 5/8/23	Mon 5/8/23		
48	0%	Calculate lifetime and efficiency of design option	4 hrs	Mon 5/8/23	Tue 5/9/23	47	
49	0%	Create model for criterion	2 hrs	Tue 5/9/23	Tue 5/9/23	48	
50	0%	Verify input and model	1 hr	Tue 5/9/23	Tue 5/9/23	49	
51	0%	**Perform configuration analysis**	0.67 days	Mon 5/8/23	Mon 5/8/23		Three people
52	0%	Compare installation methods for floating vs standing base	1.33 hrs	Mon 5/8/23	Mon 5/8/23		
53	0%	Compare benefits and drawbacks of floating vs standing base in operation	2 hrs	Mon 5/8/23	Mon 5/8/23	52	
54	0%	Create model for criterion	1.33 hrs	Mon 5/8/23	Mon 5/8/23	53	
55	0%	Verify input and model	0.66 hrs	Mon 5/8/23	Mon 5/8/23	54	
56	0%	**Perform risk analysis**	0.5 days	Tue 5/9/23	Wed 5/10/23	20,41,46	Five people
57	0%	Identify and tabulate risks of design tree options from prior analysis	0.8 hrs	Tue 5/9/23	Tue 5/9/23		
58	0%	Rank risks by probability of occurrence and effect to requirement	0.8 hrs	Tue 5/9/23	Wed 5/10/23	57	
59	0%	Apply risk mitigation on the tabled risks and rerank the risk	1.2 hrs	Wed 5/10/23	Wed 5/10/23	58	
60	0%	Create model for criterion	0.8 hrs	Wed 5/10/23	Wed 5/10/23	59	
61	0%	Verify input and model	0.4 hrs	Wed 5/10/23	Wed 5/10/23	60	
62	0%	**Perform Cost Analysis**	0.25 days	Wed 5/10/23	Wed 5/10/23	56	Five people
63	0%	Identify and tabulate costs from prior analysis: focusing especailly on manufacturing, maintenance and material	1.2 hrs	Wed 5/10/23	Wed 5/10/23		
64	0%	Identify alternatives to decrease costs, and their associated effects on prior analysis	0.8 hrs	Wed 5/10/23	Wed 5/10/23		
65	0%	Create model for criterion	0.8 hrs	Wed 5/10/23	Wed 5/10/23	64	
66	0%	Verify input and model	0.4 hrs	Wed 5/10/23	Wed 5/10/23	65	
67	0%	**Perform trade-off**	2.13 days	Wed 5/10/23	Fri 5/12/23	13	
68	0%	**Summarize trade off criteria**	0.45 days	Wed 5/10/23	Thu 5/11/23		All
69	0%	Identify key factors	2.4 hrs	Wed 5/10/23	Wed 5/10/23		
70	0%	Summarize key criteria	0.4 hrs	Wed 5/10/23	Wed 5/10/23	69	
71	0%	Identify design model outcome for criteria	0.8 hrs	Wed 5/10/23	Thu 5/11/23	70	
72	0%	**Verify criteria**	0.08 days	Thu 5/11/23	Thu 5/11/23	68	All
73	0%	Make sure criteria are clear	0.6 hrs	Thu 5/11/23	Thu 5/11/23		
74	0%	Make sure criteria are specific	0.6 hrs	Thu 5/11/23	Thu 5/11/23		
75	0%	Make sure criteria are measurable	0.6 hrs	Thu 5/11/23	Thu 5/11/23		
76	0%	**Create trade-off weights**	0.2 days	Thu 5/11/23	Thu 5/11/23	72	All
77	0%	Assign relative weights to each criterion	0.8 hrs	Thu 5/11/23	Thu 5/11/23		
78	0%	Indicate weights importance in the decision making process	0.8 hrs	Thu 5/11/23	Thu 5/11/23	77	
79	0%	Redistribute weights to reflect one of several drivers: sustainability, cost, space	0.8 hrs	Thu 5/11/23	Thu 5/11/23		
80	0%	**Verify trade off weights**	0.2 days	Thu 5/11/23	Thu 5/11/23	76	Five people
81	0%	Reflect the significance of each criterion to the overall design requirements	1.6 hrs	Thu 5/11/23	Thu 5/11/23		
82	0%	**Perform Sensitivity of Trade-of**	0.6 days	Thu 5/11/23	Fri 5/12/23	80	Five people
83	0%	Evaluate each design option against the established criteria	2.4 hrs	Thu 5/11/23	Thu 5/11/23		
84	0%	Assess the robustness of the decision-making process to changes in the weights assigned to the criteria	2.4 hrs	Thu 5/11/23	Fri 5/12/23	83	
85	0%	**Create Summary table**	0.6 days	Fri 5/12/23	Fri 5/12/23	82	All
86	0%	Calculate Overall Scores	1.2 hrs	Fri 5/12/23	Fri 5/12/23		
87	0%	Compare the overall scores of each design option	1.2 hrs	Fri 5/12/23	Fri 5/12/23	86	
88	0%	Assess the performance of each design option	0.8 hrs	Fri 5/12/23	Fri 5/12/23	87	
89	0%	Make a decision on the preferred design option that best aligns with the project requirements	0.8 hrs	Fri 5/12/23	Fri 5/12/23	88	
90	0%	Summarize trade-off results in a table	0.4 hrs	Fri 5/12/23	Fri 5/12/23	89	
91	0%	Consider the implications of trade-offs in terms of the project objectives, constraints, and stakeholders'requirements	0.4 hrs	Fri 5/12/23	Fri 5/12/23	90	
92	0%	**Calculate preliminary design characteristics**	1.88 days	Fri 5/12/23	Tue 5/16/23	67	



Project: From_begining_to_plan
Date: Fri 4/28/23

Task | Split | Milestone | Summary | Project Summary | Inactive Task | Inactive Milestone | Inactive Summary | Manual Task | Duration-only | Manual Summary Rollup | Manual Summary | Start-only | Finish-only | External Tasks | External Milestone | Deadline | Progress | Manual Progress

ID	% Complete	Task Name	Duration	Start	Finish	Predecessors	Resource Names
93	0%	**Determine turbine loads**	**0.15 days**	**Fri 5/12/23**	**Fri 5/12/23**		**All**
94	0%	Find commercially available rotors	0.4 hrs	Fri 5/12/23	Fri 5/12/23		
95	0%	Determine load estimates	0.4 hrs	Fri 5/12/23	Fri 5/12/23	94	
96	0%	Relate turbine loads to structure	0.4 hrs	Fri 5/12/23	Fri 5/12/23	95	
97	0%	Find a relation between loads of the turbine, windspeed and diameter	0.4 hrs	Fri 5/12/23	Fri 5/12/23		
98	0%	Relate turbine loads to structure	0.4 hrs	Fri 5/12/23	Fri 5/12/23	97	
99	0%	**Perform aerodynamic analysis**	**0.45 days**	**Fri 5/12/23**	**Mon 5/15/23**	**93**	**Five people**
100	0%	Research possible wing airfoils	0.4 hrs	Fri 5/12/23	Fri 5/12/23		
101	0%	Determine upwash	0.8 hrs	Fri 5/12/23	Fri 5/12/23	100	
102	0%	Relate upwash to turbines spacing and efficiency	1.2 hrs	Fri 5/12/23	Mon 5/15/23	101	
103	0%	Size distance between turbines in line	1.2 hrs	Mon 5/15/23	Mon 5/15/23	102	
104	0%	**Perform preliminary structural analysis**	**0.75 days**	**Mon 5/15/23**	**Tue 5/16/23**	**99**	**Five people**
105	0%	Determine the structure moment of inertia	1.2 hrs	Mon 5/15/23	Mon 5/15/23		
106	0%	Determine blade loading	0.8 hrs	Mon 5/15/23	Mon 5/15/23	105	
107	0%	Create preliminary force analysis for the structure	1.6 hrs	Mon 5/15/23	Mon 5/15/23	106	
108	0%	Realize a vibration analysis for the structure	1.2 hrs	Mon 5/15/23	Mon 5/15/23		
109	0%	Size truss members	0.8 hrs	Mon 5/15/23	Mon 5/15/23	108,107	
110	0%	Determine fatigue response	1.6 hrs	Mon 5/15/23	Tue 5/16/23	109	
111	0%	**Perform stability and control analysis**	**0.35 days**	**Tue 5/16/23**	**Tue 5/16/23**	**104**	**Five people**
112	0%	Determine stability characteristics of the structure	1.2 hrs	Tue 5/16/23	Tue 5/16/23		
113	0%	Determine control forces to activate/deactivate turbine	1.6 hrs	Tue 5/16/23	Tue 5/16/23	112	
114	0%	**Establish preliminary design**	**0.18 days**	**Tue 5/16/23**	**Tue 5/16/23**	**111**	**All**
115	0%	Establish rotor design from aerodynamic analysis	0.4 hrs	Tue 5/16/23	Tue 5/16/23		
116	0%	Establish support structure from structural analysis	0.6 hrs	Tue 5/16/23	Tue 5/16/23	115	
117	0%	Establish preliminary configuration	0.4 hrs	Tue 5/16/23	Tue 5/16/23	116	
118	0%	Establish preliminary wake energizer design	0.2 hrs	Tue 5/16/23	Tue 5/16/23		
119	0%	**Verification and Validation**	**0.4 days**	**Tue 5/16/23**	**Tue 5/16/23**	**92**	
120	0%	**Performance analysis**	**0.15 days**	**Tue 5/16/23**	**Tue 5/16/23**		**Five people**
121	0%	Determine blade efficiency	1.2 hrs	Tue 5/16/23	Tue 5/16/23		
122	0%	Determine power efficiency vs wind speed	0.8 hrs	Tue 5/16/23	Tue 5/16/23		
123	0%	Determine maintenance costs and interval	0.4 hrs	Tue 5/16/23	Tue 5/16/23		
124	0%	Analyze wake energizer impact stacked performance of units (2D distance)	1.2 hrs	Tue 5/16/23	Tue 5/16/23		
125	0%	**Perform Sensitivity analysis**	**0.15 days**	**Tue 5/16/23**	**Tue 5/16/23**		**Five people**
126	0%	Analyze sensitivity to trade off weights	1.2 hrs	Tue 5/16/23	Tue 5/16/23		
127	0%	**Verify analysis**	**0.13 days**	**Tue 5/16/23**	**Tue 5/16/23**	**125**	**Five people**
128	0%	Verify numerical models used for performance analysis	1 hr	Tue 5/16/23	Tue 5/16/23		
129	0%	Verify numerical models used for aerodynamics	1 hr	Tue 5/16/23	Tue 5/16/23		
130	0%	Verify numerical models used for structural analysis	1 hr	Tue 5/16/23	Tue 5/16/23		
131	0%	**Validate the design**	**0.25 days**	**Tue 5/16/23**	**Tue 5/16/23**	**125**	**Five people**
132	0%	Validate aerodynamic loading and model	0.8 hrs	Tue 5/16/23	Tue 5/16/23		
133	0%	Validate the structural loading	0.8 hrs	Tue 5/16/23	Tue 5/16/23	132	
134	0%	Validate fatigue and life time	0.4 hrs	Tue 5/16/23	Tue 5/16/23	133	
135	0%	**Verifiy sustainability**	**0.08 days**	**Tue 5/16/23**	**Tue 5/16/23**	**125**	**Three people**
136	0%	Analyze endo of life procedures	0.66 hrs	Tue 5/16/23	Tue 5/16/23		
137	0%	Analyze environmental effects	0.66 hrs	Tue 5/16/23	Tue 5/16/23		
138	0%	Analyze material production and transportation	0.66 hrs	Tue 5/16/23	Tue 5/16/23		
139	0%	**Finalize midterm report**	**0.75 days**	**Tue 5/16/23**	**Wed 5/17/23**	**119**	
140	0%	**Update work flow diagram**	**0.25 days**	**Tue 5/16/23**	**Wed 5/17/23**		**Two people**
141	0%	Apply changes to work flow diagram	2 hrs	Tue 5/16/23	Wed 5/17/23		
142	0%	**Update work break-down structure**	**0.25 days**	**Wed 5/17/23**	**Wed 5/17/23**	**140**	**Two people**
143	0%	Apply changes to work break-down structure	2 hrs	Wed 5/17/23	Wed 5/17/23		
144	0%	**Update Gantt chart**	**0.25 days**	**Wed 5/17/23**	**Wed 5/17/23**	**142**	**Two people**
145	0%	Apply updates to Gantt chart	2 hrs	Wed 5/17/23	Wed 5/17/23		
146	0%	**Update design option tree**	**0.25 days**	**Tue 5/16/23**	**Wed 5/17/23**		**Two people**
147	0%	Apply changes to design discovery tree	2 hrs	Tue 5/16/23	Wed 5/17/23		
148	0%	**Update risk assessment of project**	**0.25 days**	**Wed 5/17/23**	**Wed 5/17/23**	**146**	**Two people**
149	0%	Reassess new risks	2 hrs	Wed 5/17/23	Wed 5/17/23		
144	0%	Peer Review	4 hrs	Wed 5/17/23	Thu 5/18/23	143	All
145	0%	**Mid Term to Final Report phase**	**18.23 days**	**Wed 5/24/23**	**Mon 6/19/23**		
1	0%	**Update system architecture**	**1.67 days**	**Wed 5/24/23**	**Thu 5/25/23**		
2	0%	**Update functional flow**	**0.13 days**	**Wed 5/24/23**	**Wed 5/24/23**		**All**
3	0%	Update flow for special (yawing) operations	1 hr	Wed 5/24/23	Wed 5/24/23		
4	0%	Update flow for maintenance	1 hr	Wed 5/24/23	Wed 5/24/23		
5	0%	Update flow for regular operations	1 hr	Wed 5/24/23	Wed 5/24/23		
6	0%	Update flow for decommissioning	1 hr	Wed 5/24/23	Wed 5/24/23		
7	0%	Update flow for extreme weather conditions	1 hr	Wed 5/24/23	Wed 5/24/23		
8	0%	**Update functional breakdown**	**0.13 days**	**Wed 5/24/23**	**Wed 5/24/23**	**2**	**All**
9	0%	Update breakdown for special (yawing) operations	1 hr	Wed 5/24/23	Wed 5/24/23		
10	0%	Update breakdown for maintenance	1 hr	Wed 5/24/23	Wed 5/24/23		
11	0%	Update breakdown for regular operations	1 hr	Wed 5/24/23	Wed 5/24/23		
12	0%	Update breakdown for decommissioning	1 hr	Wed 5/24/23	Wed 5/24/23		
13	0%	Update flow for extreme weather conditions	1 hr	Wed 5/24/23	Wed 5/24/23		
14	0%	**Update Configuration and Layout (internal/external)**	**0.92 days**	**Wed 5/24/23**	**Thu 5/25/23**	**8**	**All**
15	0%	Make diagram and loading for mounting	4 hrs	Wed 5/24/23	Wed 5/24/23		Two people
16	0%	Make configuration block diagram	4 hrs	Wed 5/24/23	Wed 5/24/23		Two people
17	0%	**Make a detailed CAD drawing of the design**	**0.92 days**	**Wed 5/24/23**	**Thu 5/25/23**		**Six people**
18	0%	Create a CAD model of the structure	5.33 hrs	Wed 5/24/23	Wed 5/24/23		
19	0%	Create a CAD model of a turbine	4 hrs	Wed 5/24/23	Wed 5/24/23		
20	0%	Create a CAD assembly	4 hrs	Wed 5/24/23	Wed 5/24/23		
21	0%	Create an assembly drawing	2 hrs	Wed 5/24/23	Thu 5/25/23	18,19,20	
22	0%	**Create electrical block diagram**	**0.29 days**	**Thu 5/25/23**	**Thu 5/25/23**	**14**	**Three people**
23	0%	Create electrical block diagram	2.33 hrs	Thu 5/25/23	Thu 5/25/23		
24	0%	**Create data handling block diagram**	**0.5 days**	**Thu 5/25/23**	**Thu 5/25/23**	**14**	**Three people**
25	0%	Power generation data diagram	4 hrs	Thu 5/25/23	Thu 5/25/23		
26	0%	Control data flow diagram	4 hrs	Thu 5/25/23	Thu 5/25/23		
27	0%	**Hardware and software block diagram (interactions and flow)**	**0.5 days**	**Thu 5/25/23**	**Thu 5/25/23**	**14**	**Four people**
28	0%	Control block diagram	4 hrs	Thu 5/25/23	Thu 5/25/23		
29	0%	Hardware interface diagram	4 hrs	Thu 5/25/23	Thu 5/25/23		
30	0%	**Perform detailed design and analysis**	**6.25 days**	**Thu 5/25/23**	**Fri 6/2/23**	**1**	
31	0%	**Describe sustainable development strategy**	**0.5 days**	**Thu 5/25/23**	**Fri 5/26/23**	**22,24,27**	**All**
32	0%	Analyze energy density (power per area)	4 hrs	Thu 5/25/23	Fri 5/26/23		
33	0%	Make lifecycle analysis	4 hrs	Thu 5/25/23	Fri 5/26/23		
34	0%	Analyze ecological impact and consequences	4 hrs	Thu 5/25/23	Fri 5/26/23		
35	0%	Give an overview of part standardization	4 hrs	Thu 5/25/23	Fri 5/26/23		
36	0%	**Update resource allocation/budget breakdown**	**0.25 days**	**Fri 5/26/23**	**Fri 5/26/23**	**31**	**All**
37	0%	Update mass budget	2 hrs	Fri 5/26/23	Fri 5/26/23		
38	0%	Update power budget	2 hrs	Fri 5/26/23	Fri 5/26/23		
39	0%	Update material budget	2 hrs	Fri 5/26/23	Fri 5/26/23		
40	0%	**Determine detailed aerodynamic characteristics**	**3 days**	**Fri 5/26/23**	**Wed 5/31/23**	**36**	**Six people**
41	0%	Analyze the wake	24 hrs	Fri 5/26/23	Wed 5/31/23		
42	0%	Analyze aeroelastic effects	20 hrs	Fri 5/26/23	Tue 5/30/23		
43	0%	Determine aerodynamic loads	24 hrs	Fri 5/26/23	Tue 5/30/23		
44	0%	Analyze turbine interference	20 hrs	Fri 5/26/23	Tue 5/30/23		
45	0%	**Determine detailed material characteristics**	**1 day**	**Fri 5/26/23**	**Mon 5/29/23**	**36**	**One person**
46	0%	Determine mechanical properties	4 hrs	Fri 5/26/23	Fri 5/26/23		
47	0%	Determine and describe sustainability of materials	4 hrs	Fri 5/26/23	Fri 5/26/23		
48	0%	Report corrosion properties, and required corrosion prevention	8 hrs	Fri 5/26/23	Mon 5/29/23		
49	0%	**Determine detailed structural characteristics**	**4 days**	**Fri 5/26/23**	**Thu 6/1/23**	**36**	**Three people**
50	0%	Provide stress analysis of the structure	24 hrs	Fri 5/26/23	Wed 5/31/23		
51	0%	Perform Vibration analysis of the structure	24 hrs	Fri 5/26/23	Wed 5/31/23		
52	0%	Provide loading diagram of the structure	8 hrs	Wed 5/31/23	Thu 6/1/23	50,51	
53	0%	**Perform stability and control analysis**	**1 day**	**Thu 6/1/23**	**Fri 6/2/23**	**40,45,49**	**All**
54	0%	Perform yaw control design	8 hrs	Thu 6/1/23	Fri 6/2/23		
55	0%	Analyze required control for tidal disturbances	8 hrs	Thu 6/1/23	Fri 6/2/23		
56	0%	Estimate floating stability	8 hrs	Thu 6/1/23	Fri 6/2/23		
57	0%	**Analyze design performance**	**0.5 days**	**Fri 6/2/23**	**Fri 6/2/23**	**53**	**All**
58	0%	Estimate power produced	4 hrs	Fri 6/2/23	Fri 6/2/23		
59	0%	Determine space efficiency of the wind farm	2 hrs	Fri 6/2/23	Fri 6/2/23		
60	0%	**Analyze operations, production, and risk**	**1.38 days**	**Fri 6/2/23**	**Tue 6/6/23**	**30**	
61	0%	**Conceptually design operations and logistics**	**0.38 days**	**Fri 6/2/23**	**Mon 6/5/23**	**57**	**All**
62	0%	Give conceptual maintenance description	3 hrs	Fri 6/2/23	Mon 6/5/23		
63	0%	Describe power delivery concept	3 hrs	Fri 6/2/23	Mon 6/5/23		
64	0%	Give a description of installation and decommissioning	3 hrs	Fri 6/2/23	Mon 6/5/23		
65	0%	**Create technical risk assessment**	**0.5 days**	**Mon 6/5/23**	**Mon 6/5/23**	**61**	**All**
66	0%	Availability of materials	4 hrs	Mon 6/5/23	Mon 6/5/23		
67	0%	Market demand	4 hrs	Mon 6/5/23	Mon 6/5/23		
68	0%	Mechanical failure risk	4 hrs	Mon 6/5/23	Mon 6/5/23		
69	0%	Supporting operations failure	4 hrs	Mon 6/5/23	Mon 6/5/23		
70	0%	Ecological disasters	4 hrs	Mon 6/5/23	Mon 6/5/23		
71	0%	**Collect and list reliability, availability, maintainability, and safety (RAMS) characteristics**	**0.5 days**	**Mon 6/5/23**	**Tue 6/6/23**	**65**	**All**
72	0%	Reliability of the generator and power system	4 hrs	Mon 6/5/23	Tue 6/6/23		
73	0%	Reliability of the structure	4 hrs	Mon 6/5/23	Tue 6/6/23		
74	0%	Inherent redundancy	4 hrs	Mon 6/5/23	Tue 6/6/23		
75	0%	**Make a manufacturing, assembly, integration plan (production plan)**	**0.75 days**	**Fri 6/2/23**	**Mon 6/5/23**		**All**
76	0%	Sourcing of materials	2 hrs	Fri 6/2/23	Mon 6/5/23		
77	0%	Assembly of parts and sub-assembly	6 hrs	Fri 6/2/23	Mon 6/5/23		
78	0%	Integration with the power grid	3 hrs	Fri 6/2/23	Mon 6/5/23		
79	0%	**Outline project design & development logic**	**0.5 days**	**Mon 6/5/23**	**Tue 6/6/23**	**75**	**All**
80	0%	Outline manufacturing plan	4 hrs	Mon 6/5/23	Tue 6/6/23		
81	0%	Describe plan for operations	3 hrs	Mon 6/5/23	Tue 6/6/23		
82	0%	Detail next steps for further research	3 hrs	Mon 6/5/23	Tue 6/6/23		
83	0%	**Perform economic analysis**	**3.19 days**	**Tue 6/6/23**	**Fri 6/9/23**	**60**	
84	0%	**Make a final design resource allocation/budget breakdown**	**0.75 days**	**Tue 6/6/23**	**Wed 6/7/23**	**79**	**All**
85	0%	Create mass budget	6 hrs	Tue 6/6/23	Wed 6/7/23		
86	0%	Create power budget	4 hrs	Tue 6/6/23	Tue 6/6/23		
87	0%	Create material budget	4 hrs	Tue 6/6/23	Tue 6/6/23		
88	0%	**Create cost breakdown structure**	**0.75 days**	**Wed 6/7/23**	**Wed 6/7/23**	**84**	**Six people**
89	0%	Calculate operational costs	4 hrs	Wed 6/7/23	Wed 6/7/23		
90	0%	Calculate manufacturing costs	6 hrs	Wed 6/7/23	Wed 6/7/23		
91	0%	Calculate deployment costs	6 hrs	Wed 6/7/23	Wed 6/7/23		
92	0%	Calculate development costs	6 hrs	Wed 6/7/23	Wed 6/7/23		
93	0%	**Update market analysis**	**1.5 days**	**Wed 6/7/23**	**Thu 6/8/23**	**84**	**Four people**
94	0%	Analyze the components available on the market	4 hrs	Wed 6/7/23	Wed 6/7/23		
95	0%	Analyze market trends	4 hrs	Wed 6/7/23	Wed 6/7/23		
96	0%	Perform a SWOT analysis of the market	8 hrs	Wed 6/7/23	Thu 6/8/23	94,95	
97	0%	**Determine return on investments**	**0.94 days**	**Thu 6/8/23**	**Fri 6/9/23**	**93,88**	**All**
98	0%	Estimate the revenue	2 hrs	Thu 6/8/23	Thu 6/8/23		
99	0%	Assess the market price of product	1 hr	Thu 6/8/23	Thu 6/8/23	98	
100	0%	Assess the market volume of product	1 hr	Thu 6/8/23	Fri 6/9/23	99	
101	0%	Achievable market share for the product	2 hrs	Thu 6/8/23	Fri 6/9/23	98	
102	0%	Assess development cost of product	2 hrs	Thu 6/8/23	Thu 6/8/23		
103	0%	Assess the production cost of product	2 hrs	Fri 6/9/23	Fri 6/9/23	100	
104	0%	Assess the direct operational cost	1 hr	Thu 6/8/23	Thu 6/8/23		
105	0%	Asses the revenue	2.5 hrs	Fri 6/9/23	Fri 6/9/23	98,99,10	
106	0%	**Determine sensitivity, verification, and validation**	**3.75 days**	**Fri 6/9/23**	**Mon 6/19/23**	**83**	
107	0%	**Perform sensitivity analysis**	**1 day**	**Fri 6/9/23**	**Mon 6/12/23**	**97**	**Four people**
108	0%	Analyze sensitivity to trade-off weights	4 hrs	Fri 6/9/23	Fri 6/9/23		
109	0%	Analyze sensitivity to design parameters/requirements	4 hrs	Fri 6/9/23	Mon 6/12/23	108	
110	0%	**Describe sustainable development strategy**	**1 day**	**Fri 6/9/23**	**Mon 6/12/23**	**97**	**Six people**
111	0%	Analyze energy density (power per area)	4 hrs	Fri 6/9/23	Fri 6/9/23		
112	0%	Make lifecycle analysis	8 hrs	Fri 6/9/23	Mon 6/12/23		
113	0%	Analyze ecological impact and consequences	8 hrs	Fri 6/9/23	Mon 6/12/23		
114	0%	Give an overview of part standardization	4 hrs	Fri 6/9/23	Fri 6/9/23		
115	0%	**Perform verification & validation**	**3.75 days**	**Mon 6/12/23**	**Fri 6/16/23**	**107**	**All**
116	0%	Update description of V&V procedures for refined design	16 hrs	Mon 6/12/23	Wed 6/14/23		
117	0%	Verify requirements (check for compliance of updated design)	12 hrs	Wed 6/14/23	Thu 6/15/23	116	
118	0%	Validation of used models	30 hrs	Mon 6/12/23	Fri 6/16/23		
119	0%	**Create the compliance matrix**	**0.5 days**	**Fri 6/16/23**	**Fri 6/16/23**	**115**	**All**
120	0%	Create the compliance matrix	4 hrs	Fri 6/16/23	Fri 6/16/23		
121	0%	**Make the final updated Gantt chart**	**0.5 days**	**Fri 6/16/23**	**Mon 6/19/23**	**119,31**	**All**
122	0%	Make the final updated Gantt chart	4 hrs	Fri 6/16/23	Mon 6/19/23		
146	0%	Peer Review	4 hrs	Mon 6/19/23	Mon 6/19/23	145	All
147	0%	Preperations for Symposium	2 days	Mon 6/19/23	Wed 6/21/23	146	All



Project: From_begining_to_plan
Date: Fri 4/28/23

Task | Split | Milestone | Summary | Project Summary | Inactive Task | Inactive Milestone | Inactive Summary | Manual Task | Duration-only | Manual Summary Rollup | Manual Summary | Start-only | Finish-only | External Tasks | External Milestone | Deadline | Progress | Manual Progress

4

Project analysis

4.1. Risk analysis

The risks of the project meeting its goals should be analyzed so that corrective or mitigating measures can be planned in advance accordingly. To do so, a SWOT analysis of the project and team is performed in Subsection 4.1.1, the threats identified here are used as a starting point for the organizational risk assessment in Subsection 4.1.2. Then in Subsection 4.1.3 a risk management plan is proposed to deal with the most critical risks previously identified.

4.1.1. SWOT Analysis

Before performing the risk analysis, the SWOT analysis was performed in order to identify the strengths and weaknesses of the team and the opportunities and threats of the project. These would aid in identifying risks posed by the team's weaknesses and external threats, as well as mitigation and contingency options offered by the team's strengths and opportunities.

The team's strengths were identified as having an experienced principal tutor who has already done this type of project previously. Internally, the team can give the DSE project their undivided attention. Additionally, the team seems to have good cohesion for the incipient part of this project. Since this is an academic project at a university, the team should have easy access to research resources. Lastly, the team has a very diverse set of skills thanks to different minor programs, such as Offshore Wind Energy, FEM and Control Systems, and Computational Science and Engineering, to name a few.

The main weaknesses of the team were identified as stemming from a lack of experience and knowledge of how to run a problem of such scale. There was also a degree of unfamiliarity with the field of research itself and limited technical resources.

Opportunities for the team arise mainly thanks to the supporting staff - principal tutor, coaches, and teacher assistants. The team also identified the field of research to which the project relates as being new and growing. During the planning phase, an MSc student reached out to the team as well, offering a potentially valuable opportunity to test the wake of the design and validate numerical models.

Lastly, threats to the project stem from bad circumstances affecting the team members, such as sickness, absence due to circumstances, or fatigue. Due to such instances, the team may, in some very unfortunate cases, also lose one or more of its members. Due to the team's inexperience, the team's progress could also be hindered by poor scheduling, poor risk management, poor communication, and failure to recognize whether some requirements can even be fulfilled. There are also external threats, such as losing workspace availability which would severely hinder the team's progress.

The information of this summary is presented in the SWOT diagram Figure 4.1. The diagram presents the summary for each of the four aspects considered in the analysis above.

Figure 4.1: *SWOT diagram*

4.1.2. Organizational Risk Assessment

Following the SWOT analysis described in Subsection 4.1.1, a number of project organization risks were already identified. A few more risks were found in addition to those and added to this list. The risks were evaluated based on the likelihood of them occurring and the severity of their consequences. The explanation of scales used to classify them is presented in Table 4.1. Based on these risks and likelihoods, the risks were placed in a risk matrix, visible in Figure 4.2.

Table 4.1: *The definitions of the likelihood and consequence severity scales.*

Likelihood categories:	Likelihood of occurrence	Consequence	Definition
Very unlikely	<5%	Trivial	Daily work is slightly disrupted
unlikely	<25%	Minor	The schedule is slightly disrupted
plausible	<50%	Moderate	Overtime from some team members is required
likely	<95%	Severe	The scope of the projects needs to be re-evaluated or all members will need to work significant overtime
very likely	>95%	Catastrophic	Project can not be completed

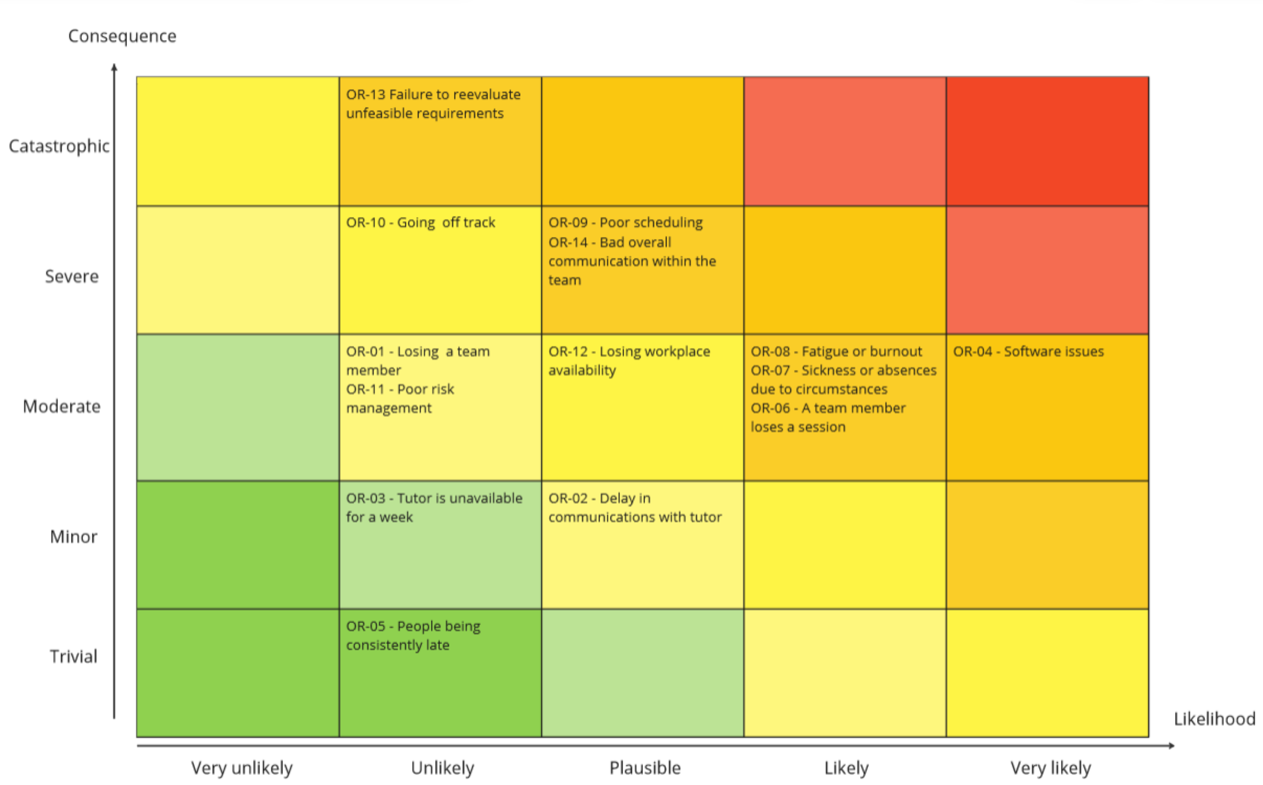


Figure 4.2: *The project management risk matrix*

The risks in the bottom left are unlikely and of little consequence. The risks towards the top right require immediate attention, as they are likely to occur and have severe consequences. The four risks that require the most attention were identified, and respective mitigation strategies and contingency plans were created. This is discussed in Subsection 4.1.3. In the mitigation and contingency plans, bulleted points comprise several solution options listed in no particular order, while numbered points represent a list of solutions to attempt in chronological order.

4.1.3. Organizational Risk Management Plan

In order to deal with the risks established in Subsection 4.1.2, a risk management plan was set up. This includes the group plan for risk mitigation, as well as a contingency plan to recover from any realized risks. The risks determined to present the greatest risk to the completion of the project were **OR-04**, **OR-09**, **OR-13**, **OR-14**.

OR-04: Software issues (Likelihood: very high, Severity: moderate)

Mitigation:

- Not introducing new software unnecessarily. If the task can be done with software the team has experience with, use that software unless changing is necessary.
- Allocating additional time to any tasks that are known in advance to require the use of the software.

Contingency:

1. Ask someone with good knowledge/experience with the software for help
2. Consider the use of alternative software, e.g. Javafoil instead of XFOIL.

3. Consider using another method to achieve the task at hand

OR-09: Poor scheduling (Likelihood: plausible, Severity: severe)

Mitigation:

- Re-evaluate the schedule on a weekly basis.
- Team members regularly communicate how tasks are progressing.
- Project manager keeps track of the schedule and suggests changes.

Contingency:

1. Overtime within reason (max. 50 man-hours extra per week in case of necessity to stay on track)
2. Removing non-critical tasks and secondary objectives
3. Changing project scope

OR-13: Failure to reevaluate unfeasible requirements (Likelihood: unlikely, Severity: catastrophic)

Mitigation:

- When a certain analysis is performed, and it is concluded that requirement seems unfeasible, renegotiate requirements with the customer

Contingency:

1. When certain requirements cannot be met, design the product as closely as possible and communicate in the requirements compliance matrix why the requirements could not be met.

OR-14: Failure to communicate within the team (Likelihood: plausible, Severity: severe)

Mitigation:

- Project manager and the rest of the team discuss what resources/time they need to complete certain tasks.
- If you are struggling or unsure about something, you should be able to bring up the issue and ask for help. This saves time and keeps group morale high.
- Communicating if you run into unexpected issues (making use of collective team experience)
- Keep a positive attitude in the workspace. Maintain respect between group members.

Contingency:

1. Set up a rigorous communication plan which clearly defines what should be communicated and to who.
2. Raise issues that have not been communicated with tutor/coaches and them for help with organization.

- In case of technical/project-related conflicts, consult with the chief engineer/project manager
- In case personal conflict arises, attempt to resolve the issue
    1. Between conflict parties
    2. Through mediation with the rest of the group

3. If an issue escalates, bring it up with DSE staff

4.2. Sustainability strategy

Energy is defined to be sustainable if it "meets the needs of the present without compromising the ability of future generations to meet their own needs." [2] Definitions of sustainable energy include environmental considerations such as greenhouse gas emissions and social and economic factors such as energy poverty.

Wind power is set to become the fundamental pillar of the global renewable energy supply. It accounted for over 6% of global energy production in 2020 [1]Generating power from wind could be used to produce hydrogen and synthetic fuels, like kerosene, which the aerospace industry uses in a climate-friendly way.

Although wind energy is sustainable, it does not mean it has no carbon emissions. This is due to the manufacturing, installation, and end-of-life procedures of the turbines. Because wind energy is inherently renewable and sustainable, the group will focus on increasing the sustainability of wind turbines in two main aspects. Firstly by increasing the possible density of turbines in wind farms, thus decreasing the area and number required; and during production and end of life by material choice and manufacturing methods. In addition to this, the team will focus on the ecological and social impacts of the project and delivered system.

4.2.1. Drivers of Sustainable development

During the design and implementation of any system, considerations must be taken to ensure that the methods and results are sustainable. This is doubly true for renewable energy systems since they use a renewable resource, and thus new projects can be implemented as soon as the lifetime of the old one is spent.

One of the biggest drivers for sustainable development in this project is the scale of implementation. Since wind farms usually consist of multiple wind turbines, even implementation into a single wind farm would lead to a large number of turbines being produced. This means any impact stemming from the design and production of the wind turbine leads to orders of magnitude larger effects per farm.

The production of wind turbines typically includes large amounts of composites for the blades and rare-earth minerals for the permanent magnets used in generators [3].

In addition to this, Multi-Rotor VAWT are large products planned to be implemented in bodies of water that house large and complex ecosystems. Minimizing the impact of these is a priority for both environmental and economic reasons. In this regard, wind farms have already been shown to affect their environment, creating turbulent current wakes underwater, and atmospheric wakes in the air [4], and thus, their development must emphasize this danger to their immediate area. Therefore the amount of area used for wind farms should be minimized. To this end, it is more sustainable for a wind farm to have a higher energy density, the impacted area will be smaller for a farm of the same power output.

4.2.2. Principles implemented for Sustainable development

The following section will introduce the various measures that will be implemented as part of the sustainability strategy

[1]URL: https://www.c2es.org/content/renewable-energy/ [cited 28 April 2023]

Life Cycle Analysis

Life cycle analysis (LCA) is the method for evaluating the environmental impact of a product through its life cycle, encompassing extraction and processing of the raw materials, manufacturing, distribution, use, recycling, and final disposal. Each stage of life of the current wind turbines will be inspected to select the areas where improvements can be made for improvements in sustainability of the project. Beginning from the construction, wind turbines consume a lot of energy, especially the production of steel support structures and concrete foundations. On average, wind power plants take between 3 to 8 months [2] to generate the amount of energy that was needed for their construction. So-called upstream emissions are included in the overall carbon balance of a wind turbine's life cycle.

On average, wind turbines are operated for about 25 years.[5] Although blades are designed to last through the lifetime of the turbine 10-year lifespan is more standard as they are often replaced with bigger, more efficient blades, besides the other operational procedures that consume energy. Still, during this time, they generate 40 times more energy than the energy required for the production, operation, and disposal of a wind power plant. An onshore wind turbine with current technology produces around 9 grams of CO2 for every kilowatt hour (kWh) it generates. A new offshore plant in the sea emits 7 grams of CO2 per kWh[3].

Cement and steel can be repurposed at the end of life in order to reduce their annual carbon emission. Turbine blades, on the other hand, produced by thermoset polymers are not recycled therefore, their carbon emission cannot be distributed over extended periods. This aspect is depicted in fig. 4.3. Some blades are burned for energy, even though this emits pollutants and is an inferior and inconsistent power source. In fact, because fibreglass is not combustible, around 60% of the scrap remains as ash, while the rest becomes air pollution.

Therefore, the project should aim to use recyclable blades in which the proposed VAWT design is advantageous. With its vertical orientation, the reduced distance from the rotational axis will minimize the moment of inertia and centrifugal forces induced, causing material requirements to be less restrictive. Also, because multiple turbines will be combined, the amount of cement to be cast per kilogram of the structure will decrease, further reducing carbon emissions.

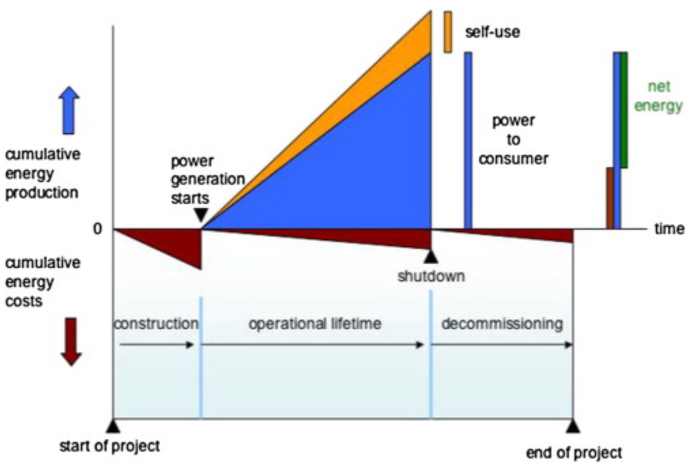


Figure 4.3: *Energy production & consumption lifetime [5]*

[2]URL: https://nctce.com.au/how-is-wind-energy-sustainable/ [cited 26 April 2023]
[3]URL: https://nctce.com.au/how-is-wind-energy-sustainable/ [cited 26 April 2023]

Deployment Environmental Impact Mitigation
In order to mitigate the effects of the turbine on its environment once deployed, various considerations will be taken while developing the conceptual design, as well as the that results from the design tree.

First, during the baseline report, research will be conducted on the sustainable development and impact of current wind farm technology. This is a crucial step to develop an understanding of the methods that can be implemented to make our VAWT more sustainable.

Options will be researched to determine the minimal impact on the environment and be made part of the trade-off.

In terms of the design trade-off, the criteria selection and their associated weights guide the choice of preliminary design. These will be made to include various factors that can accurately represent the associated effects on the environment. The most important trade-off criteria are the factors affecting the material choice, as this has the largest environmental impact overall.

In addition to the trade-off, further consideration must be made for the location where wind farms are planned. The location of the wind farm will influence whether the effect that the turbine has on the environment will have larger ramifications on less immediate surroundings or be able to minimize these effects. For example, the difference between placing a wind farm where they disrupt currents feeding into reefs nearby versus disrupting currents feeding into barren areas. Additionally, wind farms cannot disturb shipping routes, fishing areas, and other maritime activities.

Aside from the impact on maritime (plant)life, wind turbines also present a threat to bird life. The stability of bird populations can be severely impacted by a relatively small increase or decrease in mortality. A study by Schippers et al. showed that allowing a 5% increase in mortality led to a 9% to 72% decrease in population size after 10 years in followed populations [6]. Decreasing bird mortality would increase the ecological sustainability of wind energy generation.

Social sustainability
One of the key factors which makes the concept of relatively smaller vertical-axis turbines is the fact that, unlike the large horizontal-axis turbines, the components do not need be produced from the same high-performance materials. Instead, more widely available materials may be used. This, in turn, means that a much wider range of suppliers become available since such materials would be easier to produce and require less equipment. This would allow the supply of materials to become more local. This would benefit smaller local companies the most and decrease the GHG emissions associated with transport.

Note that the part size and complexity are connected to material selection. The design will allow for the use of smaller-scale parts. That, combined with more broadly available materials, which are required for the design, means that the manufacturing and production of the parts can be distributed between several smaller, local companies. This can be contrasted with traditional horizontal-axis turbines, the parts for which can only be made by large, specialized companies. A design with smaller parts made of less specialized materials allows for production to be democratized, offering a great opportunity for the field of wind energy to expand in a not-so-different way from solar energy.

Sustainable design philosophy
The department of sustainable engineering is responsible to integrate the sustainable design philosophy into the project. Each of the other engineering departments has at least one member who is also part of

the sustainability department. These members have the role to enforce the main principles of sustainable design and ensure that trade-offs reflect the main driver of this project, sustainability. The principles of sustainable engineering which will be applied in the design process of this project, as provided by Pennsylvania State University, are as follows [4]:

- "Strive to ensure that material/energy inputs and outputs are not hazardous"
- "Waste minimization over waste management."
- "Design for easy separation and purification."
- "All components must be designed for maximum mass, energy, and temporal efficiency."
- "Avoid unnecessary consumption of mass/energy."
- "Use entropy and complexity as guidelines to decide end-of-life."
- "A product must not outlast its uses."
- "A product must not have unnecessary capabilities/capacities."
- "Minimize material diversity."
- "Product creation is only one part of the cycle."
- "Evaluate products based on life-cycle analysis."
- "Prioritize the use of renewable and readily available resources."

[4]URL: https://www.e-education.psu.edu/eme504/node/5[cited 28 April 2023]

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