TECHNICAL UNIVERSITY OF CRETE

SCHOOL OF PRODUCTION ENGINEERING AND MANAGEMENT

Design of an innovative vertical axis wind turbine and assessment of the energy exploitation practices

Diploma Thesis

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Supervising

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Chania, August 2023

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Chania, August,2023

This diploma thesis is dedicated to all the people who were close and supported the achievement of my goals.

Acknowledgement

I would like to thank my family for supporting this effort and always supporting me in every decision I make.

Abstract

The aim of this specific thesis is the design and manufacture of an innovative wind energy converter generator and the evaluation of exploitation practices of electricity produced.

More specifically, the main idea came from a project of a partnership with Tupperware Brands named E- tree Project , which was carried out in stages with specific time limits and specific content.Hence, the final result of the thesis came by utilizing the stages of the E –tree project as a basic idea and developing further into new and more specific proposals.

In particular, in the first stage the main purpose is to present six candidate constructions using renewable energy sources for electricity production based on the company's -Tupperware Brands products and along the way the monitoring and analysis of these constructions in order to check the most suitable for the specific conditions.

In the course the construction that will be selected will be placed in the courtyard of its production unit Tupperware Brands in Belgium, so the whole construction and calculations are made based on climate conditions and wind speed of Belgium.In this thesis, the candidate constructions are presented briefly as the main topic is the construction of the wind turbine as well as the development of the methods of utilization of the generated energy.

At the second stage, the most suitable of the constructions was considered the vertical axis wind turbine, as it was the only one with the least energy losses compared to the rest of the constructions.For its manufacture, one of the company's best-selling products, the eco bottle, was used, a cylindrical bottle that will be made at a height of 3M, and internally-at its base, it will carry the vertical axis of a wind turbine with a hybrid Savonius-Darrius) rotor.

The overall construction is safe, both for pedestrians and birds in the area, as the wind turbine will be located in the interior space of the eco-bottle.Then the three-dimensional design was carried out inside from the ANSYS application and a more detailed calculation of the dimensions, the scale of its construction was made wind turbine as well as research of the materials and components to be used in this particular construction, so that it is as suitable as possible for the external environment but also economical option. This was followed by the costing of all the members of the wind turbine and then the whole project and various alternative forms of utilization of the generated electricity are proposed.

Περίληψη

Σκοπός της παρούσας διπλωματικής εργασίας είναι ο σχεδιασμός μιας καινοτόμου ανεμογεννήτριας παραγωγής ηλεκτρικής ενέργειας. Πραγματοποιήθηκε στα πλαίσια μιας συνεργασίας με την εταιρία Tupperware Brands, σε τρία στάδια με συγκεκριμένα χρονικά περιθώρια και συγκεκριμένο περιεχόμενο.

Στο πρώτο στάδιο, σκοπός είναι η παρουσίαση έξι υποψήφιων κατασκευών παραγωγής ηλεκτρικής ενέργειας χρησιμοποιώντας σαν βάση προϊόντα της εταιρίας Tupperware Brands και στην πορεία η παρακολούθηση και η ανάλυση των κατασκευών αυτών, ώστε να ελεγχθεί η καταλληλόλητα τους. Η προς επιλογή κατασκευή θα τοποθετηθεί στον προαύλιο χώρο της μονάδας παραγωγής της Tupperware Brands στο Βέλγιο, οπότε η όλη κατασκευή και οι υπολογισμοί που έγιναν βασίζονται στις κλιματικές συνθήκες και στην ταχύτητα ανέμου του Βελγίου.

Σε δεύτερο στάδιο, καταλληλότερη των κατασκευών κρίθηκε αυτή της ανεμογεννήτριας κάθετου άξονα ,καθώς ήταν και η μόνη με τις λιγότερες ενεργειακές απώλειες. Για την κατασκευή της χρησιμοποιήθηκε ως πρότυπο ένα από τα προϊόντα με τις μεγαλύτερες πωλήσεις της εταιρίας, τοeco-bottle,ένα κυλινδρικό μπουκάλι που θα κατασκευαστεί σε ύψος 3m και στο εσωτερικό του-στη βάση του, θα φέρει την ανεμογεννήτρια κάθετου άξονα. Η συνολική κατασκευή , είναι ασφαλής, τόσο για τους πεζούς όσο και για τα πτηνά της περιοχής καθώς η ανεμογεννήτρια θα βρίσκεται στον εσωτερικό χώρο του eco- bottle.

Στη συνέχεια ,πραγματοποιήθηκε 3D σχεδιασμός μέσα από την εφαρμογή :ANSYS και έγινε αναλυτικότερος υπολογισμός των διαστάσεων, της κλίμακας κατασκευής της ανεμογεννήτριας καθώς και έρευνα των υλικών και των εξαρτημάτων που θα χρησιμοποιηθούν στην συγκεκριμένη κατασκευή , ώστε να είναι όσο το δυνατόν κατάλληλα για τις συνθήκες εξωτερικού περιβάλλοντος αλλά και οικονομική επιλογή.

Ακολούθησε η κοστολόγηση όλων των μελών της ανεμογεννήτριας και στη συνέχεια όλου του έργου και προτείνονται διάφορες εναλλακτικές μορφές αξιοποίησης της παραγόμενης ηλεκτρικής ενέργειας.

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Chapter 1 Introduction

Electricity generation is starting to emigrate from fossil fuel to renewable energy as primary sources. It is true that, there is a growing trend towards the use of renewable energy sources for electricity generation, as fossil fuels such as coal, natural gas, and petroleum are finite resources, and their use has negative environmental impacts due to greenhouse gas emissions. Among the various renewable energy sources, wind energy has become increasingly popular due to its high potential for electricity generation, low cost of operation and maintenance, and minimal environmental impact. There are two main types of wind turbines used for electricity generation: horizontal axis wind turbines (HAWT) and vertical axis wind turbines (VAWT). HAWT are the most used and are characterized by having the main rotor shaft and generator located at the top of a tower, while VAWT have the main rotor shaft and generator located at the base and the tower is shorter. Both types of wind turbines work by capturing the wind's energy and converting it into electricity using a generator. Unlike HAWTs, VAWTs are omnidirectional and bird and bat friendly (Maalouly κ.ά., 2022).

1.1. Current Situation

1.1.1. Current Situation in Greece

Wind energy has been gaining in popularity in many countries due to its potential to provide clean, renewable energy. Europe is no exception and is actively seeking to increase its reliance on wind energy. In the EU, the share of electricity produced from wind energy has grown from 6.5% in 2011 to over 12% in 2019. Wind Europe, an industry body, updates its capacity scenarios to 2030 every two years to reflect the latest market and policy developments. This involves surveying all the countries in the region and assessing their potential for wind energy. Europe is also working towards the EU's goal of achieving at least 32% of its energy from renewable sources by 2030. Wind energy will be a major part of this effort, and countries in the region are investing in wind technology and infrastructure to ensure that they are able to meet this target. At a time when Europe is trying to reform the energy strategy, the course of wind energy in our country is of particular interest. Nowadays, 2.779 wind turbines are currently operating in Greece, with most of them located in Evia, Boeotia, the Peloponnese, Thrace, Fthiotida and Crete. According to the most recent data of the Hellenic Scientific Association of Wind Energy (ELETAEN), the total wind power in Greece until the end of June was 4.534 mW. Based on the statistical survey, in the first half of this year, 28 new wind turbines with a total output of 83.1 mW were connected to the network. This size is not significantly different from the power installed in the second half of 2021 and is three times less than the power of the first half of the previous year.

Geographical distribution in Greece: Greece has made significant progress in developing its wind power sector, with more than 4.5 gigawatts (GW) of installed onshore wind capacity. The country's Independent Power Transmission Operator (IPTO) is creating the country's largest interconnecting project to transmit clean energy. The following picture shows in detail the distribution of wind parks in Greece,as it is so far. In terms of regions, Central Greece remains at the top of wind installations, since it hosts 1,861 mW (41%), in second place is the Peloponnese with 639 mW (14%) and in third Eastern Macedonia – Thrace, where 534 mW (12%) are located. They are followed by western Greece with 370 mW, Crete with 203 mW, Central Macedonia with 158 mW, Troizinia and the islands of the Saronic Gulf with 148 MW, the Ionian islands with 120 mW, Epirus with 109 mW, the South Aegean with 97 MW, the North Aegean with 40 MW, Attica with 35 mW and Thessaly with 19 mW. At county level, in the first place is Evia, where almost 1/3 of the country's wind turbines have been placed.

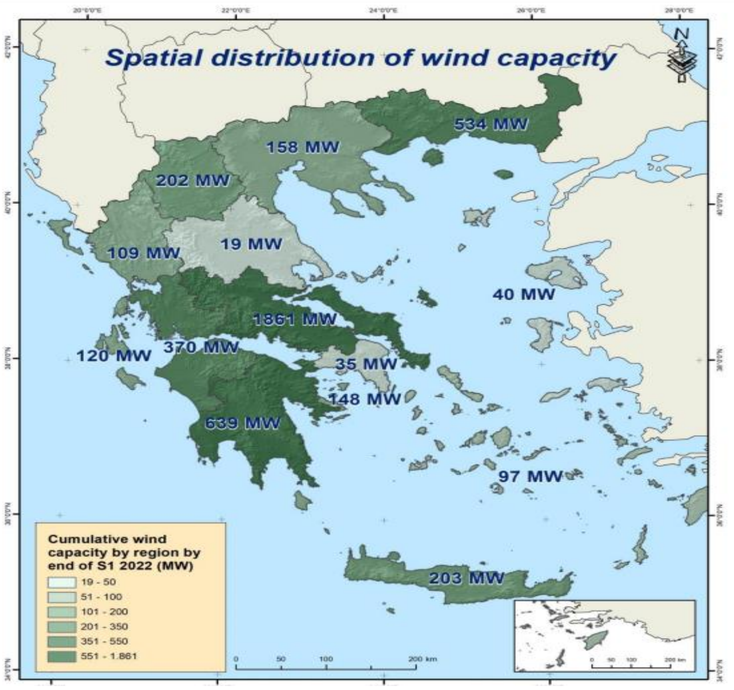


Figure 1.Geographical distribution of wind parks in Greece(ELETAEN,2022)

The largest wind farm is located in Crete, but there are also several wind farms located in Peloponnese, Evia, and the Aegean islands. This project is aimed at reducing emissions, boosting energy efficiency, and enabling countries with limited land areas to exploit their marine areas for renewable energy production. The exploitation of the high wind potential in our country, in combination with the rapid development of technologies integrated into modern efficient wind turbines, is of enormous importance for Sustainable Development, saving Energy Resources, Environmental Protection and tackling climate change.

Investment groups and manufacturers: In the field of wind energy, more than 30 business groups operate, which operate wind farms in various regions of the country. The group with the most installed megawatts is Terna Energy with 703 mW, followed by Ellaktor with 482 MW, ENEL Green Power with 368 MW, Iberdrola Rokas with 304 MW and Total Eren with 250 mW.

EDF also has significant installed capacity with 238.2 mW, Motor Oil Renewable Energy with 232.3 mW, Mytilineos group with 193.2 mW, PPC renewables with 171.3 mW and Jasper Energy with 113 mW.As for the first half of the year, Iberdrola Rokas (33.6 mW), Elica of Copelouzos group (20.7 mW), Cubico (12 mW) and other companies with smaller investments were completed and connected to the network.

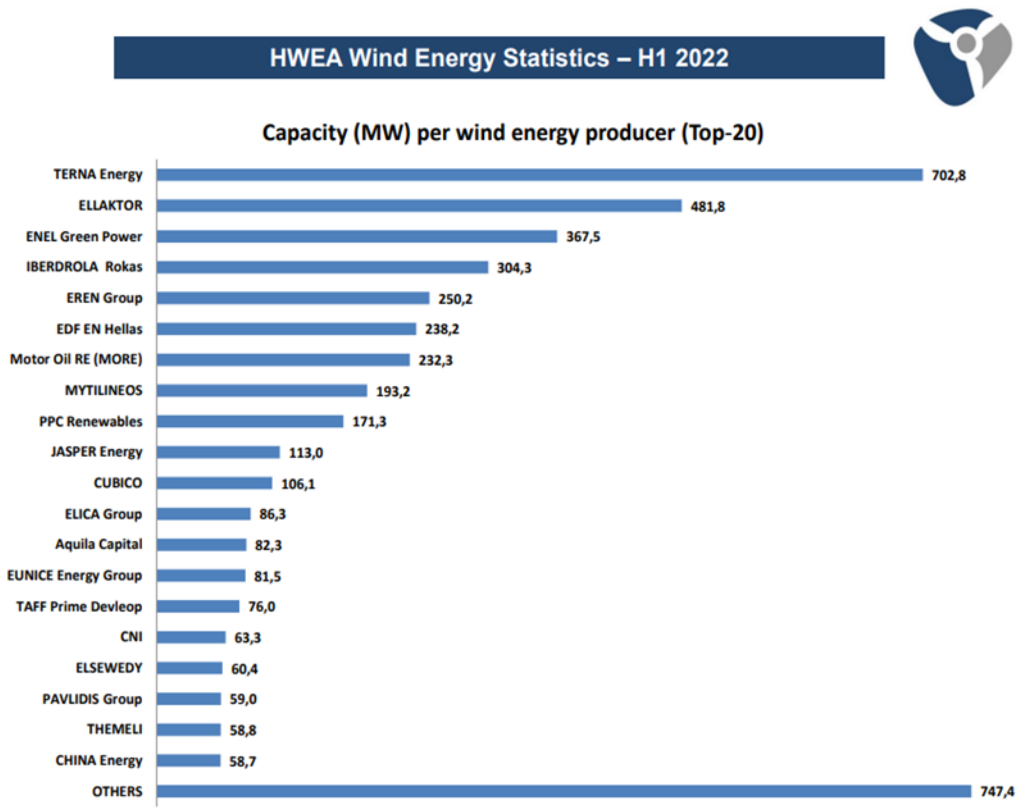


Figure 2.Capacity (MW) per wind energy producer (ELETAEN,2022)

1.1.2. Current situation in Belgium

Over the last decade, Belgium has seen a huge increase in its installed wind power capacity, going from around 912 megawatts in 2010 to a staggering 4,780 megawatts in 2021. Europe is one of the biggest players in the global wind energy

sector, with Belgium placing sixth in the world for its offshore wind capacity. This remarkable growth has been driven by the country's commitment to renewable energy targets, with construction works expected to continue in the coming years.
In 2021, Belgium had the sixth highest offshore wind capacity in the world, a major accomplishment given the country's small and busy population. To further progress this clean energy transition, a recent report recommends updating the country's long-term energy strategy to include a clear commitment to 2050 climate neutrality.

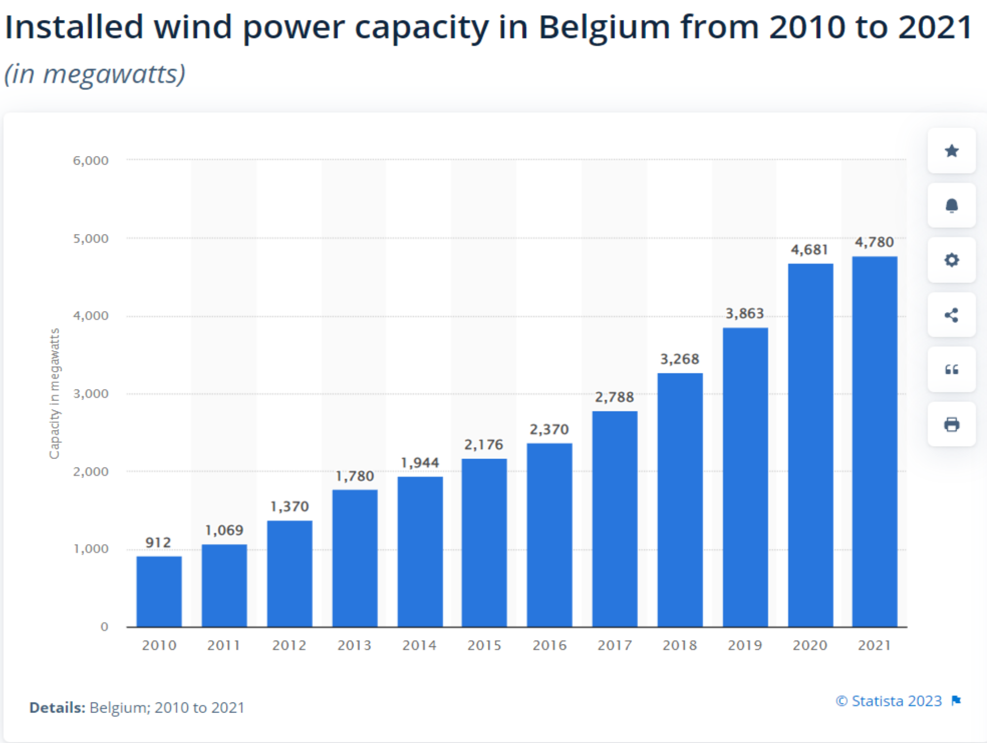


Figure 3.Installed wind energy power capacity in Belgium from 2010-2021. (ELETAEN,2022)

Belgium's renewable energy potential is relatively limited, so meeting the 2030 renewable energy targets set by the European Union will prove to be a challenge. The resulting 18.3 % as it seems to the picture below is the combination of all stated contributions from the different regions and thus relates to Belgium's renewable potential which admittedly could be relatively limited.To ensure that the country meets its goals, Belgian governments should refrain from imposing regional targets, as has been done in the burden sharing agreement. Instead, they should take an approach that encourages cooperation between regions, both within Belgium and across the EU.
Cooperation between regions can be facilitated using cooperation mechanisms, such as allowing regions with excess renewable energy to offset deficits in other regions through the transfer of energy. This approach has been used successfully in other EU countries and could help Belgium meet its targets in a more efficient manner. Additionally, Belgian governments should consider the renewable energy potential

of each region when setting their targets, as it will make it easier to reach the desired objectives.

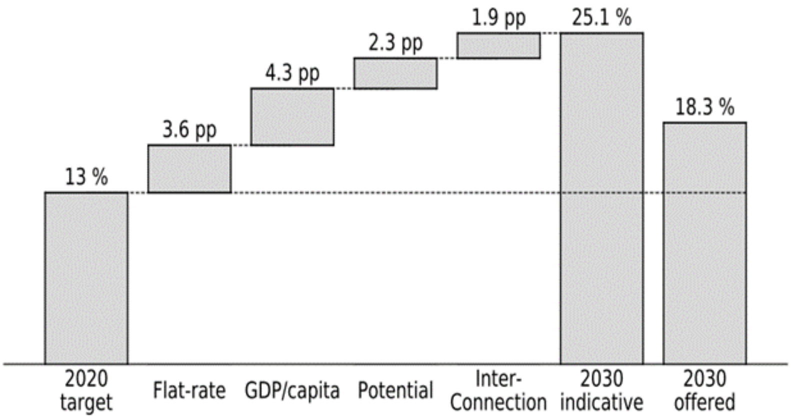


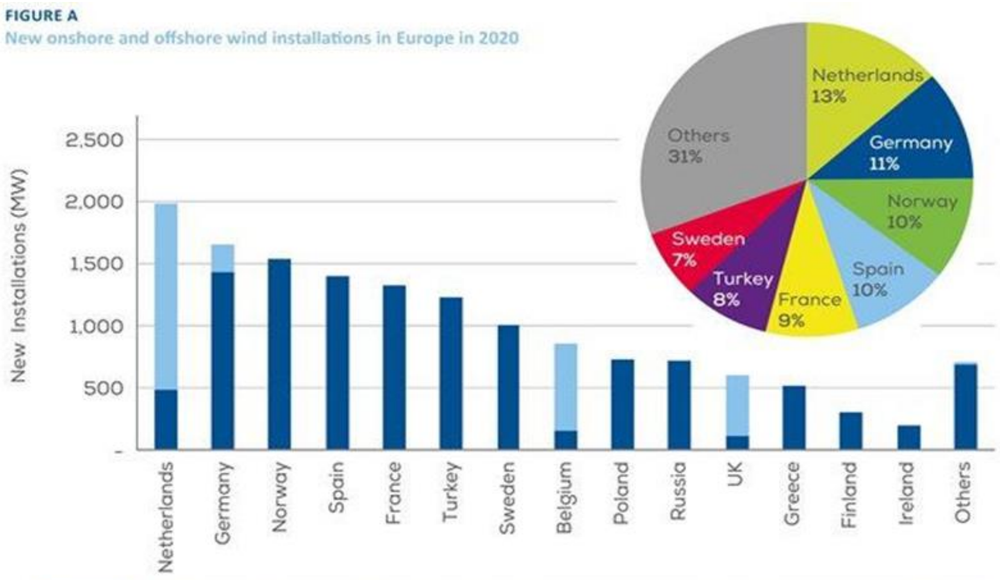
Figure 4.The Belgian renewable energy targets (pp stands for percentage points).

Source: https://www.mech.kuleuven.

In conclusion, an approach that encourages cooperation and takes into account the renewable energy potential of each region is the best way for Belgium to meet its 2030 renewable energy targets. By utilizing cooperation mechanisms and taking into account the renewable energy potential of each region, Belgium can increase its chances of success

1.1.3. Current situation in Europe.

New wind farms with a total capacity of 14.7 GW (14,700 MW) were installed in Europe in 2020. 10.5 GW (10,500 MW) was installed in the European Union and covered 16% of the electricity consumed (EU 27 and UK).In Europe today the total installed capacity is 220 GW (220,000 MW).The figure 5 below shows the new installed capacity in Europe for 2020.New 517 MW were installed in Greece, with first countries: the Netherlands, Germany, Norway, Spain, France and Turkey.The figures below show the picture of wind farm installations in Europe for 2020.



	Netherlands	Germany	Norway	Spain	France	Turkey	Sweden	Belgium	Poland	Russia	UK	Greece	Finland	Ireland	Others
Offshore	1,493	219	-	-	-	-	-	706	-	-	483	-	-	-	17
Onshore	486	1,431	1,532	1,400	1,318	1,224	1,007	152	731	713	115	517	302	196	688
Total	1,979	1,650	1,532	1,400	1,318	1,224	1,007	858	731	713	598	517	302	196	705

Source: WindEurope

Figure 5.New onshore and offshore wind installations in Europe in 2020.

Source:WindEurope

The five countries with the largest installed wind capacity are**:**

1. Germany-62,627 MW-covered 27% of the annual total electricity consumed.
2. Spain – 27,264 MW-covered 22% of the annual total electricity consumed.
3. France-17,949 MW-covered 9% of the annual total electricity consumed.
4. Italy-10,852 MW-covered 7% of the annual total electricity consumed.
5. Sweden– 9,992 MW-covered 20% of the annual total electricity consumed.

1.1.4. Indicatively for Greece and Cyprus

Greece had in 2020 installed wind capacity equal to 4.113 MW-it covered 27% of the annual total electricity consumed.Cyprus had in 2020 installed wind capacity equal to 158mw – it covered 6% of the annual total electricity consumed. The following table presents by Country, The New installed capacity for 2020, the total installed capacity and the share of wind coverage of electricity consumed for 2020.As mentioned earlier wind energy covered 16% of the annual total electricity consumed in the European Union and the United Kingdom.

TABLE 1

New installations and cumulative capacity in 2020[6]

EU-27 (MW)	NEW INSTALLATIONS 2020			CUMULATIVE CAPACITY			SHARE OF WIND IN 2020		
	ONSHORE	OFFSHORE	TOTAL	ONSHORE	OFFSHORE	TOTAL	ONSHORE	OFFSHORE	TOTAL
Austria	25	-	25	3,120	-	3,120	12%	N/A	12%
Belgium	152	706	858	2,459	2,261	4,719	5%	9%	14%
Bulgaria	-	-	-	691	-	691	4%	0%	4%
Croatia	152	-	152	803	-	803	10%	0%	10%
Cyprus	-	-	-	158	-	158	6%	0%	6%
Czechia	-	-	-	337	-	337	1%	N/A	1%
Denmark	136	-	136	4,478	1,703	6,180	30%	19%	48%
Estonia	-	-	-	320	-	320	11%	0%	11%
Finland	302	-	302	2,515	71	2,586	9%	0%	9%
France	1,318	-	1,318	17,947	2	17,949	9%	0%	9%
Germany	1,431	219	1,650	54,938	7,689	62,627	22%	6%	27%
Greece	517	-	517	4,113	-	4,113	15%	0%	15%
Hungary	-	-	-	329	-	329	2%	N/A	2%
Ireland[7]	196	-	196	4,326	25	4,351	38%	0%	38%
Italy[8]	137	-	137	10,852	-	10,852	7%	0%	7%
Latvia	-	-	-	66	-	66	2%	0%	2%
Lithuania	-	-	-	548	-	548	13%	0%	13%
Luxembourg	30	-	30	166	-	166	N/A	N/A	N/A
Malta	-	-	-	-	-	-	0%	0%	0%
Netherlands	486	1,493	1,979	4,174	2,611	6,784	9%	3%	12%
Poland	731	-	731	6,614	-	6,614	9%	0%	9%
Portugal	4	17	21	5,461	25	5,486	25%	0%	25%
Romania	-	-	-	3,029	-	3,029	12%	0%	12%
Slovakia	-	-	-	3	-	3	0%	N/A	0%
Slovenia	-	-	-	3	-	3	0%	0%	0%
Spain[9]	1,400	-	1,400	27,259	5	27,264	22%	0%	22%
Sweden	1,007	-	1,007	9,801	192	9,992	20%	0%	20%
Total EU-27	8,024	2,435	10,459	164,510	14,583	179,093	13%	2%	15%

OTHERS (MW)	NEW INSTALLATIONS 2020			CUMULATIVE CAPACITY			SHARE OF WIND IN 2020		
	ONSHORE	OFFSHORE	TOTAL	ONSHORE	OFFSHORE	TOTAL	ONSHORE	OFFSHORE	TOTAL
Bosnia & Herzegovina	48	-	48	135	-	135	N/A	N/A	N/A
Kosovo	-	-	-	32	-	32	N/A	N/A	N/A
Montenegro	-	-	-	118	-	118	N/A	N/A	N/A
North Macedonia	-	-	-	37	-	37	N/A	N/A	N/A
Norway	1,532	-	1,532	3,977	2	3,980	7%	0%	7%
Russia	713	-	713	905	-	905	N/A	N/A	N/A
Serbia	-	-	-	374	-	374	N/A	N/A	N/A
Switzerland	12	-	12	87	-	87	N/A	N/A	0.2%
Turkey	1,224	-	1,224	9,305	-	9,305	8%	0%	8%
Ukraine	144	-	144	1,314	-	1,314	N/A	N/A	N/A
UK	115	483	598	13,740	10,428	24,167	N/A	N/A	27%
Total others	3,788	483	4,271	30,023	10,430	40,453	N/A	N/A	N/A
Total Europe	11,813	2,918	14,731	194,533	25,013	219,546	13%	3%	16%

6. All numbers are rounded and therefore may not add up.
7. Irish figures are an estimate.
8. Italian figures are up to 31 October 2020.
9. Spanish figures are an estimate from Red Eléctrica de España.

Wind energy in Europe - 2020 Statistics and the outlook for 2021-2025

WindEurope

Figure 6.New installations and cumulative in 2020. Source:WindEurope

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In the five highest positions in terms of coverage of the annual consumed electricity (as shown by the figure below) by wind farms are the :

- Denmark with 48%

- Ireland with 38%
- Germany with 27%
- United Kingdom with 27%
- Portugal with 25%
- Greece is at 15%.

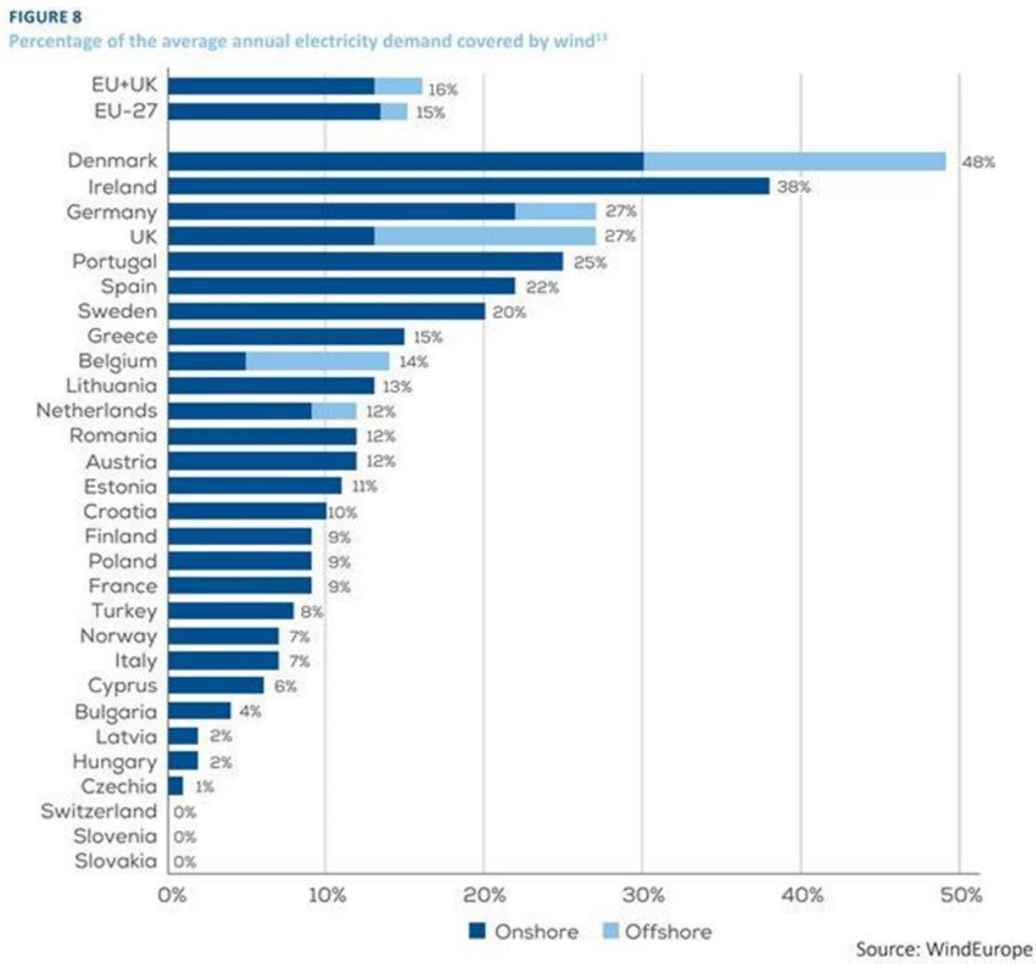

Figure 7.Percentage of the average annual electricity demand covered by wind. Source:https://proceedings.windeurope.

1.1.5. The future of wind energy in Europe by 2025

New 105GW (105,000 MW) wind farms are expected to be installed in Europe in 2021-2025 in line with existing target commitments by national governments, of which 70% will be onshore.The figure below presents the estimates of the annual New wind installed capacity for the period 2021-2025.

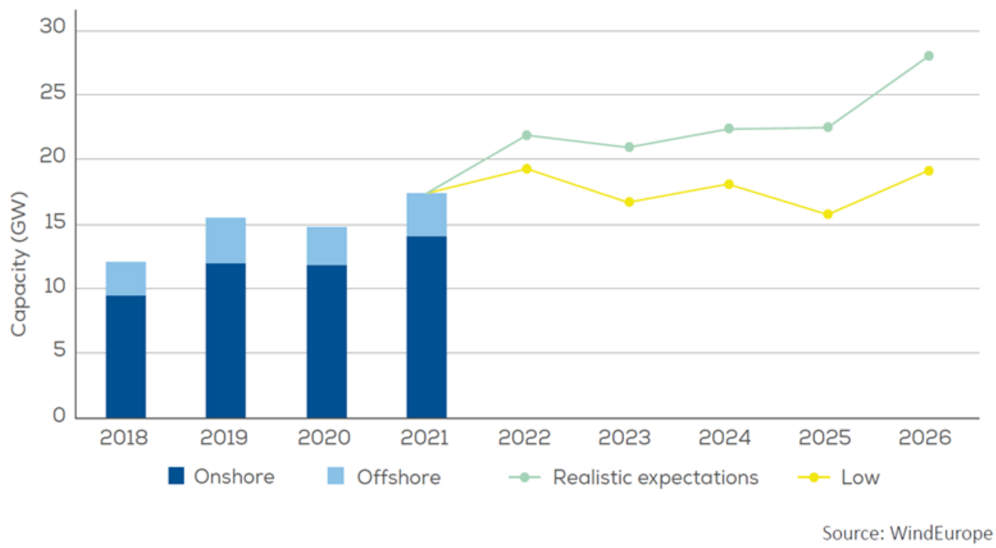

Figure 8. 2022-2026 new onshore and offshore wind installations-WindEurope's scenarios. Source:WindEurope

The European Union of 27 is estimated to install 75 GW (75,000 MW) by 2025 at a rate of 15GW (15,000 MW) per year.

72% of the new facilities will be onshore and 28% marine wind farms.It is estimated that Germany will install new wind capacity of 16,000 MW, France 12,000 MW, Sweden 7,000 MW and the Netherlands 6,000 MW.Res-Renewable Energy Sources and especially wind farms have an auspicious future and strong prospects to continue their successful course in Europe, as is expected to see 5.7 GW of repowering projects (repowered capacity) over the next five years, which translates to 2.9 GW being decommissioned and replaced with new, more efficient and higher-capacity turbines. On average, the output capacity of these repowered wind farms is doubled, leading to a significant increase in electricity output. Additionally, the number of turbines in these repowered wind projects is decreased by 27%, further increasing the efficiency of the wind farm. Germany is currently the largest European market for repowering, with approximately 16GW in wind farms expected to cease receiving 20-year support by 2030. The Netherlands is currently the most active repowering market, with 170 wind farms having been repowered so far. Other countries that have seen significant repowering activity include Denmark, Spain, Italy and France.

According to Wind Europe's Realistic Expectations Scenario by the end of 2030Germany leads the EU in terms of wind energy capacity, with 85 GW of cumulative capacity in the Central Scenario - more than a quarter of the entire EU. France follows close behind with 43 GW, while the UK places third with 37.5 GW, 60% of which is planned to be offshore. Together, these three countries make up more than half of the entire EU's cumulative wind energy capacity. Outside of the EU, Turkey and Norway constitute significant wind energy fleets with 28 GW and 11 GW respectively. These countries have made impressive strides in developing their wind energy infrastructure and have set a strong example for other nations to follow.

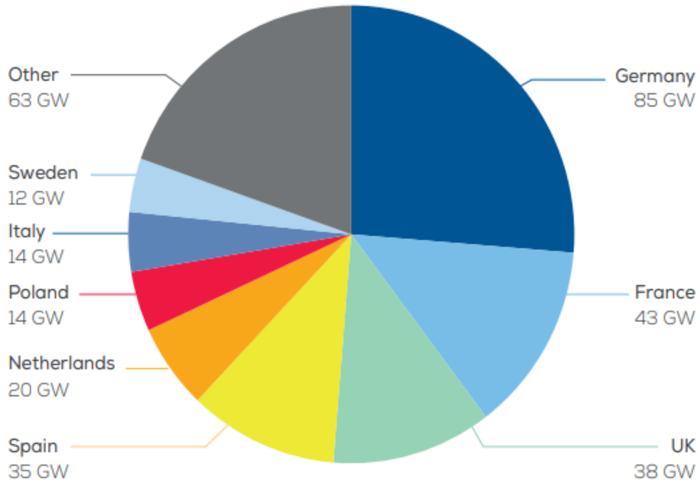

Figure 9. Central Scenario in the EU (GW) by 2030 wind energy installed capacity by country. Source:https://proceedings.windeurope.

In conclusion, after citing all these statistics from reliable sources, it is easy to conclude that wind energy is competitive, fast growing and is the solution for a safe, reliable and economical energy source for the European continent.
The data come from the European Wind Energy Association (WindEurope) and are reflected in the publication on "Wind energy in Europe – 2020 Statistics and the outlook for 2021-2025", published on 02/2021.

Chapter 2 Wind Energy- types of energy converters

2.1. Wind Energy Converters (WEC)

Wind turbines are devices that convert the wind's kinetic energy into electrical energy. They are an increasingly important source of renewable energy and are used in many countries in order to reduce both the energy costs and the reliance on fossil fuels. The first known practical wind power plants were built in Sistan, an Eastern province of Persia (now Iran), from the 7th century. These were vertical axle windmills called Panemone, which had vertical drive shafts with rectangular blades.Made of six to twelve sails covered in reed matting or cloth material, these windmills were used to grind grain or draw upwater, and were used in the gristmilling and sugarcane industries.

Wind energy has been used by humans since ancient times to power machines such as windmills, sailing ships, and wind-powered pumps. Wind energy is a renewable source of energy that is widely available regardless of altitude, climate, and soil morphology. Wind-powered pumps were used to drain polders in the Netherlands and for animal husbandry in arid areas. With the development of electricity, wind machines found new applications such as lighting buildings away from major energy production centers. In the 20th century, small wind installations were developed for agricultural or domestic use, as well as large-scale wind turbine installations that could be connected to large, centralized electricity networks. Wind energy is an important source of renewable energy today and is used to power homes, businesses, and industry.

2.1.1. Brief History of windmills.

Windmills are indeed a remarkable piece of technology with a rich history that spans centuries and various regions of the world. They have played a crucial role in harnessing the power of the wind for various practical purposes, shaping the course of agriculture and industry. The concept of wind power has ancient origins, possibly dating back to the Greek inventor Tesibius in the 3rd century BC. However, the earliest known wind-powered grain mills can be traced to Persia between 500 and 900 AD, initially designed for water pumping and later adapted for grain milling. While there may have been earlier wind-powered devices, historical evidence is limited. The primary application of windmills for many centuries was the grinding of grain. In fact, as late as the 20th century, windmills in the Netherlands were responsible for processing the entire wheat harvest of Northern Europe. Wind power spread to Europe through trade and the Crusaders, becoming a common technology. Dutch engineers made significant contributions to windmill technology, especially in low-lying regions where windmills were used to drain water. They introduced the horizontal axis design, allowing the sails to remain stationary while capturing wind energy. This innovation marked a crucial step in the evolution of windmill technology. The Middle East was also a hub for early wind power adoption, particularly in food production. Wind pumps and windmills were extensively used by the 11th century. Merchants and Crusaders played a role in introducing this technology to Europe. Interestingly, the vertical axis wind turbine, which had a different design compared to the familiar horizontal axis windmills, was used in places like China and the Middle East around 200 BC. This design primarily served the purpose of pumping water. Unfortunately, there is limited visual documentation of these early vertical axis wind turbines, making their exact operation somewhat uncertain.

In Nashtifan village in Iran, a traditional windmill design with a vertical axis is still in use today. It features sails made from reeds or wood attached to a central vertical axis with horizontal struts. This ancient design has been preserved and continues to function.Modern wind turbines, with their sleek horizontal axis blades, have evolved significantly from these early designs. They are highly efficient and contribute significantly to renewable energy production. However, it's fascinating to see how the principles of harnessing wind power have persisted and evolved over thousands of years, from ancient Persia to the wind farms of today.

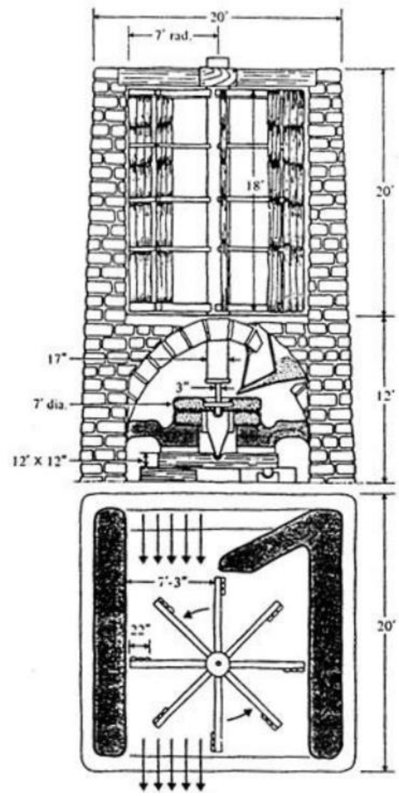

Figure 10. representation of a Persian type windmill [source: "the Traditional Crafts of Persia, Their Development, Technology, and Influence on Eastern and Western Civilization», H. E. Wulff, 1966]

Figure 11. windmill in Nashtifan village, Iran, built with the traditional design, source: Mehr News Agency, Amir Ghaderi.

Vertical-axis windmills have been used in China since at least 1219 m. Allah. It is also believed that they may have been used in agricultural work up to 2000 years ago. In Greece, vertical-axis windmills have been used extensively to pump water for crops and livestock since the early days.

In more recent times, vertical-axis wind turbines have gained popularity in rooftop applications and are even being deployed offshore. The US Department of Energy's ARPA-E funding office initiated a grant program with the aim of developing megawatt-scale vertical-axis turbines for offshore wind farms. Companies like SeaTwirl and ARC Industries are also introducing vertical-axis turbines for use in both rooftop and offshore settings. Interestingly, the earliest windmills in Western Europe, dating back to around 1300 A.D., were of the horizontal-axis configuration. The reasons behind the shift from the vertical-axis Persian design to the horizontal-axis European design remain somewhat unclear. However, it is worth noting that European water wheels also featured a horizontal-axis configuration, which may have served as a technological model for the early windmills.

Another factor contributing to this transition could be the higher structural efficiency of drag-type horizontal machines over drag-type vertical ones. Vertical machines lose a significant portion of their rotor collection area due to shielding requirements. The first illustrations from 1270 A.D. depict a four-bladed mill mounted on a central post, known as a "postmill," which was already quite advanced compared to Persian mills. These mills utilized wooden cog-and-ring gears to convert the motion from the horizontal shaft into vertical movement to turn a grindstone.

One significant improvement in European mills was the use of sails designed to generate aerodynamic lift. This innovation boosted rotor efficiency compared to Persian mills by increasing rotor speed, which, in turn, improved grinding and pumping capabilities. Over about 500 years, European windmills underwent a gradual process of refinement. This evolution took windmills from the traditional post mill design to the modern wind turbine design. These refinements included adding curvature along the cutting edge of the sails, positioning the spar at 1/4 of the string position, and incorporating nonlinear twists in the wing design from the root to the edge. Some windmills even featured aerodynamic brakes, boilers, and various types of fins. These design changes allowed windmills to serve a wide range of applications, from grain milling to processing products such as spices, cocoa, paints, dyes, or tobacco.

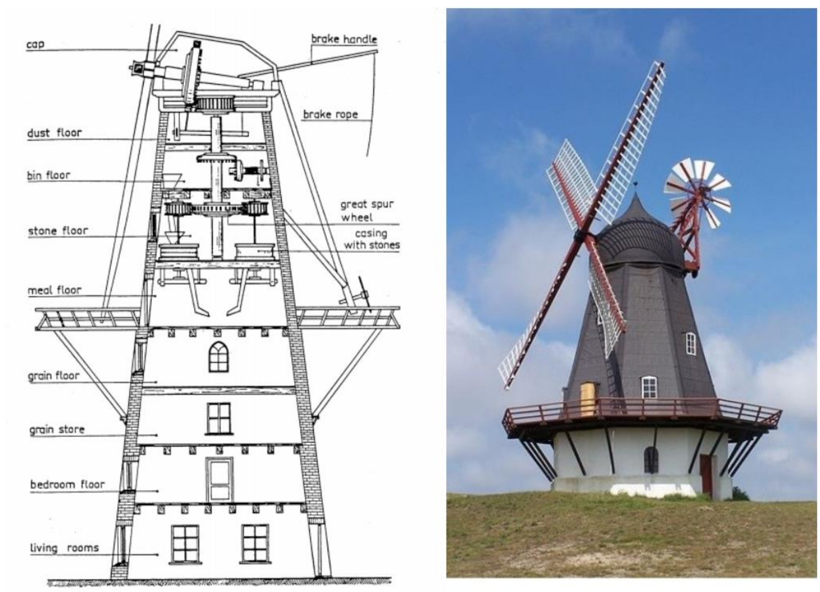

Figure 12. Cut of a Dutch windmill, left [source: "the Dutch Windmill", F. Stokhuyzen,1965]. Windmill in Sønderho, Fanø, Denmark, right. Source:http://en.wikipedia .org/wiki/Windmill]

Early wind turbines: The first wind turbine used to convert wind energy into power was built by Scottish engineer and physicist, James Blyth in July 1887. His ten meter high wind turbine had blades made of fabric and was installed in a rural house. It served to charge a species of batteries from which he later derived the energy for lighting, thus becoming the first house in the world to be powered by electricity.On the other side of the Atlantic,Charles F. Brush built the first electricity-generating wind turbine in Cleveland, Ohio in 1888. It was a 4-ton, 60-foot monster with 144 blades and a long, comet-like tail. Its rotor was 17 meters in diameter and it had a built-in box in order to adjust the speed to its desired operational mode.

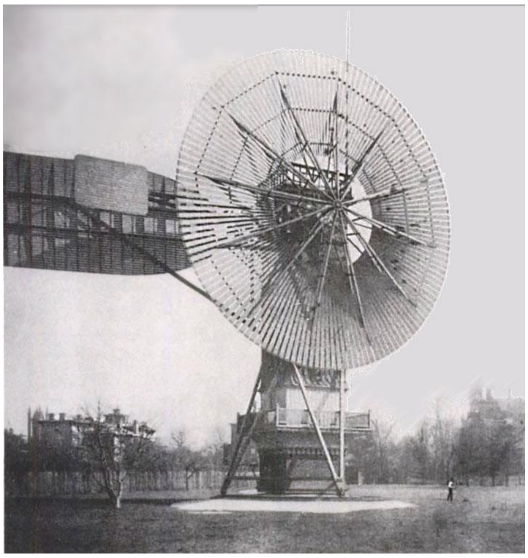

Figure 13. First scottich wind turbine /Brush's windmill at Clevelan, Ohio, 1888.The first use of a windmill for example electric current [source: "Wind Power Fundamentals", a. Kalmikov, K. Dykes, mit Wind Energy Group & renewable energy projects in action

The next step was taken in 1891 by Poul la Cour, a Danish scientist, inventor and educationalist who developed the first wind engine for electricity generation in 1891. His invention used simultaneously all the basic principles of aerodynamic design, such as low stability and four fins. However, after World War I, the use of wind turbines to generate electricity spread widely in Europe but was replaced by more efficient and cheaper fossil fuels due to the wind turbines' inability to produce large quantities of electricity. Between the mid-1920s and 1930s, 1-3 kW generators were produced by companies such as Parris-Dunn and Jacobs Wind, making widespread use of electricity possible in rural areas of the Midwest. These systems were originally used for lighting farm estates as well as charging batteries needed to operate radios. However, demand for electricity in rural areas increased and the Great Recession caused a decline in the wind turbine market. This led to an increased focus on the expansion of the power grid, which marginalized the use of such technologies. By the 1940s, most wind turbines had been removed from rural farms and replaced with more reliable sources of electricity. A very important achievement took place in 1920 in Fance and that was the manufacture of the vertical axis wind turbine by G.J.M. Darrieus.

The Darrieus wind turbine is comprised of several curved aerofoil blades affixed to a rotating shaft or framework. The unique shape of these blades allows them to endure tension forces at high rotational speeds. This design features a vertical shaft that supports two airfoil blades, each resembling a bow. The tips of these blades are connected to the top and bottom of the shaft. This innovative turbine design was patented by Georges Jean Marie Darrieus, a French aeronautical engineer, with the patent application filed on October 1, 1926. However, there are significant challenges associated with safeguarding the Darrieus turbine against extreme wind conditions and ensuring it can self-start.

2.1.2. Subsequent developments

In the European area, developments began after the end of World War II.As in the United States, the main application for these systems was to interface with the central electricity grid.At that time the scientific world turned to the research and development of wind turbines. This resulted in 1957 in Denmark, Gedser to develop his own wind turbine with a nominal power of 200kW and a diameter rotor 24 m. In the European area, developments began after the end of World War II. and because of the temporary shortage of fossil fuels. As in the United States, the main application for these systems was to interface with the central electricity grid. Gedser Mill's 200 kW wind turbine in Denmark it operated successfully until 1960 until the decline in fossil fuel prices it made wind turbine technology uncompetitive. In Germany the Professor Ulrich Hutter developed a series of advanced horizontal-axis raft medium-sized wind turbines, in which the innovation of airfoils was exploited fiberglass type and plastic flaps variable pitch to achieve smaller weight and thus higher performance.The reason for the further development of wind turbines was oil crisis that occurred in 1973 in the Arab countries. However, despite the rapid development of technologies, the effort remained unfinished due to political interventions to serve micropolitics and business interests. The result of the federal government's efforts to support the development of small wind turbines was the creation of 13 different designs with power ranging from 1 kW to 40 kW, 5 large 100 kW to 3.2 MW horizontal axis turbines, and numerous vertical axis power wind turbine rafts that ranged from 5 to 500 kW. Additionally, local and state governments have implemented demand-side policies to promote the use of wind energy and help achieve energy efficiency goals. Worthy of mention is the absolute success of the Darrieus program which resulted in the construction of a 34-meter Darrieus wind turbine with variable speed applicability.

Figure 14.A historical photo of Sandia National Laboratories' experimental 34-meter-diameter, vertical-axis wind turbine built in Texas in the 1980s. (Image courtesy Sandia National Laboratories)

Another application in the vertical axis wind turbine was that of form fins pear which highlighted the construction problems of type wind turbines Darrieus from fiberglass. This species failed to cope with a strong or moderate winds. Also wind turbines with vertical and straight blades e.g. type ' H ' were developed in the 1970s in the United States and the Great Britain and the 1990s in Germany.In the early 1990s, many of the experimental machines of megawatts deployed in Germany, Sweden, and other countries were no longer operational. At the same time, research efforts in the European network of research laboratories focused on the theoretical field of basic and applied research and innovation development in wind energy. This included developing longer and lighter rotor blades, taller towers, more reliable drivetrains, and performance-optimizing control systems. Through research, the wind industry has been able to make significant advances in the average capacity factor and reduce the cost of wind energy. Research is continuing to make wind energy more reliable and cost-effective.

2.1.3. Recent developments

During the period from 1973 to 1986, the purchase of wind turbines changed significantly as small-scale production of wind power with an output of 1-25 kW used for agricultural or domestic uses was converted into interconnected medium-scale wind farms with wind engines power of 50-600 kW. The majority of wind turbine installations were in California, where more than 17,000 wind engines with an output of 20-350 kW were installed between 1981-1990 producing a total of 3,000,000 MWh, a sufficient quantity to feed a city of 300,000 inhabitants.

From 1980 to the present, wind turbine installations have gradually increased in Europe and Asia. In 1990, the cost of generating electricity combined with the inexhaustible source of wind created in northern Europe led to a small but reliable market, with most of the market activity shifting to specific areas. Facilities with wind turbines with a power of 50 kW to 500 kW or even 1.5 MW were made reality from partnerships or individuals in Denmark, Germany and the Netherlands. The exploitation of the European wind potential with installations totaling more than 10,000 MW has benefited not only the energy sector in Europe but also development through the hundreds of industries active in the field of wind energy. However, the introduction of cheap natural gas by Canada has slowed down developments in this area.Nowadays, there are 10 to 12 large-scale plant manufacturers worldwide 200 kW-3.0 MW consisting of systems of various configurations. Greater advanced settings at least from an aerodynamic point of view were developed at U.S.A. under the auspices of the Ministry of energy. European construction companies such as Tacke, Micon, Vestas, Siemens and Enercon focused on rotorcraft wind turbines conventional design but with important innovations such as low speed wind turbines or variable speed systems incorporating advanced electronic applications.

2.1.4. Definition of parameters

The performance of wind turbines is influenced by factor such as ssolidity, number of wings, type of air foil, angle of incidence, Reynolds number, λ (Tip speed Ratio) and ratio H/D. All the above could be said to be geometrical characteristics of the wind turbine, since they mainly depend on the dimensions of (such as the c chord length of the fin, the R radius of the rotor, the angle or the point of placing the blades on the wind turbine) as well as from the angular velocity of rotation ω. The characteristics of the fluid that use the wind turbine for the production of a project is stable, since we refer to air (such as density p, kinematic viscosity N, and per consistency and dynamic viscosity : $\mu = \nu * \rho$.
Below is an extensive reference and analysis of the above factors and diagrams of experimental or computational studies are given in order to understand and visualize their effect on the aerodynamic behavior of the wind turbine, having as a criterion the increase of the attributed energy as:

$$C_p = \frac{pm}{\frac{1}{2}\rho A V^3}$$

2.1.5. Power factor and power curve

To clarify the influence of the various factors in performance of a wind turbine should set the power factor. The power factor of a wind turbine is essentially an indicator valuation, since it measures how efficiently a wind turbine converts the available energy of the wind in electricity. Thus, we can define the power factor as

$$Cp = \frac{energy\ generated\ by\ the\ wind\ turbine}{total\ wind\ energy}$$

Or

$$C_{p=\frac{P}{\frac{1}{2}\rho A V^3}}$$

where ρ refers to the density of the air, A at the surface which encloses the rotor and the V at air speed. From the definition above is understood that the wind turbine produces energy slowing the air passing through its wings, taking advantage of his kinetic energy. Therefore, to be 100% efficient should stop all air, which means it will be a solid barrier to flow without producing work. So, there is a constraint, which forms the Betz-Joukowsky boundary. According to this, the maximum energy a wind turbine can produce is limited to59.3% of the total kinetic energy of the air. The maximum theoretical its value □□ is 0.593.

In terms of the power curve, this is a diagram that shows the change of □□ usually in terms of wind speed or Lor λ- (Tip Speed Ratio- TSR). On this curve it is observed the yield of the wind turbine for any speed within its field of operation,based on which it is designed. As is evident in the following diagram seems to distinguish a point at which there is the optimal efficiency-maximum power output, i.e. maximum □□. It is also remarkable the Betz limit mentioned before, as well as the power curves for various types of wind turbines, showing their variation in range function and the λ for which yield the maximum □□.

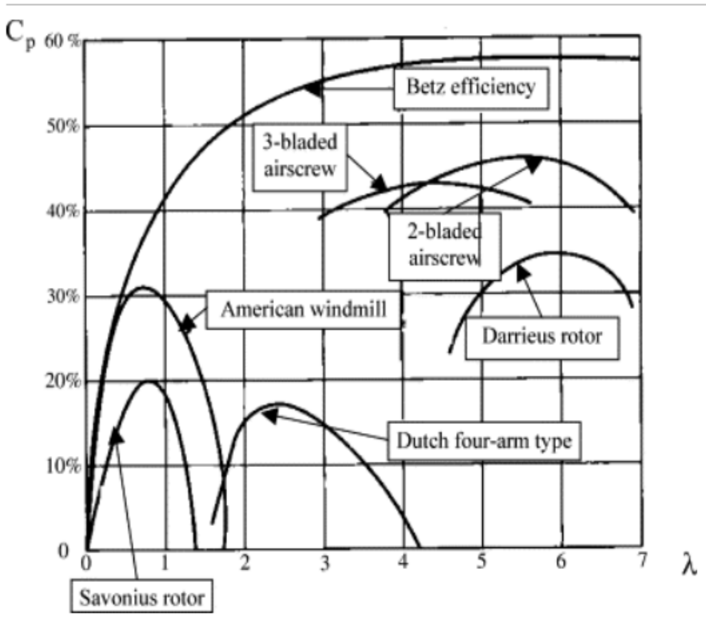

Figure 15.Performances of main conventional wind machines.(Menet, 2004)

2.1.6. Tip speed ratio (TSR or λ)

The design of wind turbines must be such that matches the angular speed of the rotor with the wind speed, having as aim for optimal performance, i.e. to exploit the maximum possible power of air flow. If the rotor rotates too slowly, then most air passes through the wing gaps and exploits very small force. Conversely, if it rotates too fast, then fins behave as solid obstacles to air flow, as a result of which we have reduced power extraction. Therefore, the election of tip speed ratio should be such so that we have maximum efficiency. Tip speed ratio is defined as the speed of wing tip to wind speed:

$$\lambda = \frac{\omega r}{V}$$

and depends on the special design of the turbine, the profile of the airfoil and the number of vane. The optimal λ depends on the relationship of time$t_w$that takes H disturbed flow to be regained, towards the time $t_s$needed by a fin with angular velocity ω to take the place of the next.

So, $t_{s=\frac{2\pi}{n\omega}sec}$and $t_{w=\frac{s}{v}sec}$.

When it is $t_s > t_w$ then a part of the air remains unaffected, and if$t_s < t_w$ then part of the air does not pass through the rotor. So, themaximum power extraction is done when the two times are almost equal, $\omega_{opt=\frac{2\pi V}{ns}}and\lambda_{opt=\frac{r\omega_{opt}}{V}=\frac{2\pi}{n}(\frac{r}{s})}$

As shown above by the mathematical formula, the tip speed ratio depends on

the number of wings (n), and for a smaller number, the rotation of the turbine should be faster.

It is true that: $\frac{s}{r} \approx \frac{1}{2}$ and so $\lambda_{opt=} \frac{2\pi}{n}\frac{r}{s} \approx \frac{4\pi}{n}$

If the spoiler is properly designed, then the optimal λ can be increased by 25-30%, and by increasing the rotational speed can also have an increase in power output. When a fin passes through the flow it leaves behind a turbulent cast and if the next flap meets the cast while it is still turbulent, then it will not be able to perform satisfactorily and will accept great oscillatory tendencies. But if it rotates a little later, then the fins will not encounter turbulent flow. Thus, for fins that are not correct designed, λ is small and the wind turbine will tend to slow down, and it's decked out. For a large number of λ, the turbine will have reduced efficiency and will be charged with great tendencies, at the risk of disaster.

The power factor is : $\boldsymbol{C_p} = \frac{\boldsymbol{P_t}}{\boldsymbol{P}} = \frac{\boldsymbol{Pt}}{\frac{1}{2}\boldsymbol{\rho\pi R^2 V^3}}$ where P_t is the power that

takes advantage of the turbine and P is the available air power.

The maximum theoretical value is 0.59, however in reality it is less due to

losses.

2.1.7. Parts of a wind turbine

At this point it is worth mentioning that both types of wind turbines they generally have the same components. All the wind turbines consist of three main structural parts: the nacelle, the tower and the base.

There are also many individual elements described below:

Nacelle: The nacelle is the bulky horizontal part that is mounted at the top of the wind turbine tower and to which the rotor abuts. The nacelle includes the transmission system (gearbox), the low and high axles gear, the generator, the controller, and the brake.

Rotor: The rotor consists of the shaft and the vanes.

Blades: Most turbines consist of two or three blades. The movement of the wind over the blades causes them to rotate through a central axis as well converts wind motion into circular motion in the wind turbine. Basic characteristic of the wings is their aerodynamic shape, which plays an important role in their performance. Most wind turbines consist of three blades, while two blades are usually found in small wind turbines to facilitate in construction and installation level.

Transmission system: The transmission system connects the low speed shaft with the high-speed spindle and increases the rotation speed from 30 - 60 revolutions minute (rpm) at 1200 - 1500 rpm, i.e. the rotation speed required by the more generators to produce electricity. The transmission system it is an expensive and heavy structural element of the wind turbine. Wind turbines up to 150 kW have a two-level transmission system, while 300 kW wind turbines have a three-level system levels (two levels and an intermediate shaft) and those over 450 kW have a system two-level transmission in combination with a toothed wheel.

High speed shaft: The high-speed shaft is connected to each other transmission system and the generator.

Generator: Converts the kinetic energy of the wind into alternating current electricity.

Controller: The basic function of the controller is to give commands to the motor yaw about how much and where to turn the nacelle, so that the rotator17 always be against the wind flow.

Brakes: It is a disc brake, which can be applied mechanically, electrically or hydraulics to stop the rotor in emergency situations necessity. Over speed control in wind turbines is ensured by two modes: aerodynamic or mechanically braked. Speed control aerodynamically is the best method for slowing down the wind turbine.

Deflection mechanism and motor: The deflection mechanism is one mechanism that turns the rotor and therefore the entire nacelle so that ensure that it is against the direction of the wind.

Anemometer: Calculates the wind speed and transfers the relevant data of the measurement to the controller.

Wind vane: It is a mechanism that informs the controller about the wind direction, so that the deflection mechanism is activated accordingly.

Hub: It is the point where the wings are fixed and is made of cast iron.

Tower: The tower is the part of the wind turbine on which the nacelle and the rotor. The height of the wind turbine is an important factor against the design of wind turbines of the horizontal axis type. As his speed wind power increases with height, taller towers allow more to be produced electricity.

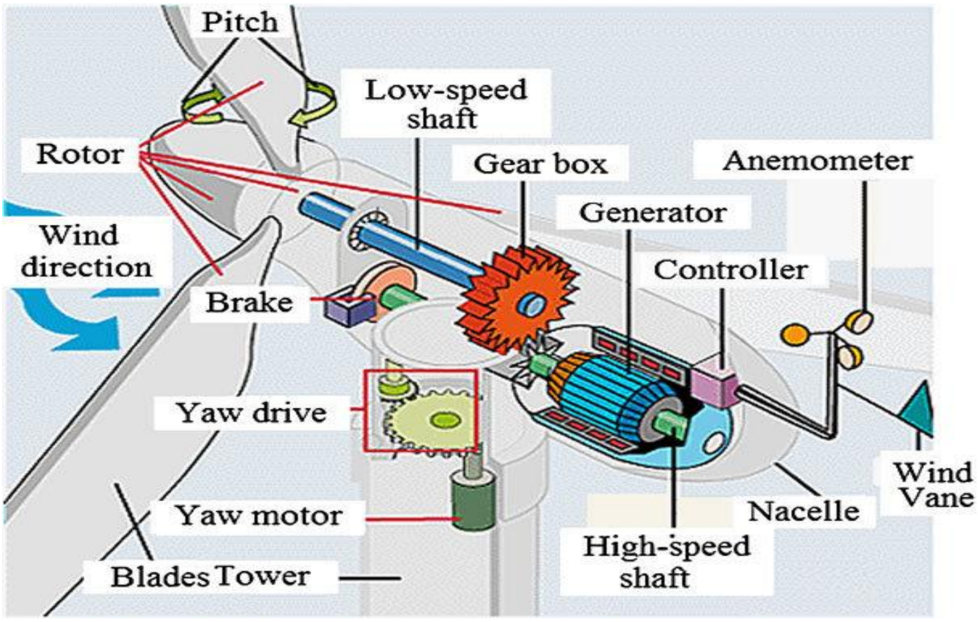

Figure 16.Structural elements of a HAWT.
Source: http://hdl.handle.net/10889/12581

2.2. HAWT-Horizontal axis wind turbines

In wind turbines of this type, the axis of rotation runs parallel to the direction of the wind and is horizontal to the ground. All wind turbines of this design feature a propeller-style rotor that is supported on a horizontal shaft, with most having two or three blades. One of the key advantages that makes this type of wind turbine so popular is that they do not require very high wind speeds to start turning, exhibit a high aerodynamic efficiency, and are relatively easy to assemble. However, the primary drawback of horizontal axis wind turbines is that the generator and gearbox must be mounted on top of a tower, which makes them more expensive and challenging to manufacture. Additionally, unlike vertical axis wind turbines, horizontal axis turbines require an active rotation mechanism or, more commonly, a tail fin to help them align with the direction of the wind.

2.3. VAWT- Vertical axis wind turbines

The vertical axis wind turbines, which are also the basic subject of the specific thesis, have their axis of rotation perpendicular to the ground and vertical to the wind flow. The main advantage of this arrangement is that the machine does not need to oriented towards the wind to be efficient, that is, it can spun by the wind that comes from every direction at every moment, so no orientation mechanism is required. This fact applauds the construction of wind turbines in places with high variability in wind direction. The electric generator in these machines can be placed close to the ground, which implies a simple and economical design for the tower. Vertical axis wind turbines are easily accessible systems and often do not need a support pillar. But there are also some disadvantages that negatively affect it functionality of such wind turbines. The main disadvantage is that most of times it is not possible to start their rotation without an external interference, due to their high starting torque. In addition, according to their rotation, there are points where the wind contribution is almost mechanical energy

In urban areas where wind energy tends to be in-consistent and highly turbulent, a VAWT is preferred thanks to its low starting torque characteristics, its independence from the wind's direction and many more advantages like being in-expensive to build and of simple design. Also, wind power is a key player in overcoming the increasing worldwide energy demand. The United Nations, state that by 2050, the 68% of the world population is projected to live in urban areas. That means, that the integration of renewable energy sources into the urban grid connection is of vital importance to assist coping with the current inflow of people. VAWT are automated systems that can provide this king of assistance to a future smart city, without harming its aesthetics.

Last but not least, the existence of wind energy converters in poor countries and remote areas is considered to be critical as well, since they are often used for water pumping and other necessary power supplied devices. Further research enhancing the efficiency of wind energy converters must be conducted in order to lower their CO_2 footprint and make them more reliable.

2.4. Comparison of horizontal and vertical axis wind turbine

In the construction of a vertical axis wind turbine, we have the following advantages:

1. Depending on the type of vertical-axis wind turbine, constructing it can often be more straightforward compared to building a horizontal-axis wind turbine. This ease of construction primarily stems from two factors: the simplicity of crafting the blades and the absence of a requirement for a wind turbine braking system during strong winds.

2. Vertical axis wind turbines do not require constant reorientation towards the wind, thanks to their design. They are capable of capturing wind from all directions, making them a better choice for areas with inconsistent wind patterns or when placed near obstacles, although their performance may be somewhat reduced in such situations.
3. Their construction cost is lower than the construction cost of a horizontal axis wind turbine due to simpler design.
4. They are safer because there is no risk of a blade breaking, nor do they move at the high speed of turns that horizontal axis wind turbines move.

In contrast, the disadvantages of a vertical axis wind turbine are mainly the following:

1. The first and most important disadvantage is that vertical axis wind turbines have very low efficiency. This applies to a large extent to the "savonius" type where they do not exceed 15%, but also to a lesser extent to the other types (a good small horizontal axis wind turbine has an average efficiency of 30%-40%).
2. From the previous one it follows that a vertical axis wind turbinein order to have approximately the same production as a horizontal axis, the vertical axis should have up to three times the contact surface with the air. This implies a large volume and weight of the structure.
3. Due to lower rpm, stronger winds are needed to start charging the batteries (given the same motor in a horizontal axis wind turbine)

2.4.1. VAWTs several advantages over HAWTs.

One of the main advantages is that theyare omnidirectional, meaning that they can capture wind from any direction, while HAWTs require wind to come from a specific direction to generate electricity. This makes VAWTs more suitable for use in urban areas where the wind direction is often unpredictable. VAWTs are also generally more bird and bat friendly than HAWTs, as they have a smaller blade size and slower rotational speed, which reduces the risk of birds and bats being struck by the blades. In addition, VAWTs have lower manufacturing and installation costs compared to HAWTs, which makes them more economically attractive. Building-integrated wind turbines (BIW) are a type of VAWT that are designed to be incorporated into the design of buildings, such as being mounted on roofs or inside wind ducts. BIW offer the potential for generating electricity in urban areas while also improving the aesthetics of the building. They are also generally quieter than HAWTs, which makes them more suitable for use in urban areas where noise levels need to be kept low.

Optimizing wind turbines for their specific operating conditions is important, especially for VAWTs operating in urban environments with frequent wind fluctuations. VAWTs have a longer response time than HAWTs and may not be able to fully absorb wind energy during periods of fluctuations. This can lead to overestimation of the wind turbine efficiency factor and incorrect feasibility assessments of projects using VAWTs. The passive rotation of a VAWT, i.e. its response to wind variations, can provide information on its transient behaviour and improve its performance under fluctuating wind conditions. VAWTs have an important role in electricity generation in urban environments and in reducing greenhouse gas emissions. Continued research is needed to better understand the potential of VAWTs in these applications.

Hybrid rotors are one of the most advanced VAWT types that work by combining lift and drag forces and are known for their good self-starting abilities, particularly in lower wind potential regions, like Belgium. They have gained increasing attention from researchers in recent years due to their unique power characteristics and the potential to improve the performance of VAWTs. Hybrid rotors can be constructed by combining Savonius and Darrieus rotors in various configurations, and they have been studied using different numerical methods and experimental techniques to understand their power characteristics.

Alternatively, the studies by Ghosh et al. (2015), Liang et al. (2017), and Jacob and Chatterjee (2019) all examined the performance of hybrid wind turbines, which consist of a combination of Darrieus and Savonius blades. These studies found that the hybrid rotor is able to generate more power than a Darrieus rotor alone. They also explored the effect of factors such as attachment angle, radius ratio, and the specific combination of blades on the performance of the hybrid turbine. Overall, these studies suggest that hybrid wind turbines have the potential to be more efficient than traditional designs.It appears that the studies by Hosseini and Goudarzi (2019) and Liu et al. (2019) both introduced new types of hybrid wind turbines, which consist of a combination of Bach-type Savonius and Darrieus rotors. They found that these hybrid turbines had better performance than traditional Darrieus turbines, particularly in small tip-speed ratios (TSRs). The study by Hosseini and Goudarzi (2019) showed that the Bach-type Savonius internal rotor improves the performance of the hybrid turbine, while Liu et al. (2019) found that a modified Savonius (MS) rotor inside the Darrieus rotor suppressed dynamic stall and improved performance at high TSRs. Both studies emphasized the importance of selecting the right combination of components for optimal performance in hybrid VAWT design.

According to several studies conducted, the hybrid wind turbine with a combination of a Bach Savonius type internal rotor and a Darrieus type external rotor can have a better performance than a Darrieus wind turbine alone. The use of a modified Savonius rotor inside a Darrieus rotor improves the efficiency of the hybrid turbine and suppresses the stall potential of the Darrieus rotor at high peak speed ratios. Furthermore, the selection of hybrid rotor components is important for the optimal design of a hybrid vertical axis wind turbine. The aspect ratio has a significant effect on the power output of a hybrid wind turbine, with the average power factor decreasing as the aspect ratio increases. Finally, the introduction of a new type of hybrid wind turbine significantly improved its performance, with an increase in output power of up to 40% compared to a Darrieus wind turbine. The influence of non-dimensional parameters, such as the overlap ratio, arc angle and the design details of the external rotor, also affect the performance of the hybrid wind turbine.

This thesis' main scope is to design and create a visually appealing, functional energy generator that can serve as a symbol for the TWB WW Innovation Centre, while also incorporating innovative features and aligning with Tupperware's purpose, vision, and values. In addition, it is also important to consider how the generated green energy will be used. It will be important to carefully plan and coordinate the various aspects of the project in order to achieve the desired results.

Chapter 3 Methodology- Project's Scope

3.1. Project Plan and Technology options.

The diagram bellow shows in detail the steps from the initial idea of the project to its final stage. So, as the flow chart shows, in the beginning the basic idea was to build a structure that will run on res, it would be a commercial – eye catcher structure based in innovation, scalable model and most important a state of art and generation solution.At first, all the technological options that met these requirements were presented and then, as shown in the flow chart, the 6 best ones that meet the existing weather conditions were selected so that the machine could operate. Of the options that existed and explained in detail above in the paper, the best choice was the Eco bottle- Shell Concept. At the final stage, technological and mechanical development of the construction took place and various forms of utilization of the generated electrical energy were developed as well as various ways that can be used for the environment of the plant.

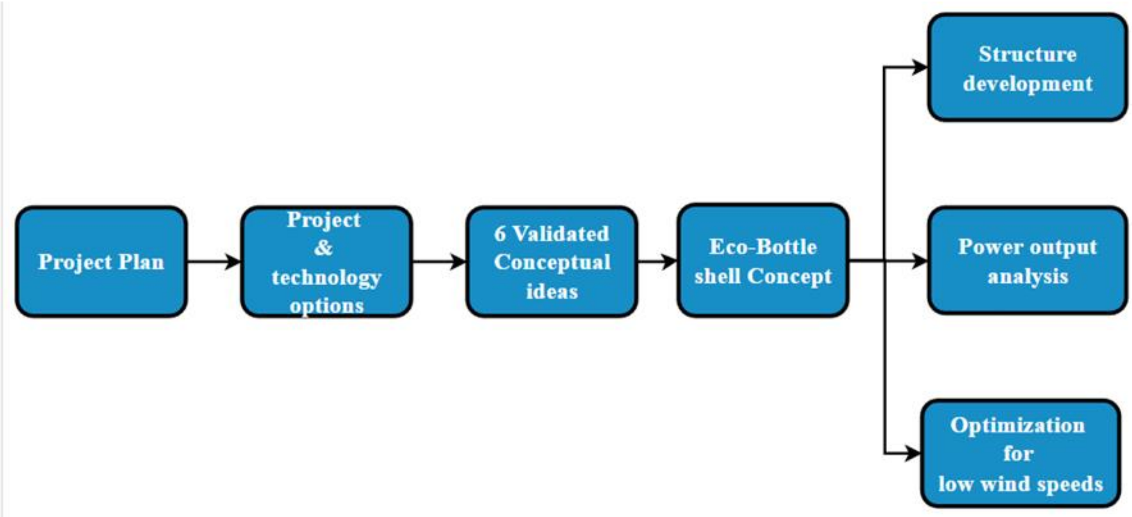

diagram 1.Project Plan Flowchart

3.2. Project's Scope

This project was carried out in collaboration with a student of the School of Mechanical and Aeronautical Engineering, had as a basic idea the construction of a construction consisting of recyclable plastic and the production of electricity using a renewable energy source. More specifically, each one of us had to invent three imaginative constructions that would meet the above specifications. Making a brief analysis on each of the possible constructions about which renewable energy will be used as the main source of electricity production, which materials and in what quantity will be used, whether it will be as a stable construction and at the same time friendly to the environment and the surrounding space and much more, the best choice turned out to be the Eco -bottle that this thesis is about.

3.3. Project & technology options

Figure 17. The main concept

The main project's scope is the development of an eye catching, workable and functional energy generator which will act as symbol for TWB WW Innovation Centre. The manufactured device should host innovative features and be inspired by Tupperware's purpose, vision, and values. Into the next chapters, deciding where the produced green energy is going to be used is also considered to be part of this project.

First and foremost, keeping the initial proportions of the already existing eco-bottle is mandatory, since the construction will mimic this world wide bestseller product.Also, the structure is going to be optimized for relatively low wind speeds (average 5m/s)since the location of the site is not considered ideal due to the surrounding buildings(turbulent air flow).Below are briefly presented the possible options developed before the choice of the wind turbine and therefore the Eco-bottle.

3.3.1. Artificial tree – hybrid solution / E-tree

The E-tree was the primary idea that the above requirements were realized. The main reason this initial idea was an artificial-hybrid tree was that it was a symbol representing hope and creativity, it also represents an environmentally friendly look and certainly a blooming effect. The company's products made of recyclable plastic will be used to build small wind turbines that will be the leaves of the artificial tree. For greater electricity generation at the base of the artificial tree, electric panels will be installed to exploit solar power. This is a hybrid combination for electricity generation.

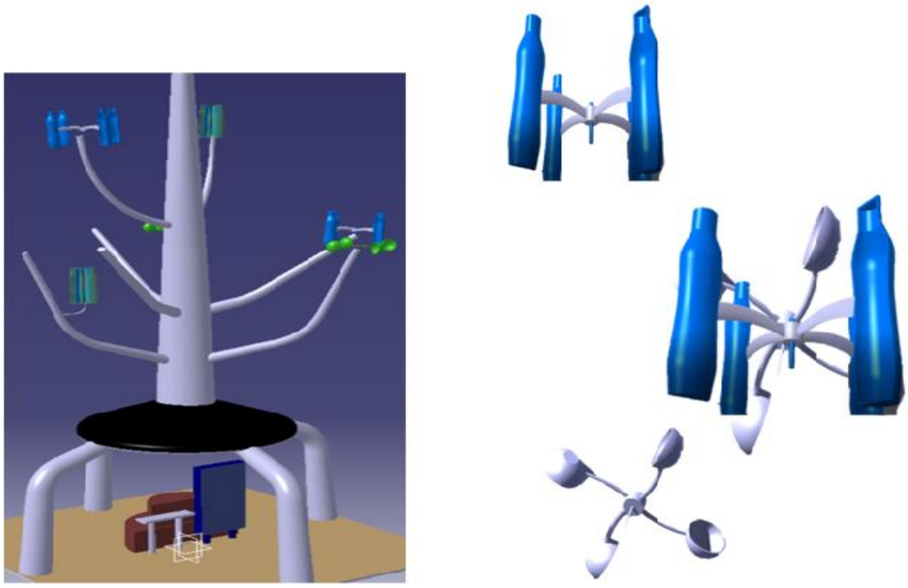

Figure 18.A draft plan 'E- tree' designed in ANSYS 3D and possible 'leaves' on the right.

- Symbol that stands for nourishment & fertility
- Leaves used will be from recycled plastic, having the shape of variant Tupperware's products.
- Small cost, effective.

3.3.2. TW logo frame concept.

The second idea that emerged was the one with the TW brands logo structured from colored metal frames. This would be a 3D metal frame designed or a cube Assembly could be achieved from a denser grid. The small wind turbines mentioned in the whole concept above will again be used as small sheets inside the metal cubes in conjunction with the solar panels. This idea could be completed with the appropriate lighting so that it could be very attractive (LED strips and spot lighting)

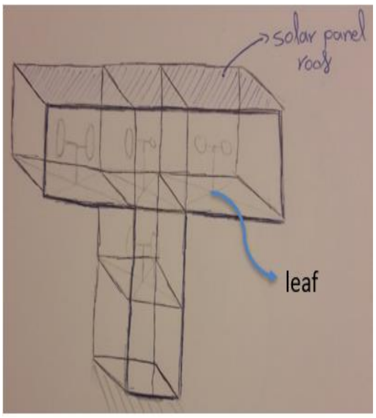

Figure 19.The logo frame concept.

Figure 20. Final metallic logo frames in the outside of the factory

- 3D Metallic frame design
- Solar & Wind energy harvest
- Small cost, effective

With the appropriate lighting can be vey attractive (led strips and spot lighting)

Figure 21.Metallic frame.

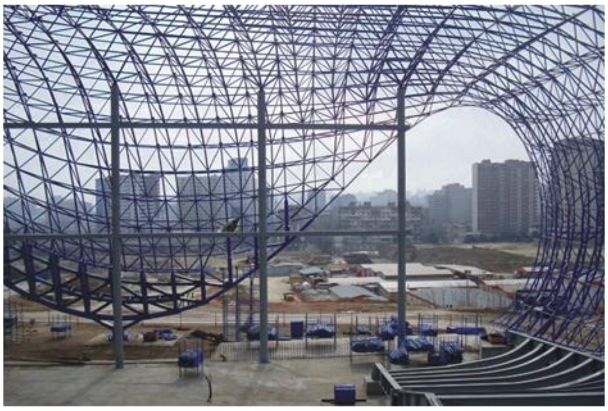

Figure 22. Possible cube of metallic frame structure.

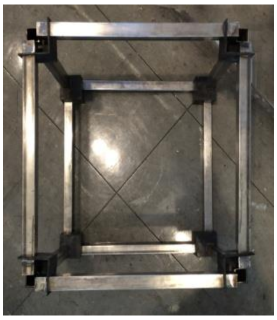

Figure 23. A metallic cube as it possibly would be.

3.3.3. Genealogical e-Tree.

The genealogical tree is vital. It shows life and continuity, like Tupperware products. Tupperware genealogical path highlights the beginning and evolution over the years. So that it starts from the Earth and evolves over the years with the corresponding products ending up in the current form.

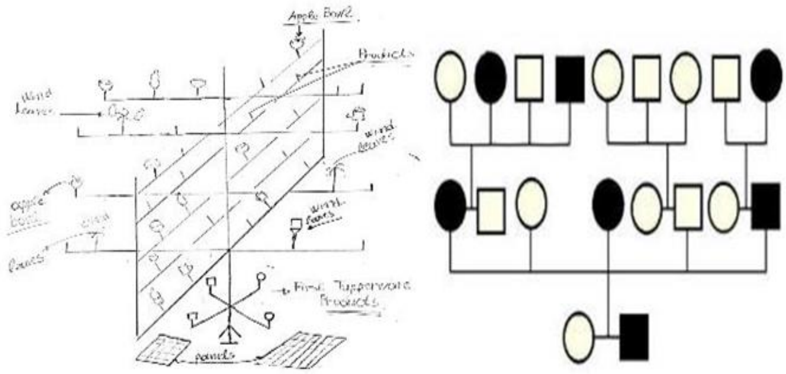

Figure 24.A draft plan as possible final and a pedigree.

- The main idea came from the design of Biology's pedigrees.
- The products will be presented in chronological order. Specific products, called rotating leaves will do the energy conversion.
- There will be a 4 m central axis and 5 floors-branches in total to rely on the main axis .
- Leaves will supposed to be Tupperware rotating products that will operate like the wind turbines. This way each floor will have some leaves that will convert wind energy into electricity

3.3.4. The only way to harvest rainfall energy.

Considering that Belgium where the construction will be located has the most rainfall, rainwater could be used to generate electricity after being stored in a water tank placed at a certain height on the top of the plant.

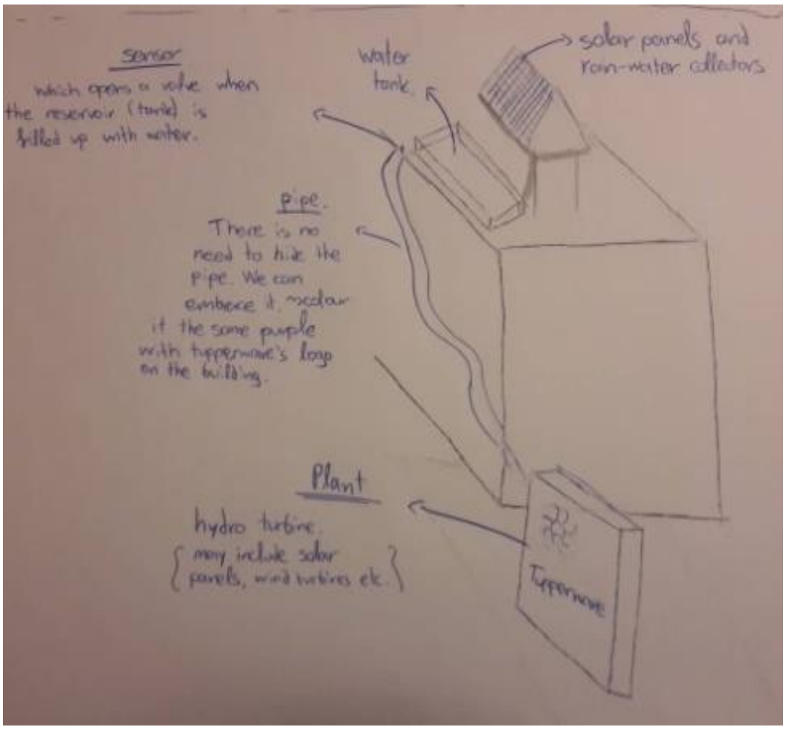

Figure 25.A water tank as a final draft

The water tank would consist of a sensor on top that opens a valve when the tankfills up with water, and a pipe that could be painted with the colors of Tupperware's logo in order to embrace it. The pipe would lead to a hydro plant where a water turbine would be placed and solar panels too. Rainwater collectors will be placed on top of the tank to collect rainwater and solar panels to collect the solar energy.This choice as a final stacture is briefly described by the following:

- very innovative
- 2-part plant
- Complex
- Expensive
- Belgium is very rainy

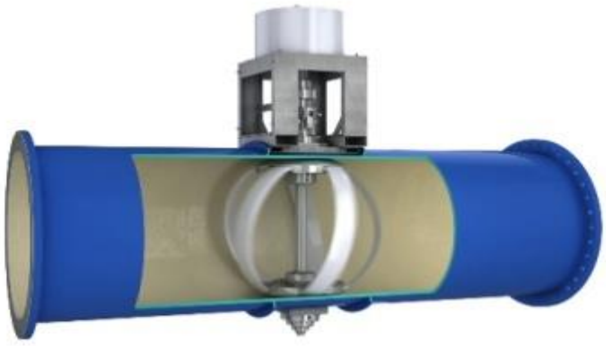

Figure 26. A hydro turbine

Also, this type of hydro turbine could be added into the pipe and can be visible via a plexiglass cover.

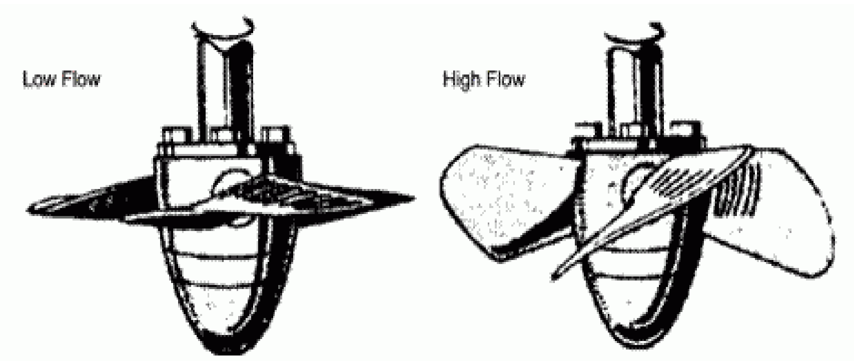

Figure 27.Hydro turbines

- This will be a small hydro plant, but we can adjust our harvesting tools

After the water passes from the hydro generator it can create an animation-illusion using Tupperware's recycled products or logo letters.

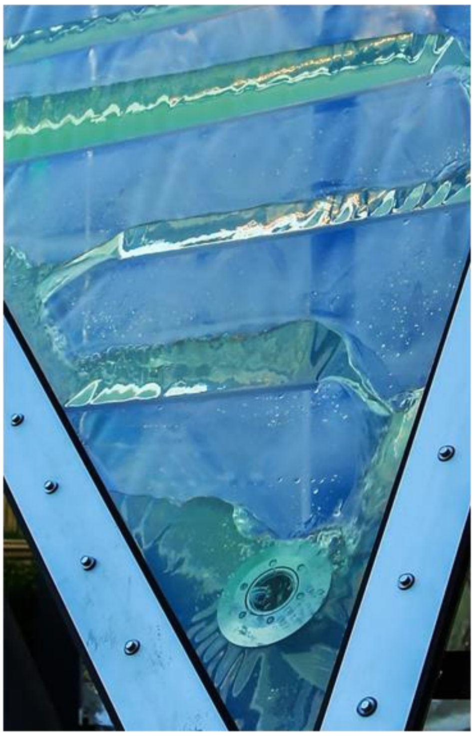

Figure 28.The water from the tank creating animation.

diagram 2. Electricity production from hydro energy.

3.3.5. Solar-Classic hydro-piezoelectric

Another option appeared for final construction was a piezoelectric floor at the factory entrance. Piezoelectricity refers to the phenomenon where certain materials generate an electric charge when subjected to mechanical stress or pressure. This effect was first discovered in 1880 by Pierre and Jacques Curie, who found that certain crystals, such as quartz, exhibited this behavior. Piezoelectric tiles are made using special materials, such as crystals and ceramics, in which electric charge builds up when mechanical stress is applied ” such as a foot pressing down.When a piezoelectric material is deformed or subjected to an external force, it causes a displacement of positive and negative charges within the material, leading to the accumulation of electric charge on its surfaces. This charge separation results from the asymmetrical arrangement of atoms or molecules within the crystal lattice structure of the material.

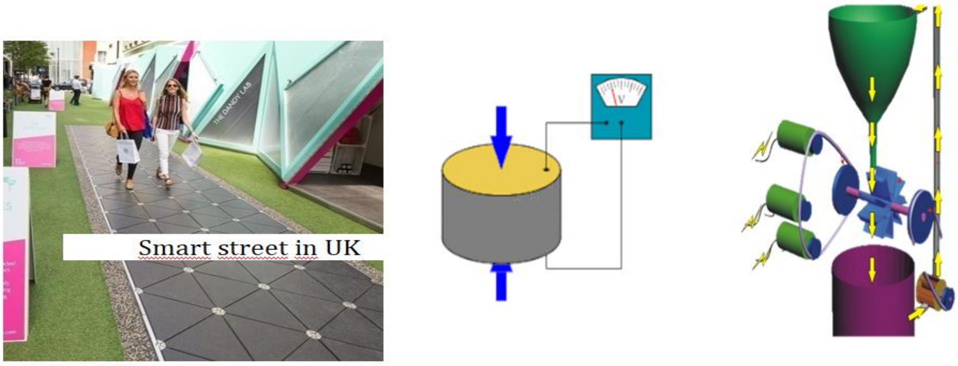

Figure 29.Smart Street in UK. Piezoelectric effect working with hydro energy on the right.

- Piezoelectric floor on entrance or solar panel on the passageway
- Passageway could be the main artery and the other parts ofthe plantcan be the veins
- Piezoelectric effect: up to 5w per footstep.

Additionally, piezoelectricity is found not only in crystals but also in certain ceramics and biological materials, as you mentioned, such as bone, DNA, and proteins. This property plays a role in biological processes like bone growth, sensory mechanisms, and even energy harvesting from biomechanical movements.

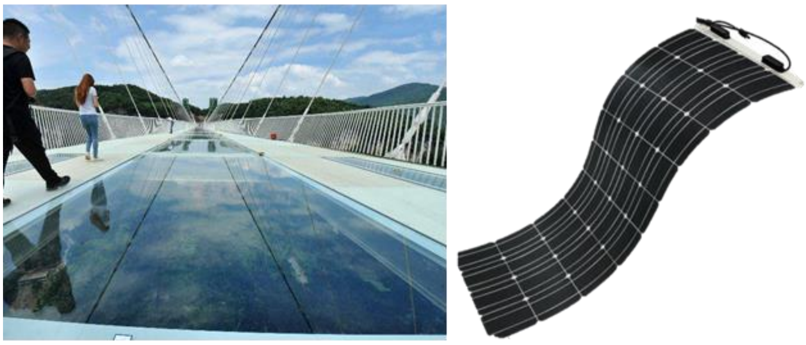

Figure 30. Solar panel passageway.Source: https://www.google.com

Piezoelectricity has practical applications in various fields. For example, it is widely used in sensors, actuators, transducers, and electronic components. Piezoelectric materials are often used in devices like microphones, accelerometers, ultrasound transducers, and pressure sensors. They can convert mechanical energy into electrical energy and vice versa, making them valuable in various technological applications. Many studies have been done looking at harnessing the energy of pedestrians walking through crowded public spaces. The conclusions are all similar: it is possible to harvest part of this energy, but the yield is quite low. Unfortunately, it seems piezoelectric tiles weren't quite what was called for in the primaries. Apart from electrical panels and pedestrian energy collection, no products of the company were used while at the same time the production of electricity generated in this way is low.

On the other hand, piezoelectric tiles can work fantastically well as self-powered sensors, tracking the movement of people through these public spaces.Overall, piezoelectricity is an interesting and useful phenomenon that has found widespread applications in various fields, contributing to the advancement of technology and our understanding of natural systems.

3.3.6. Shell type concept –Eco bottle.

The 6th validation draft was the Eco-bottle. The Eco bottle was the chosen as the final construction for many reasons. The most important reasons for this choice were because it met all the initial specifications demanded and, above all, more electricity generation could be achieved than all previous options. The Eco bottle was one of the bestsellers Tupperware products, so it was a an eye catching choice and for sure a memorable construction.

Figure 31. The main inspiration for the Eco-bottle.

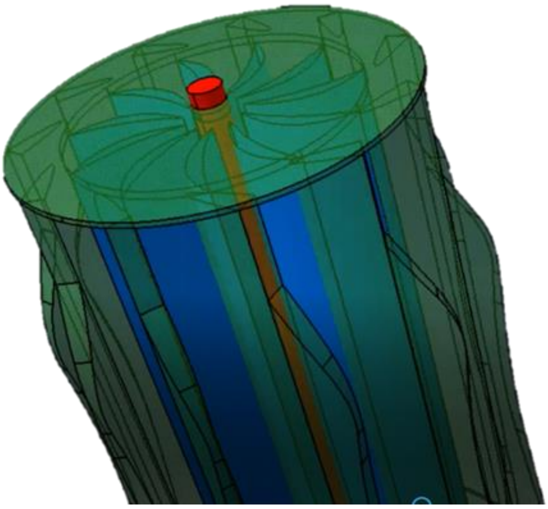

Figure 32. The blades and the material used for the WEC.

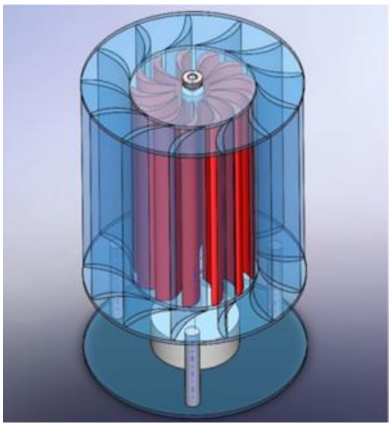

Figure 33. Safe to humans & birds

- low cut-in wind speed
- compact design
- scalable
- Low Sound emissions

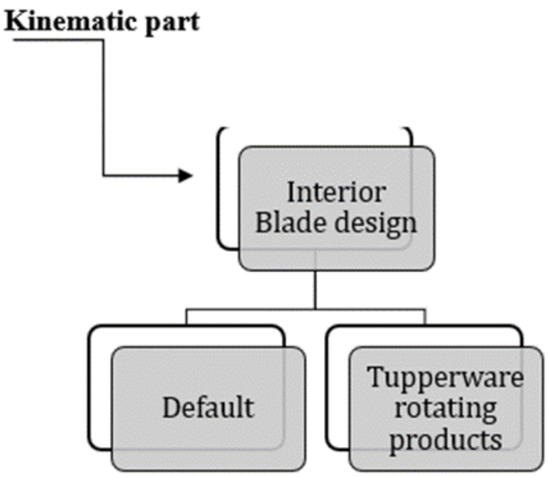

diagram 3.The kinematic part of the final structure.

Iinitially, there was a brief development and presentation of each energy final option. It was then sought which of these options was the best under the specific conditions required.Considering the weather conditions prevailing in Belgium in accordance with the criteria requested by the company, we came to the conclusion that the best choice would be the Eco-bottle Shape. At the same time , a rating was made for the specific characteristics that each construction had and so the final conclusion was made for the choice of construction.There are the scores of each possible energy alternative bellow such as the final decision.

Table 1. Scoring explanation: Advantages 0-->5 and Disadvantages 5-->0. So, for instance, if a concept is extremely expensive it will get 0 points in that section.

Criteria		Eco-bottle	E-tree	3D frame	Rainfall energy	Genealogical tree	Piezoelectric
Efficiency	solar	2	2,5	2,5	3,5	2,5	3,5
	wind	3,5	4	3	0	3	0
	hydro	0	0	0	2	0	3
Marketing story		4	4	3	5	4	4
Creativity/innovation		5	4	4	5	4	5
Cost		3,5	3	5	3,5	3	2
Scalable		4	4	5	3,5	5	3
Ease of implementation	Technical boundaries	3	2,5	3,5	3	2,5	3,5
	Legal boundaries	4	2	3	3	2	3,5

Climatological boundaries		**3**	**3**	**3**	**3**	**3**	**3**
Total score		**32**	**29**	**32**	**31,5**	**29**	**30,5**

Into the next chapters, deciding where the produced green energy is going to be used is also considered to be part of this project.
First and foremost, keeping the initial proportions of the already existing eco-bottle is mandatory, since the construction will mimic this world wide bestseller product. Also, the structure is going to be optimized for relatively low wind speeds (average 5m/s) since the location of the site is not considered ideal due to the surrounding buildings (turbulent airflow).There are not any serious legal boundaries involved since the structure is considered to be safe both for the pedestrians and surrounding animals. Though, some kind of certification is needed in order to implement this construction.

3.4. Vertical Axis Wind Turbines.

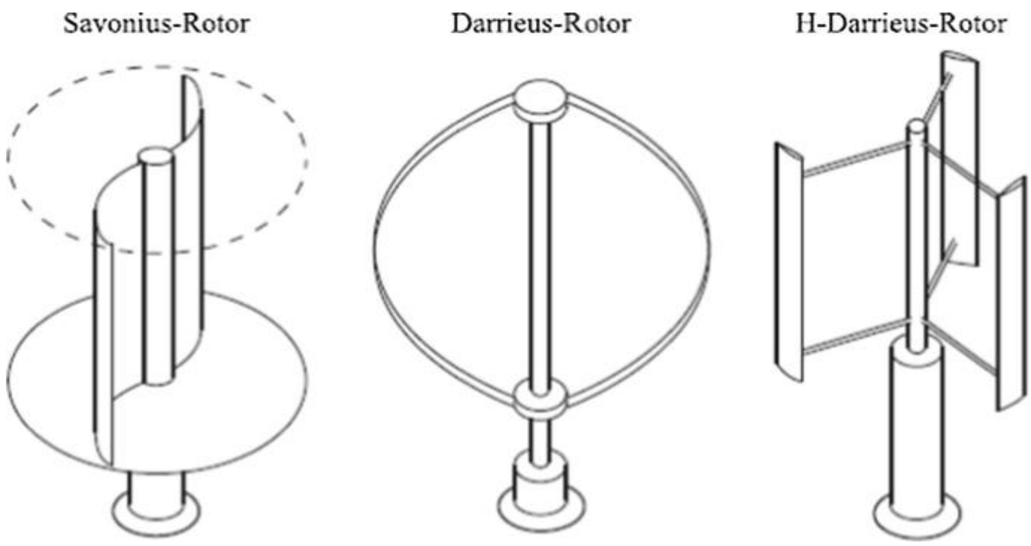

Figure 34.Different models of Vertical axis wind turbines. (Menet, 2004)

3.4.1. Savonius

Finnish engineer Sigurd Savonius invented the type of wind turbine that bears his name. Savonius wind turbines, also known as "S-rotor" wind turbines, have a sigmoidal rotor and are characterised by a vertical axis of rotation and semi-cylindrical or cup-shaped blades. The simple geometry of this type of wind turbine is an advantage that reduces the manufacturing costs. The power output can be increased or reduced by deforming the rotor blades. The geometric shape of the blades has a significant effect on power generation.Savonius wind turbines have a high starting torque, but they cannot rotate faster than the speed of the wind. The operating principle is based on the fact that the blade niche has a higher aerodynamic drag than the curved blade when the wind hits. This difference in forces, combined with the air 'returning' through the gap, leads to the rotational drive of the wind turbine.

The Savonius type offers high starting torque, but consumes more air than other types of wind turbines. This means that the efficient speed-to-air ratio is lower. Nevertheless, the Savonius is a reliable solution because of its high starting torque and can be used to generate electricity. Its simple geometry and the adaptability of the rotor blades make the Savonius wind turbine an economical and reliable choice for sustainable wind energy production.

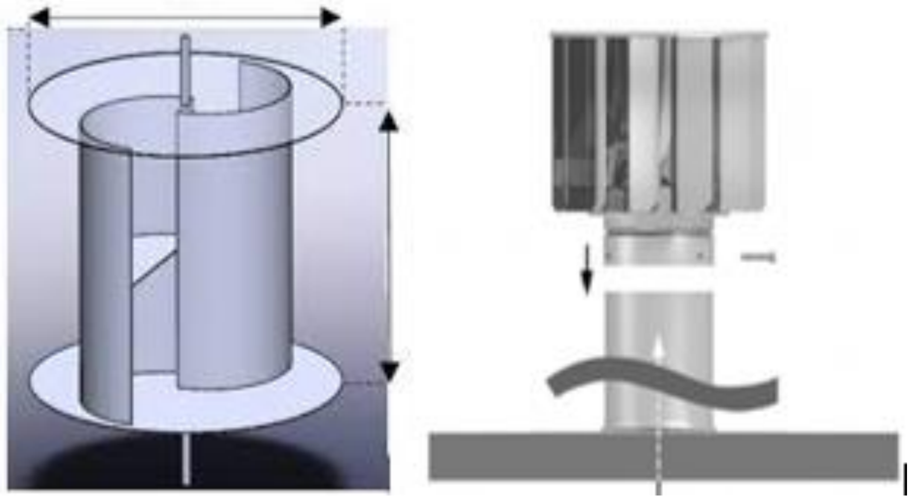

Figure 35. Savonius rotor, left. A Vawt with many blades ,right.(Menet et al, 2004)

Nowadays this type of fins are used only in special applications, such as the manufacture of small water pumps as it has many restrictions about the utilization of wind potential and that’s why the maximum power factor reaches 0.25, a value that cannot compete with the performance of modern wind turbines.

Many studies have confirmed that Bach-type blades are more effective than other types of blades, such as semicircle, Benesh, and elliptical blades. They have also shown that the modified Bach-type blades have even better performance than the original Bach-type blades. These studies have demonstrated that the use of Bach-type blades can significantly improve the power generation of Savonius wind turbine.

According to several studies carried out, Bach blades and their modified versions are an alternative to improve the performance of the Savonius wind turbine. A numerical and experimental study conducted by Alom and Saha (2019) indicated that the modified Bach blades showed better performance compared to the semicircular and Benesh types. Also, the elliptical type vanes showed the best

performance. Another experimental project by Roy and Saha (2015) also demonstrated the effectiveness of modified Bach wings.
They compared the aerodynamic performance of two-bladed wings to the same profile characteristics with four other types and reported that the modified Bach wings were more efficient than the other cases.
Finally, Scheaua's (2020) study focused on evaluating the geometric parameters of Bach and Benesh blades in the power generation of the Savonius wind turbine. This study showed that the Bach blades performed better than the Benesh blades, with the modified Bach model offering a 4% higher power factor compared to the classical Bach model under specific conditions.

3.4.2. Darrieus

The first vertical axis wind turbine was invented and designed by the French engineer George Darrieus in 1931 in Canada. There are two designs, the primary one being the fins egg-shaped and the other with vertical fins (H-Darrieus).In the original design there were two curved fins symmetrical about the vertical axis. It has relatively low starting torque, but it cannot start by itself when the wind is blowing. That is why it is usually combined with a small Savonius type wind turbine so that starts to move, or a third fin is added to achieve autonomy starting or by external excitation through the electrical network where it is connected. Each type of Darrieus wind turbine consists of two or more symmetrical blades in shape of an airfoil, which are attached to the axis of rotation. The air passing through the fins creates aerodynamic lift, due to positive angle of attack that they face relative to the flow, resulting the wind turbine’s rotation.

Figure 36. Darrieus Vertical Axis Wind Turbine.
Source:https://www.symscape.com/

A wide range of airfoil shapes and aerodynamic parameters have been studied in relation to Darrieus turbines, with the goal of finding the optimal design for maximum performance and efficiency. The studies concluded that the airfoil shape and its aerodynamic parameters play an important role in the performance of Darrieus turbines. Other studies have also been done on various airfoil types for Darrieus turbines, with similar conclusions. Overall, it seems that different airfoil shapes and aerodynamic parameters can have a significant impact on the performance of Darrieus turbines.

Apparently, the results showed that as the pitch angle increased, the power coefficient also increased, up to a certain point, after which it began to decrease. The study concluded that the optimal number of blades and pitch angle for a Darrieus wind turbine depend on the specific operating conditions, such as the TSR and solidity, and that further research is needed to fully understand the complex interactions between these factors and the turbine's aerodynamic performance.

The study by Sepehrianazar et al.(2019) focused on the impact of urban microscale wind flow on the performance of a two-bladed Darrieus wind turbine. The authors found that the placement of the turbine between two high-rise buildings was crucial for its efficiency, and that by optimizing the turbine's position, its efficiency could be improved by up to 21.8%. Additionally, the study acknowledged the issue of dynamic stall, which is a phenomenon that occurs when the turbine blades experience a sudden change in the angle of attack during rotation, leading to a decrease in power generation. The authors suggested that further research is needed to understand how to mitigate the effects of dynamic stall on the performance of Darrieus wind turbines.

One of the main challenges associated with designing and operating a Darrieus turbine is the constant change of angle of attack experienced by the blades as they rotate. This creates cyclic loading on the blades, making it difficult to design them to withstand these loads. Additionally, the speed of rotation of the turbine is usually higher than the wind speed, which can cause the turbine to experience dynamic stall, reducing its efficiency. Another significant drawback of the Darrieus turbine is its difficulty in self-starting. This is due to the symmetrical design of the airfoils, which makes it hard to generate the necessary torque to initiate rotation. This problem is being addressed through the use of new airfoil designs and control strategies that are intended to improve the self-starting capabilities of the Darrieus turbine.
Overall, the Darrieus turbine has many potential advantages, including its ability to operate in low wind speeds, its relatively simple structure, and its high efficiency. However, there are still many challenges associated with its design and operation that need to be addressed to improve its performance and reliability.

3.4.3. Giromill

The Darrieus-type vertical axis wind turbine (VAWT) is a promising type of wind energy technology and has become increasingly popular due to its ability to generate a substantial amount of energy from the wind. It is characterized by two or more aerofoil-shaped blades which rotate around a vertical axis. The blades are designed to generate lift, pulling the blades along and consequently driving the turbine. The Fig.36 bellow demonstrate the H-Darrieus concept although the eggbeater-type Darrieus VAWT is the most common type and is known to reduce bending stress in the blades. This variation of the Darrieus concept has been successfully deployed in various areas of California in the past Giromill or H-rotor type wind turbines were also designed by George Darrieus in 1927. In these vertical axis wind turbines, the type fins (egg beater) used in common Darrieus is replaced with vertical vanes which are connected to the axis of rotation through horizontal supports. The specific arrangement of the fins achieved the protection of the structure from the bending of the fins due to developing centrifugal forces. A typical H-rotor vertical axis wind turbine is shown in the figure below:

Figure 37. A giromill VAWT.

It consists of the vertical axis of rotation, the support arms and the fins which are supported in such a way that their axis is parallel to the axis of rotation.

The H-Rotor is a type of vertical axis wind turbine (VAWT) developed in the United Kingdom during the 1970s and 1980s. It was developed as an alternative to the straight-bladed Darrieus VAWT, as its complex mechanism used to feather the blades was found to be unnecessary. Instead, it relies on the drag and stall effect created by the blades leaving the wind flow, which restricts the speed the opposing blades can propel the whole configuration forward. As a result, the H-Rotor is self-regulating and efficient, reaching its optimal rotational speed shortly after its cut-in wind speed. Furthermore, due to its low profile and small size, it is an ideal option for offshore applications, as it can be installed with minimal seabed disturbance. The advantages of this type are the high initial torque, constant curvature and they also have a higher coefficient of performance. In addition, H rotor wind turbines are more efficient when operating in storms and the blades can bend more easily. The development of small-scale wind turbines has been hampered by the lack of reliable information on the performance of these products and the claims made by the manufacturers. While research on the straight-bladed Darrieus VAWT has yielded promising results, such as its potential to overcome the starting torque problem, the complicated design of the variable pitch blade configuration has rendered it impractical for smaller capacity applications. For this reason, the simple straight-bladed Darrieus is more attractive for small-scale wind turbines, with some companies marketing related products like the Pinson/Asi cycle turbine. This configuration falls into two categories: fixed pitch and variable pitch. Fixed pitch VAWTs have been found to provide inadequate starting torque, however, as opposed to the more complex variable pitch blade configuration.

With further research and development, the simple straight-bladed Darrieus VAWT may become increasingly attractive for small-scale wind turbines, provided adequate information on the performance of the products and the claims made by the manufacturers can be obtained. By improving their understanding of the aerodynamic factors which inhibit the self-starting process, engineers may be able to develop more efficient and cost-effective small-scale wind turbines in the near future.

3.4.4. Hybrid Wind Generation Darrius-Savonius

The vertical axis wind turbine hybrid model consists of two types of W/T on a common axis. This combination includes the advantages of both types of wind turbines.The hybrid vertical axis wind turbine model has much better auto-starting and conversion efficiency at higher flow rates.The advantage of the high starting torque presented by the Savonius wind turbine, exploited by the companies, which carry out a construction that combines in the same vertical axis both Savonius and Darrieus.This combination makes the wind turbine capable of producing useful power from low wind speeds. The efficiency of this particular model reaches 25%, meaning that Savonius can reduce Darrieus' performance at high speeds air as the latter alone achieves an efficiency of over 30%.The goal of these hybrid vertical axis wind turbines (VAWTs) designs is to improve the self-starting ability of Darrieus rotors, as well as to improve their power characteristics at various tip speed ratios (TSRs) and particularly at lower TSRs. These improvements are achieved by attaching a drag-based rotor to a primary lift-based rotor in a variety of different configurations. There has been limited research on hybrid VAWTs on the table below.

Table 2. Details of previous studies on hybrid wind turbines.(Asadi & Hassanzadeh, 2022)

Authors	Re	TSR	Internal rotor	External rotor	Number of blades		$\frac{D_2}{D_1}$	φ
					internal	external		
Gupta et al. (Gupta et al., 2008)	0 to 1.6×10^5	0.3 to 0.69	Bucket type G/d = 0,0.162,0.2	Egg-beater type	3	3	–	–
Mohamed (Mohamed, 2013)	4.3×10^5 to 6.1×10^5	0.5 to 5	Semi-circle	NACA 0012	2	2, 3	–	–
Bhuyan and Biswas (Bhuyan and Biswas, 2014)	1.4×10^5 to 2.3×10^5	2.1 to 3.3	Semi-circle G/d = 0, 0.1, 0.15 0.175, 0.2	NRELS 818	2	3	0.3	–
Ghosh et al. (Ghosh et al., 2015)	9.9×10^4	0.32 to 0.52	Semi-circle G/d = 0.168	Egg-beater type	3	3	1	–
Sahim et al. (Sahim et al., 2018)	1.6×10^5 to 4.3×10^5	0.1 to 2.7	Semi-circle	NACA 0020	2	2	0.3 to 0.8	90°
Jacob and Chatterjee (Jacob and Chatterjee, 2019)	3.6×10^5	1 to 2.4	Semi-circle G/d = 0	NACA 0018	2	3	0.66 0.33 0.18	–
Hosseini and Goudarzi (Hosseini and Goudarzi, 2019)	1.9×10^6	1 to 5	Bach type	NACA 0021	2	3	0.25	–
Liu et al. (Liu et al., 2019)	4.9×10^5	0.5 to 2.8	Modified Savonius	NACA 0015	3	3	0.28	–
Pallotta et al. (Pallotta et al., 2020)	4.5×10^4 to 2×10^5	0.3 to 4.5	Modified Bach	NACA 4418	2	3	0.46	–

Table 2 provides a brief overview of previous studies conducted on hybrid wind turbines, offering valuable insights into potential research gaps in this field. Gupta et al. (2008) conducted an experimental investigation into the impact of the overlap ratio of Savonius rotors on the performance of a hybrid rotor. In their study, they positioned the Savonius rotor above the Darrieus rotor. Their findings revealed that the maximum power coefficient was achieved when there was no overlap (zero-overlap ratio), with a value of 0.51.Past research on hybrid wind turbines has primarily concentrated on assessing the influence of various design parameters on system performance. For instance, Gupta et al. (2008) delved into the effects of the overlap ratio between a Savonius rotor and a Darrieus rotor on hybrid system performance, concluding that the highest power coefficient was obtained when there was no overlap, yielding a coefficient of 0.51.

In another study, Mohamed (2013) explored the advantages of employing a hybrid Vertical Axis Wind Turbine (VAWT) featuring a Darrieus rotor and an airfoil-based rotor in an H-shaped configuration. The results of this investigation indicated that the hybrid system exhibited improved performance compared to its individual components.It is essential to note that the studies mentioned here are just a few examples within the extensive body of research on hybrid wind turbines. Many more studies on this subject have likely been published, underscoring the continued interest and potential for further advancements in this field..

Previous studies have focused on using various techniques to improve the self-starting ability and power production of hybrid VAWTs. For example, Mohamed (2013) used a Savonius rotor in combination with a Darrieus rotor to improve self-starting ability and found that this technique was effective. Bhuyan and Biswas (2014) tested a three-bladed Darrieus rotor with non-symmetric blades and then used a Savonius rotor with conventional blades as an internal rotor to improve self-starting ability and power production. They also studied the effect of the overlap ratio between the Savonius blades on the performance of the hybrid rotor and found that an overlap ratio of 0.15 had the best performance. These are just a few examples of the ways in which previous studies have attempted to improve the performance of hybrid VAWTs

Chapter 4 Methodology Application

4.1. Block Diagram, main components and operation of the WEC

In the fig 37, there is a handwritten draft diagram of the main components and their placement in the structure:

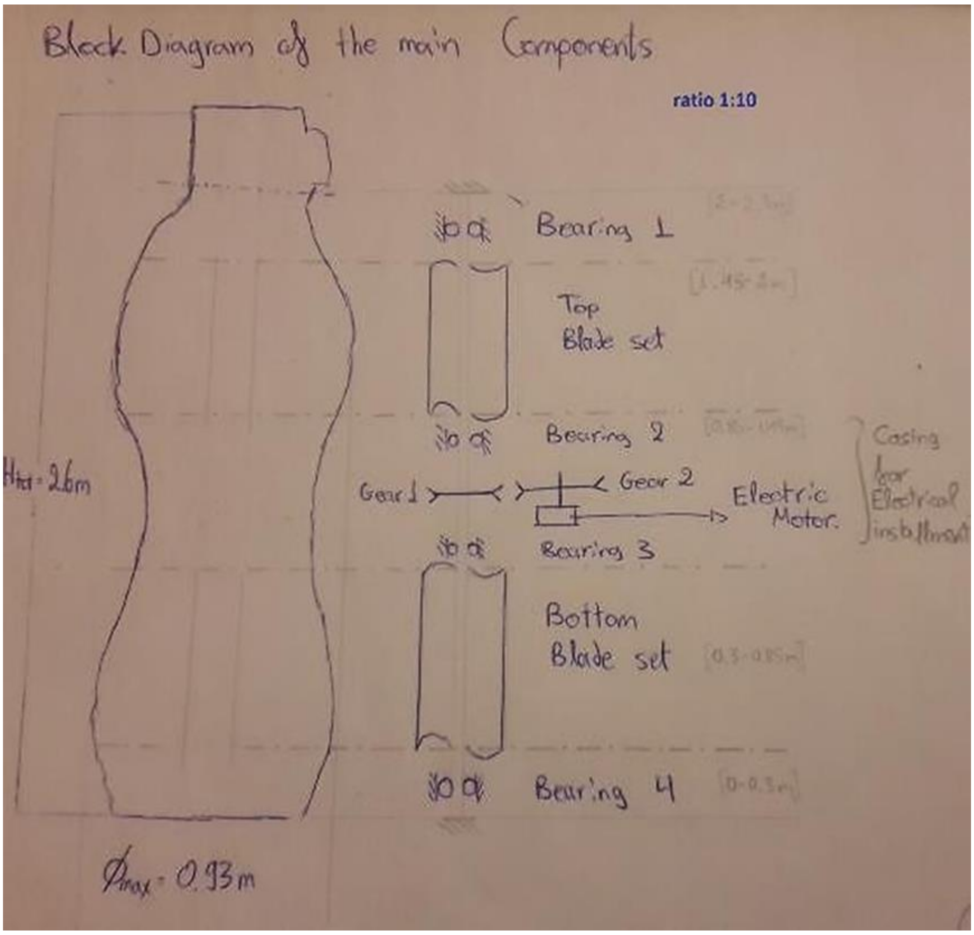

Figure 38. Block diagram of the main components

Moreover, the structure seen above was also designed using the ANSYS 2020 3D software, in order to make the idea clearer.

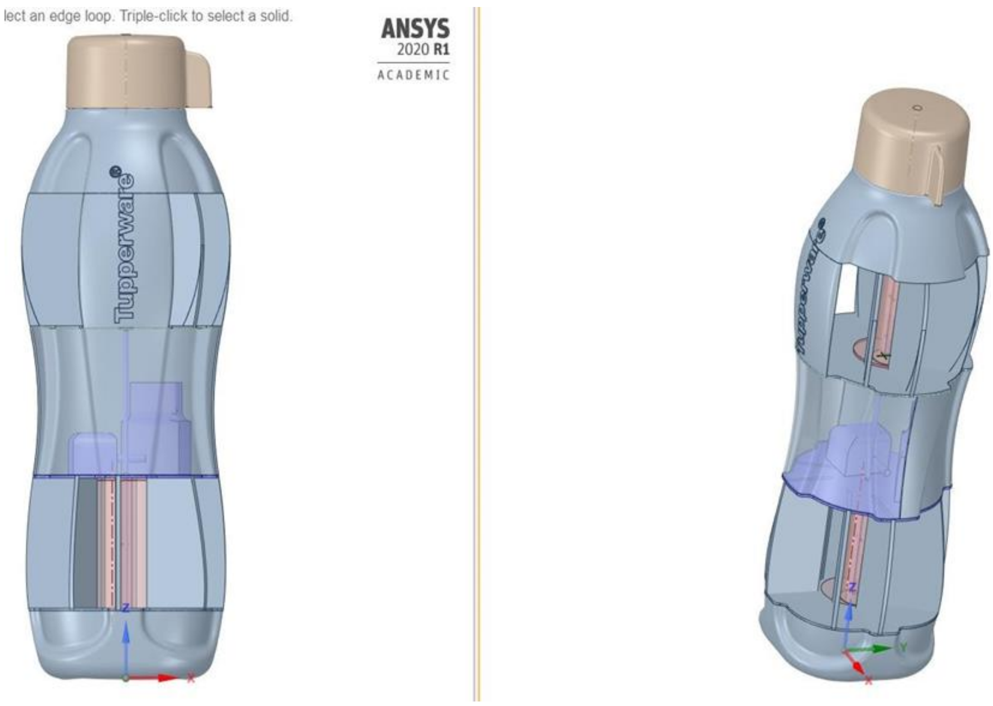

Figure 39. The final Eco- bottle – wind turbine designed in ANSYS 3D

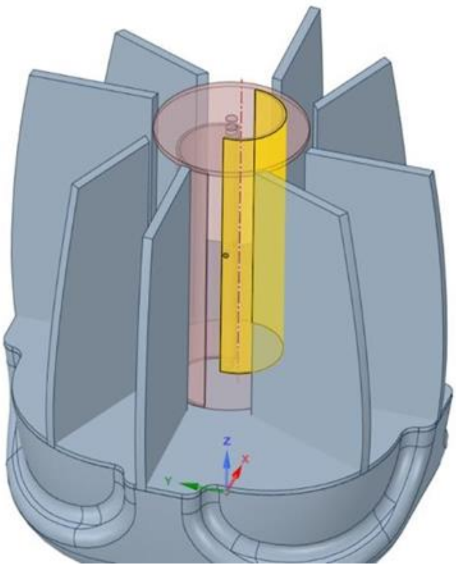

Figure 40. The rotor and blades of the final turbine

The above assembly(fig.38-39) design, seems functional, but in order to avoid any unwanted_vibrations from the middle of the structure where the motor is installed, which may shorten the overall lifespan, the motor is proposed to be placed at the bottom of the machine. That's why the following block diagram was introduced, hosting 2 alternatives for the rotor.

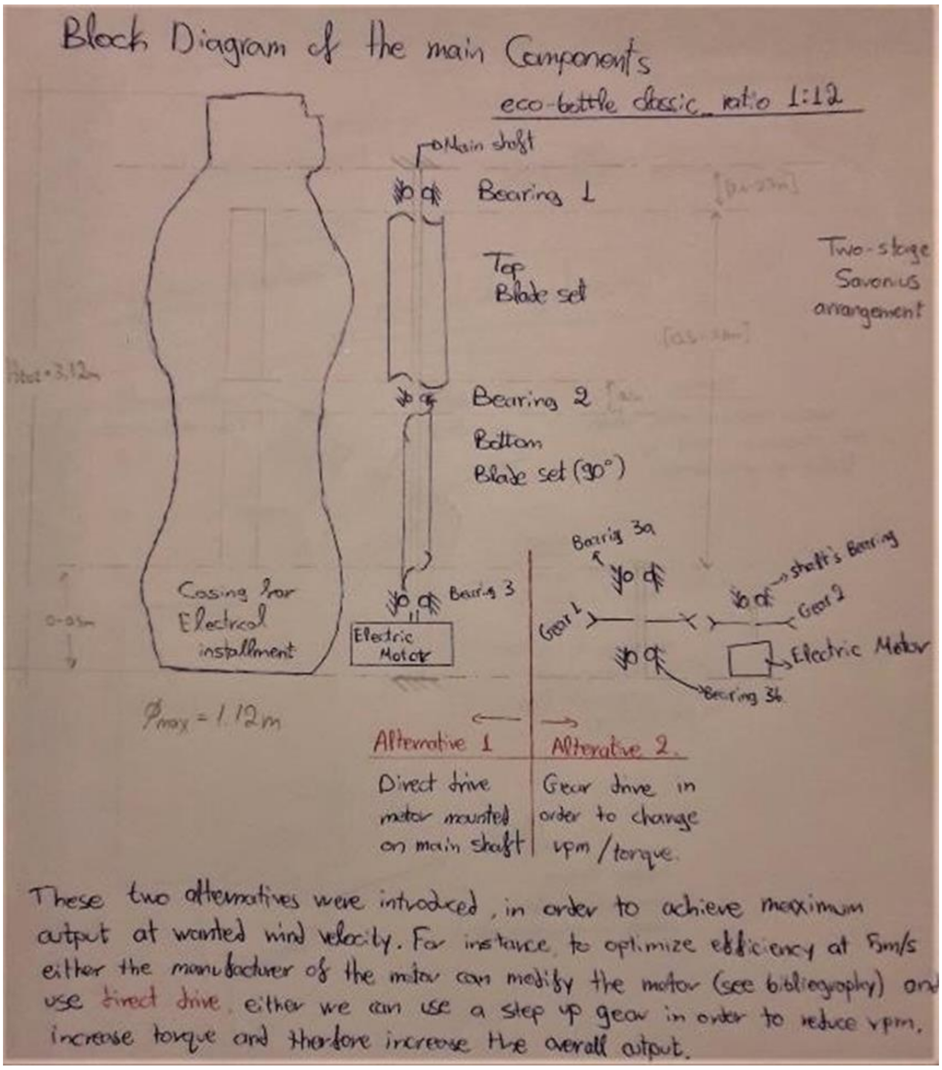

Figure 41. Block diagram and the two motor alternatives.

There two alternatives were introduced, in order to achieve maximum output at wanted wind velocity.
For instance to optimize efficiency at 5m/s either the manufacturer of the rotor can modify the motor and use direct drive, either a step up grow can be used I in order to reduce rpm, increase torque and therefore increase the overall output.

Table 3. The two motor alternatives

Alternative 1	Alternative 2
Direct drive motor mounted on main shaft.	Gear drive in order to change rpm/torque

4.2. Two-stage Savonius VAWT structure development

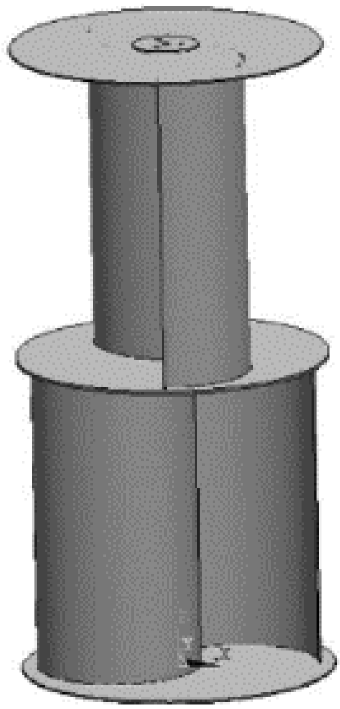

Figure 42. Scheme of the present prototype.(Menet, 2004)

As it is shown to the fig.11, the main idea behind this blade setup is to combine two identical Savonius type blade sets, but in a different orientation(90degrees).By this, we will be able to achieve a two-pulse configuration that will enhance the performance of the machine . Examining the diagram shown below, the starting torque coefficient of the two-stage rotor is never negative whatever the direction of the wind, and never around the value zero. Then, after each period without wind, the starting of the rotor will be facilitated.A good angular stability of the dynamic torque during the running of the rotor is also expected. Yet, between the blade sets, which will share the same shaft, a bearing will be installed so that the horizontal displacement gets diminished (the aspect ratio (AR) is considered high H/D=2/0.4=5).Also, end plates will be added as well, because they provide an increase in efficiency up to 10% when comparing a structure without end-plates.(Menet, 2004)

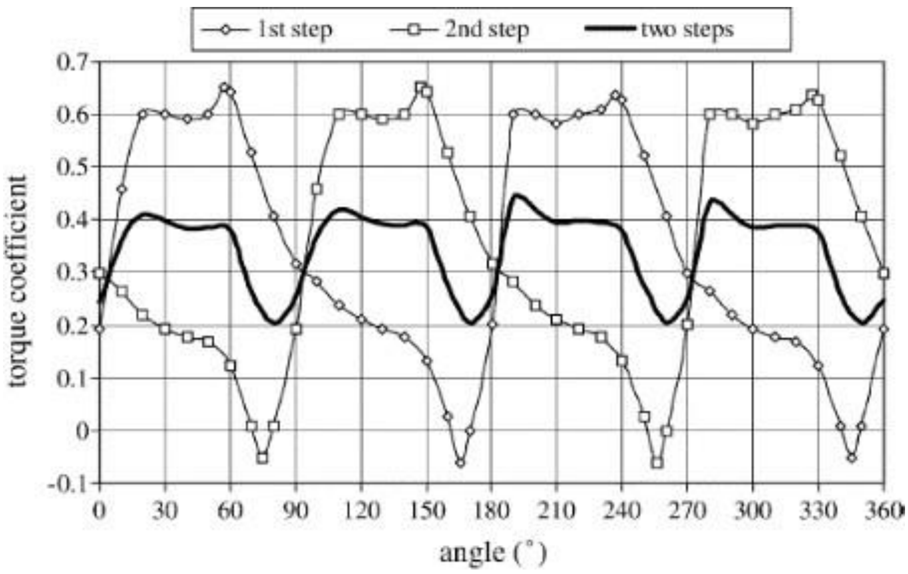

Figure 43. Expected starting torque for the present prototype.(Menet, 2004)

Also, details towards the design of the blades are going to be further developed below at rated wind speed of 10 m/s, but the setup will be optimized for wind velocity of 5m/s(maximum coefficient of performance Cp (coefficient of performance) and tip-speed ratio λ will be equal to 1 at this specific wind speed).

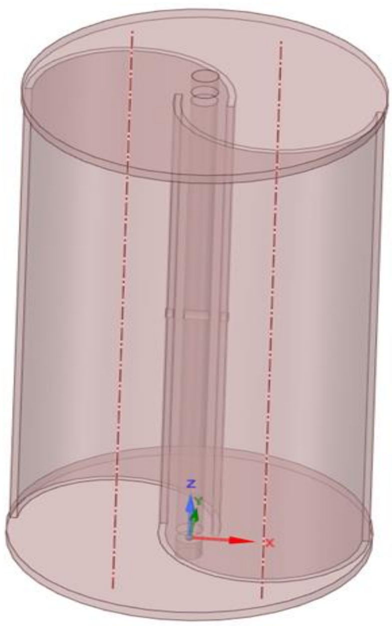

Figure 44.WEC's final rotor and blades, designed in ANSYS 3D.

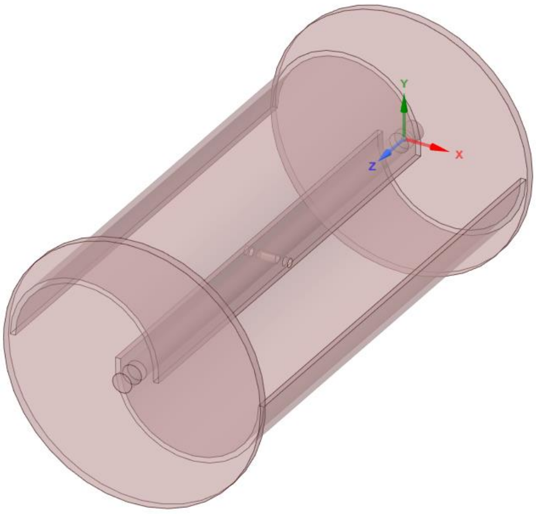

Figure 45.WEC’s final rotor and blades ,designed in ANSYS 3D.

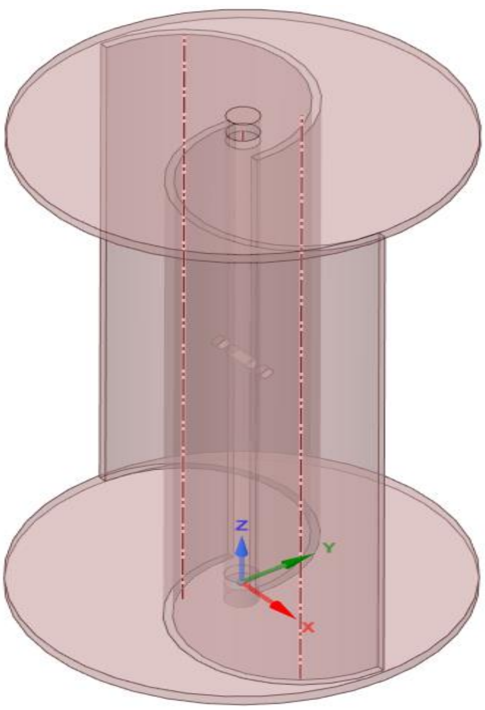

Figure 46. WEC’s final rotor and blades ,designed in ANSYS 3D.

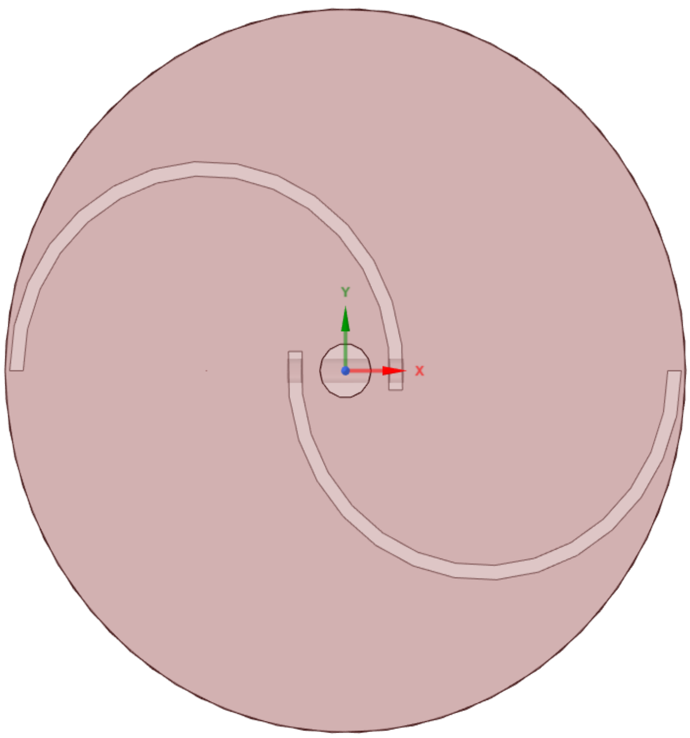

Figure 47.WEC's final rotor ,designed in ANSYS 3D,

- The dimensions in total are 600mm high and 400mm in diameter
- The geometry in the figure below is two terminal flanges and the wings are two semicircles.
- We consider 1200 rpm as maximum speeds
- Maximum load at 1.5kN which is applied in the center of each semicircle (<-
- Resistance to external environment (radiation, humidity).
- Life expectancy 10-15 years
- Construction of two pieces

Material selection of the rotor blades will be defined after the component analysis in the next chapter,but structural composite materials and aluminium alloys are being considered (light weight materials, providing that they suit the load and stress requirements).

4.2.1. Technology of Guiding Barriers (GB)

Introducing the exterior guiding barriers, we can improve performance and increase the efficiency of the Savonius rotor without changing the basic structure of the rotor. The main idea behind this is to minimize the negative torque by directing the air flow exclusively to the advancing blade. Numerous studies have shown that by this configuration, Cp was improved up to an increase of 38%(Mahmoud et al, 2012).

Except the improvement in performance, this innovative setup, is protecting both the rotor from weather conditions and humans or animals from the rotor itself.

Finally, do not forget that thanks to the guiding barriers we can mimic the eco-bottle's curves. The material of the guiding barriers is yet to be defined, since individual load analysis of each component is going to be developed bellow, but composite materials and aluminium

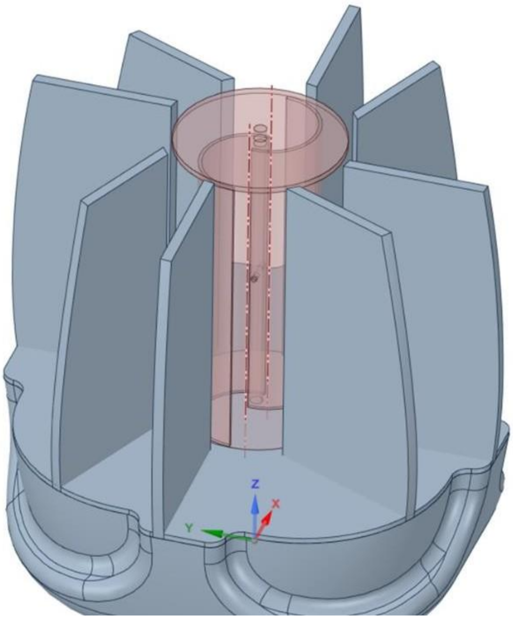

Figure 48. final rotor and final blades

4.2.2. Motion, power and load analysis of the Web

In this section, some basic equations are going to be used, to find out what are the capabilities of this setup. But it should be mentioned, that due to some assumptions, there is a possibility that results may differ onto some point. Once the design is finished, this step can be repeated in order to confirm or not these first calculations.

Chapter 5 Results

5.1. Power output usage

Firstly, we will calculate the available energy at are refence point of 10m/s. According to Betz'sLaw, we can see that:

$$P_{available} = \frac{1}{2}\rho A v^3$$
$$P_{available} = \frac{1}{2} * 1.224 * 2.2 * 0.4 * 10^3$$

$$P_{available=} 538{,}56 watt$$

where, ρ is the air density (1.224 kg/m^3) and A (A=H*D) is the sweep area of the rotor blade. From the available wind energy, only a percentage is considered as extra ctable power Protor:

$$P_{rotor} = \frac{1}{2}\rho A v^3\, C_p$$

$$P_{rotor} = \frac{1}{2} \cdot 1.224 \cdot 2.2 \cdot 0.4 \cdot\ 10^3 \cdot 0.4$$

where Cp is the coefficient of performance the structure (it cannot be higher than 0.593 as Betz mentions).
At common VAWTs, this coefficient is around 0.2 to 0.3, but we will considerourstobe0.4thanks to the guiding barriers added.

□□□□□□□= ½ ·1.224·2.2·0.4· 10^3·0.4

□□□□□□=538.56·0.4

□□□□□□≅□□□.□□ □□□□

What's more, we expect the generator's efficiency to be around 80% so our final output is expected to be:

□□□□□□=□□□.□□ □□□□

Wind power, once converted to electricity, will then be stored in batteries to be harnessed. The Eco-Bottle wind turbine will produce P_{final}=172.34.The basic thought was initially that the energy produced could be serviced and harnessed by the plant's employees. So if you assume that a mobile phone needs a 15 watt charger to charge, about 8-9 people will be able to charge their mobile phone or 2-3 people will be able to charge their laptop.

The upper wattage value leads to the following energy production:

- Per day:4.14kWh
- Per month:124.085kWh
- Per year:1490kWh

The amount of the annual energy output, gets further understood by the following table:

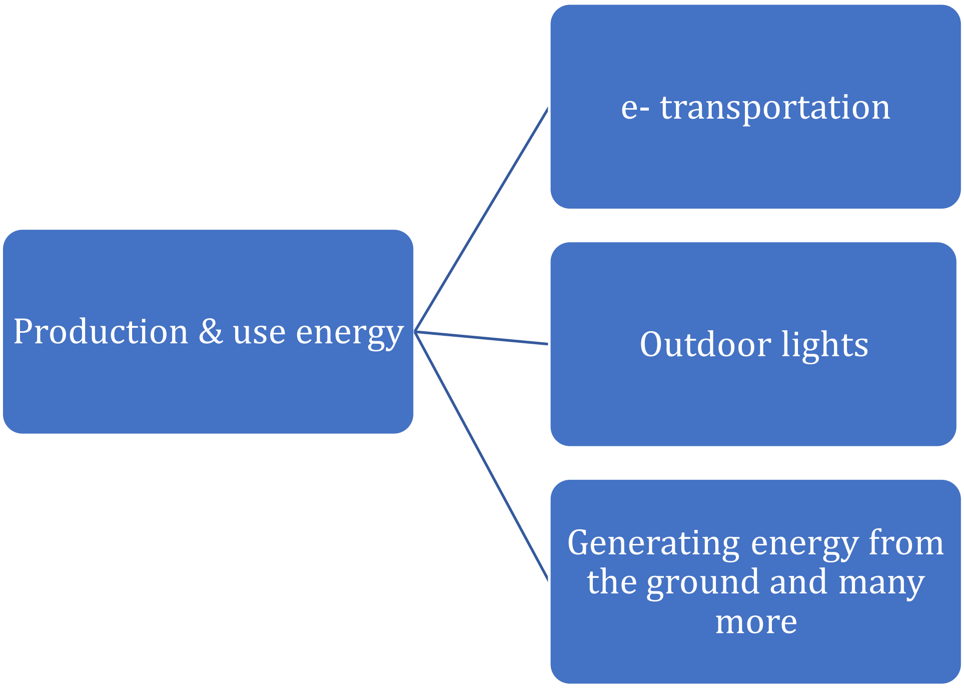

diagram 4. Alternative proposals for the output usage.

The diagram 4 suggests different ways of using the generated electricity. In the context of eco-mobility and since the construction is based on res, apart from making it easier for employees or visitors to be able to charge the electrical devices. Then a calculation was made as it seems below on how many e-bikes, e-cars and e-scooters will be able to charge so as to encourage the employees to choose other, more ecological forms of transportation from the car from the moment they can charge it at work using res.The second alternative is to use e-energy, is its utilization in order to place lights in the outside area of the factory, which will be supplied by the Wind converter. We could mount one small vertical axis wind turbine on each flag (and add the appropriate lighting on it).Another alternative is generating energy from the ground . Passageway could be the main artery and the other parts of the plant can be the veins Piezoelectric effect could be up to 5w per footstep. The piezoelectric floor on entrance or solar panel on the passageway.

Table 4. Transport proposals using the generated electricity

Machine	Energy consumption	Charges per year	Charges per month
smartphon e	0.015kWh/charge	99,268	8,272km
e-bike	0.8kWh/100km	186,250km	15,500km
e-scooter	1.44kWh/100km	103,472km	8,622km
e-car	18.6kWh/100km	8,005km	667km

In the table 4 we see an assumption regarding the quantity of transportation vehicles that can be used daily from the company's personnel for a range of **10km and 20km.**

Town of Aalst to site: 5(10) km + 5(10) km = 10(20) km total daily.

So, 5 days a week*4weeks=20dayspermonth

- e-bike:15,500/20/10(20) =78(39)bikes daily
- e-scooter: 8,622/20/10(20) = 43(21) scooters daily
- e-car:667/20/10(20)=3(1.5)e-cars daily

From the above calculations we lead to the following results:

10km daily:

- 78 employees can commute to work via an e-bike daily
- 43 employees can commute to work via an e-scooter daily
- 3 employees can commute to work via an e-car daily

20km daily:

- 39 employees can commute to work via an e-bike daily
- 21employees can commute to work via an e-scooter daily
- 1employeecancommutetoworkviaane-cardaily

The above, are examples where the produced energy could be used. Other ideas can be suitable as well such is the lighting of the parking lot at Belgium's site or a part of the building exterior lighting.

5.2. Cost analysis

Before proceeding to the cost analysis, it should be mentioned that this paragraph originally comes after the analytical component analysis. That is, because each individual analysis is going to define if the recommended materials can be used or not. Moreover, due to the circumstances that occur due to covid-19, companies and suppliers weren't so easily responsive to our questions towards material fabrication. However, we managed to contact via email with relevant companies that supply materials suitable for wind turbine construction to get approximately a price about the final cost. Therefore, the following values were obtained by giving the final dimensions of the prototype wind generator to the respective companies that had the materials we wanted. In the following table 5, we can see a range of pricing for the main components of the structure, based on the research made in the market.

Table 5.A rank of main components' prices

Item	Pieces	Price(€)
Motor	1	500
Frame(+cutting)	1	400-600
Bearings	3	3x15
Blade set	2	2x400
Shaft	1	40
Gear set	2	2x40
Others(+personnel)	-	400-600
Maximum Overall		**2,600€**

5.2.1. Motor selection options

While buying an engine, a buyer needs to keep certain parameters in mind. The voltage, the current and the torque are the triptych which is essential for the appropriate choice. More specifically, the current is what feeds or can damage the motor. Voltage is responsible for maintaining net current. Torque is a key part as the original design torque estimate needs to be checked.

The main objective of the prototype was to convert mechanical torque into electricity. The slow operation of the Savonius rotors created a problem and several solutions were considered. It was decided to use a conventional car alternator with an electrical power of about 80 Car alternators had the advantage of low price and high reliability. However, they operated and produced electricity at high rotational speeds, whereas the speed expected for the prototype was about 400 rpm. One solution was to increase the rotational speed of the rotor by using a stepped gear. However, this solution was complex and had low efficiency. Therefore, it was preferred to restart a conventional car generator using a conventional electrical method. Another alternative was to use ceramic magnets, but their price was quite high. The car alternator used was a modified Ford A127 12V 55A.

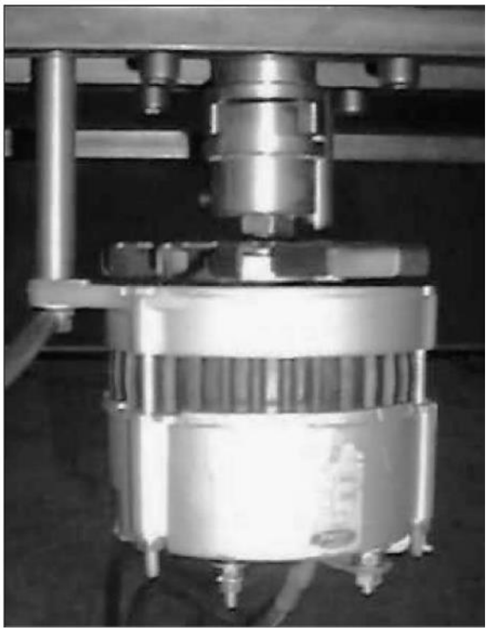

Figure 49. The modified car-alternator under the structure.(Menet, 2004)

5.2.2. Frame[Guiding Barrier, top &bottom cup, motor casing]options

The whole frame on which the rotor was implanted has not been completely designed. Particularly, it needs to withstand mechanical stresses and provide stability to the rotor. The purpose of the study is to conduct experimental measurements in real wind conditions, so a basic "minimalist" frame has been constructed for this purpose. The recommended materials for the frame include metal plates-sheets made of stainless steel (304/316/410) and aluminum alloy (ex. 3105).mechanical stresses and assure a complete stability to the rotor. For our study, we have just built a ‘‘minimalist’’ frame in order to make some experimental measurements in real wind conditions. The material suggested for the whole frame is metal plates-sheets (stainless steel304/316/410), aluminum alloy(ex.3105).

5.2.3. Bearing options

The bearings have been calculated based on the following factors:

• the bearings will be subjected to dust and humidity as they are intended for use outdoors.

•they must operate continuously for several thousand hours.

• they must withstand mechanical stresses

caused by the weight of the rotor, centrifugal forces, and resistance of the rotor (particularly in case of significant wind speed differences).

The first two criteria have guided us in selecting SKF S6203-2RS ball bearings. The third criterion determined the length l between the two bearings on the shaft of the rotor: l=50cm. At this length, the bearings are anticipated to last for 120,000 hours, which is more than ten years under normal operational conditions.

5.2.4. Gear selection

To assemble the rotor shaft and modified alternator shaft properly, we recommend using a flexible coupling known as the JFLEX S50 VKR. This coupling is highly efficient in transferring mechanical torque and compensating for any alignment errors between the two shafts. Additionally, it is capable of effectively dissipating mechanical vibrations..

5.2.5. The storage of electric power -batteries.

For our prototype structure, we should have used stationary or semi-stationary batteries, commonly referred to as "slow discharge batteries." This type of accumulator allows for frequent charges and discharges, making it well-suited for applications like wind electricity generation. However, it's important to note that these batteries come at a higher cost, approximately double that of conventional batteries. Given that our prototype is intended for initial testing over a relatively short period, we have opted for the more economical conventional battery. It's worth mentioning that our system has been designed to accommodate both types of

12 V batteries. Furthermore, when selecting the diameter of the wire used to connect the modified alternator to the existing battery, it's crucial to choose a wire that can handle high electric currents. This is particularly important to ensure the safe and efficient operation of our system.

5.2.6. Blade material options

Composite materials are often used in wind turbines for blades and nacelles. The blades are the most important and costly part of a wind turbine and consist of two surfaces that are attached to each other. The blades are reinforced with composite materials such as CFRP and GFRP, which are fibre-reinforced. The properties of these materials differ: CFRP is lightweight and has a low density, while GFRP has a medium weight and medium density. The use of these materials offers many advantages, such as reducing the weight and improving the aerodynamics of the wind turbine. In addition, the fibres can be arranged in different orientations to enhance the strength and safety of the GFRP material. Overall, the use of composite materials in the construction of wind turbines brings economic and technical advantages.

Variant Information about Eco-Bottle.

Estimated specifications:

- Starting wind speed:1.5m/s
- Cut-inspeed:2m/s
- Rated wind speed:10m/s
- Safe wind speed(cutout):24m/s

Design with respect to Category 1-2storms (up to 50m/s).

5.3. Future goals

There are a few steps missing to construct this idea:

- Design and Engineering (CAD/CAM)
- Energy output & cost validation
- Prototype testing and feedback
- Manufacturing

Chapter 6 Conclusion -Proposals

The present work was based on the emergence of innovative methods of wind turbines in relation to the company Tupperware Brands. The process of creating such a wind turbine is a difficult and expensive process. The positive thing is that its innovation led to the emergence of a new model with less energy losses.

It would be good to take care of highlighting new technological research related to the construction and highlighting of new models of wind turbines. Research needs to take place in different places and countries in order to achieve the creation of a structure that stores without channelling the excess energy. The inclusion of more wind turbines can also help save environmental resources. The planet has been strained by human actions, let the effort be made to exploit the environment without negative consequences for it.

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