PATHWAY TO NET ZERO

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"For the Energy sector, what is the most responsible path to reach net zero and beyond?"

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Introduction

What is Net Zero?

Net Zero is a global commitment to reduce global greenhouse emissions, as close to zero as possible, with the remaining emissions then being absorbed by the environment.

Why Net Zero?

Earth's temperature has risen by an average of 0.06° Celsius per decade since 1850. Changes to global temperature can have severe problems for the environment, the sea and land will be unable to sustain life, leading to plant and animal life extinction due to their natural habitat becoming inhospitable. By 2030, the global CO2 emission is projected to increase by 9% based on current national action plans. However, CO2 emission must be reduced by 45% before 2030 to keep the global temperature from increasing by 1.5° Celsius.

Due to human activity and advancements in technology, CO2 emissions have increased to unprecedented levels, which has led to a rise in global temperature and other implications for the environment. In recent years governments have invested in projects to lower CO2 emissions by utilising alternative energy sources. Net Zero is a significant challenge that will require collaboration between not just nations but also communities. It is a challenge that requires a complete transformation of how we live, produce, and consume. It is a growing coalition with over 140 countries pledging to halve global emissions by 2030 and become Net Zero by 2050.

One of the ways to Net Zero is by encouraging the use of renewable energy. Although alternative energy sources such as wind, thermal, and hydropower are already in use, only 14% of primary energy is sourced from renewable technologies.

	Fossil CO_2 emissions (kt_{CO2}/year)		**% of World**
	1990	**2022**	**2022**
China	910,077.7	12,667,428.4	32.88%
USA	4,595,406.7	4,853,780.2	12.60%
EU	3,488,583	2,804,806	7.28%
India	213,947.3	2,693,034.1	6.99%
Russia	1,413,943.0	1,909,039.3	4.96%
Japan	848,591.0	1,082,645.4	2.81%

Figure 1.1: Top countries (including EU) CO2 emission data extracted from Crippa et al (2023).

The top five countries with the highest CO2 emissions are responsible for 60% of global greenhouse gas emissions (CO2), however, their renewable sources only account for 6.7% to 16% of their energy consumption.

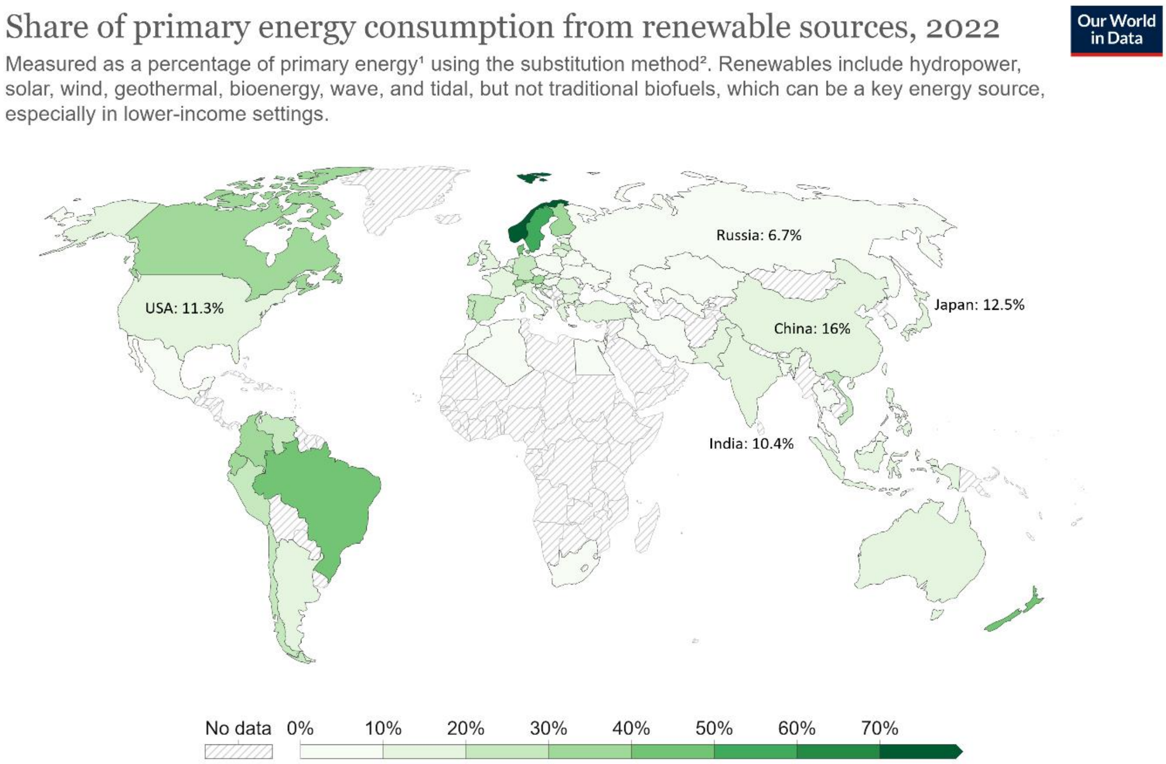


Figure 1.2: Share of primary energy consumption from renewable sources, adapted from Ritchie et al (2020).

This report will discuss the following renewable energy sources:

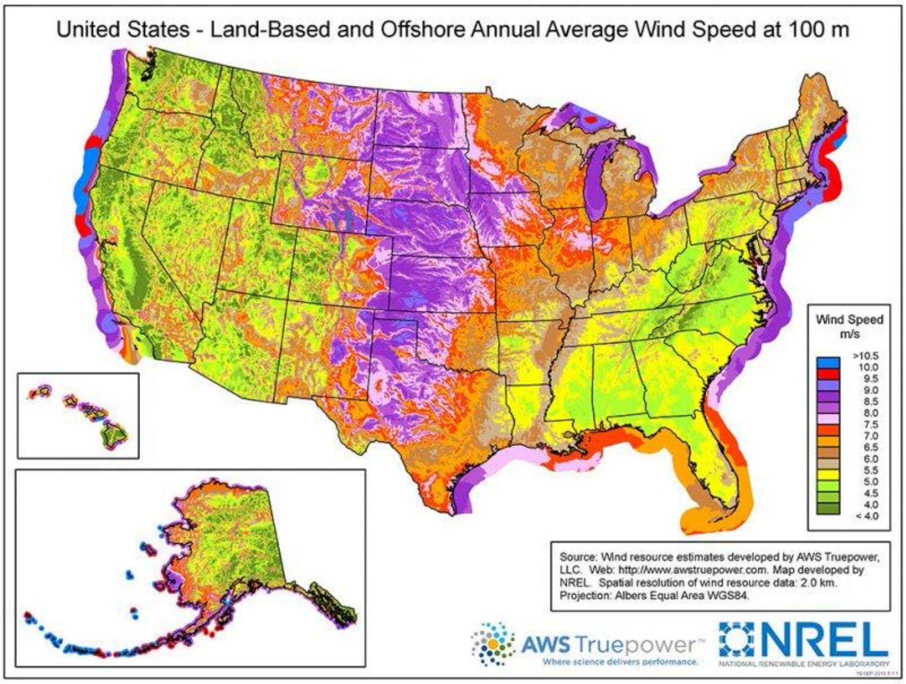
- Wind
- Bioenergy Carbon Capture Storage
- Solar Thermal

To identify the most responsible path to net zero in the energy sector is by focusing on the utilisation of renewable energy and its innovative technologies. Additionally, this report will also discuss the advantages and disadvantages of each approach along with the accompanying policies and recommendations for the transition towards a sustainable future.

Renewable Energy Sources

Wind Energy

Wind energy is the 4th largest energy source and the 3rd largest electricity generator in the USA (10.1%), it is expected to grow from 1900 TWh/yr (7% of the world's energy) to 12,000 TWh/yr (25%) in the next two decades (ACP, 2023; GE, 2024).



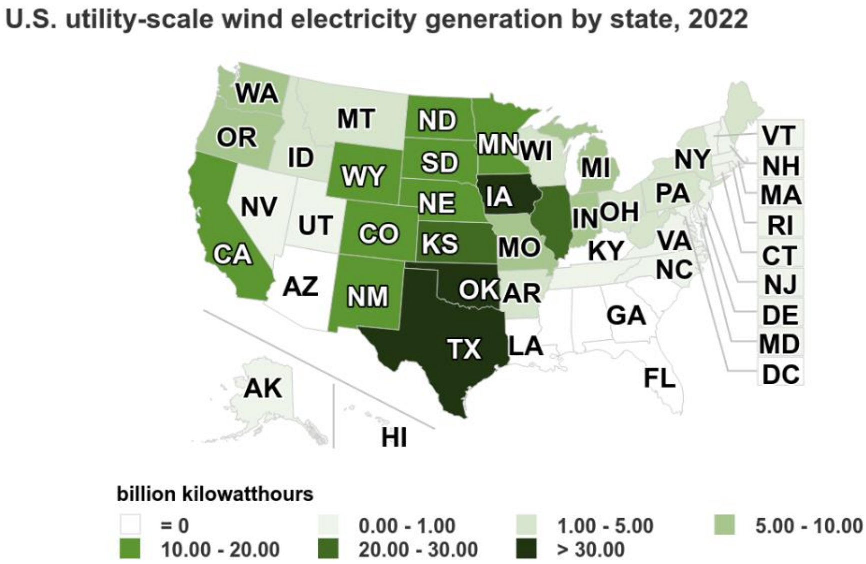


Figure 2.1: Map of average wind speed in the US (green = low, pink= higher) from NREL (2013).
Figure 2.2: Map of wind electricity generation by state. (light = low, dark = higher) from EIA (2023).

Wind farms require an annual average wind speed of 13 mph (5.8 m/s) for utility-scale turbines. For smaller wind farms at least 9 mph (4.0 m/s) is needed. The ideal farm sites include the top of hills, open plains, water (coastal and offshore), and mountain gaps that funnel and intensify wind. In the US, the Midwest and Great Plains are the optimal environments for this technology. Wind speeds are generally greater, the further high up in altitude, large wind turbines are placed on towers that range from about 500 feet to as high as 900 feet tall (EIA, 2023; Roy and Traiteur, 2010).

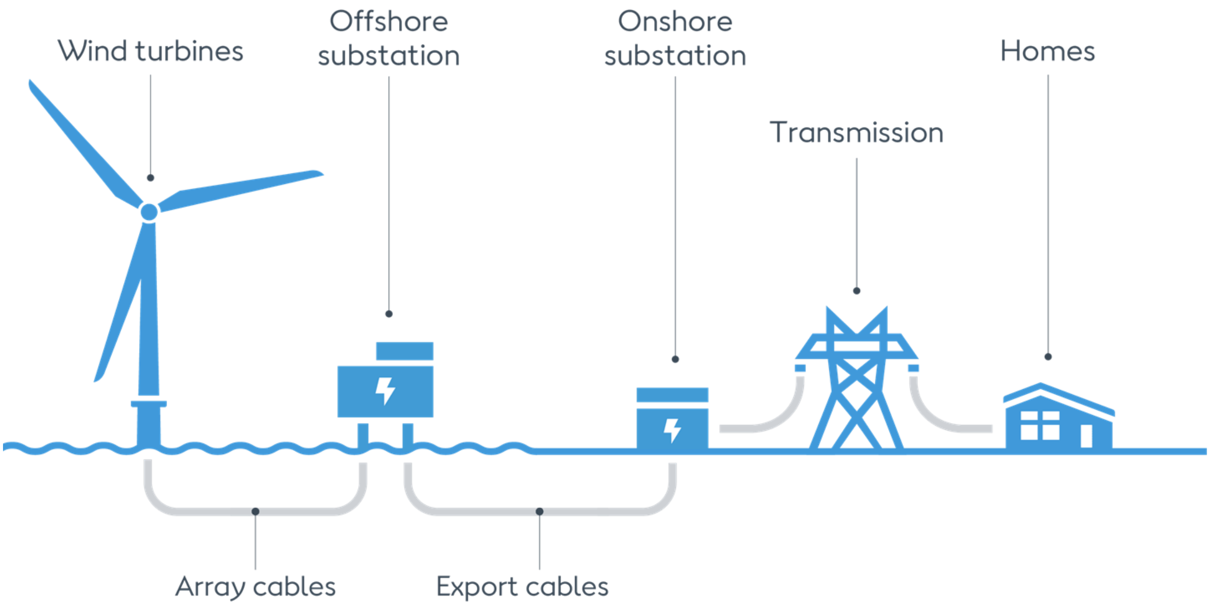


Figure 2.3: Wind energy generation schematic (offshore & onshore) by WTS Energy (2023).

Wind energy is created by the turbines capturing the wind's kinetic energy as it flows against the blades, the blade rotor turns the main shaft connected to a gearbox converting the roto's low-speed & high-torque power into high-speed & low-torque power. The generators create electricity from the blade rotor's rotating power. This produces DC power which is then converted to AC by a power converter before being transported by buried cables, the electricity is delivered to the power grid and then reaches the end users (households & commercial buildings).

Case Study: San Gorgonio Pass Wind Farm, USA

Profile	San Gorgonio Pass Wind Farm
Location	California, USA
Date	1981 - Present
Capacity	647 MW
Partnership	*Oliver Electric Power Corporation* Riverside County U.S. Bureau of Land Management

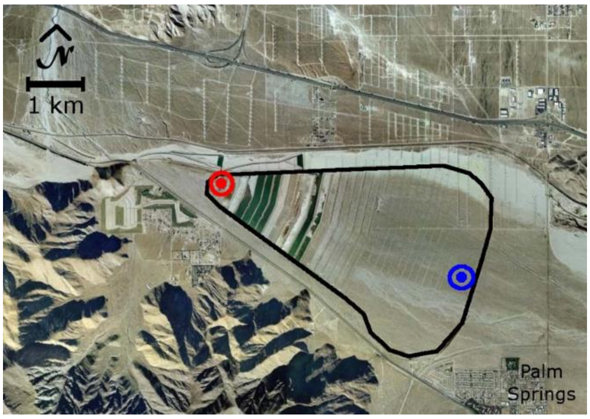


Figure 2.4 (left): Wind farm outside of Palm Springs, CA by opie2 (2022).
Figure 2.5 (right): Google Maps outline of the San Gorgorino wind farm with 1989 boundary (Kelley et al 2010).

San Gorgonio wind farm is one of the major farms in California, it extends from the eastern slope of the San Gorgonio Pass to North Palm Springs. Located in a deep mountain pass in the northwestern region of Coachella Valley, the geography enables the intensity of the wind to provide enough electricity to power Palm Springs and the entire Coachella Valley. The 70-mile-long wind farm was developed in the 1980s, it previously hosted 1,220 turbines some of these are now replaced with large turbines, bringing the total number to 802 turbines with a total rate capacity of 647 MW (Hoen *et al*, 2020).

The city of Anaheim (2013) signed a Power Purchase Agreement with San Gorgonio Farms, Inc. for 31 MW of intermittent renewable wind energy, generating 100% of the city's electricity between December 2013 to 2023. In California, wind energy has diverted 336 million metric tons of CO2 emissions in 2022 (ACP, 2023).

Advantages and Disadvantages of Wind Energy

Over time the technology for wind turbines has improved leading to lower production costs. From 2010 to 2020, the global weighted-average levelised cost of electricity (LCOE) of onshore wind fell from USD 0.089/kWh to USD 0.039/kWh, a reduction of 56%. Economically, wind projects are becoming more justified as the LCOE of newly commissioned offshore wind projects has also reduced by 48% (IRENA, 2023). The opposition may argue that the presence of wind turbines is an eye sore and ruin the aesthetic of an area, however, in pursuit of aesthetics, humans have already caused problems from eugenics where certain dog breeds have been modified to be more appealing by sacrificing their health or deforestation and limited diversity in urban gardening and crops have also caused native plants to suffer. Placing the wind farm on plains away from human population and offshore can relieve the organisations from these criticisms however they will need to consider whether the wind turbines will obstruct the bird's migration route. The maintenance of offshore wind farms will also be more expensive as the sea conditions can batter the farms and reduce their life expectancy requiring frequent check-ups from highly specialised engineers.

Bioenergy Carbon Capture Storage (BECCS)

Bioenergy has always been used by mankind to provide heating and in modern times, it is used as bioethanol to fuel vehicles and continue providing electricity by burning biomass. The BECCS is part of the Carbon Capture Storage technology, which has been in use since 1972.

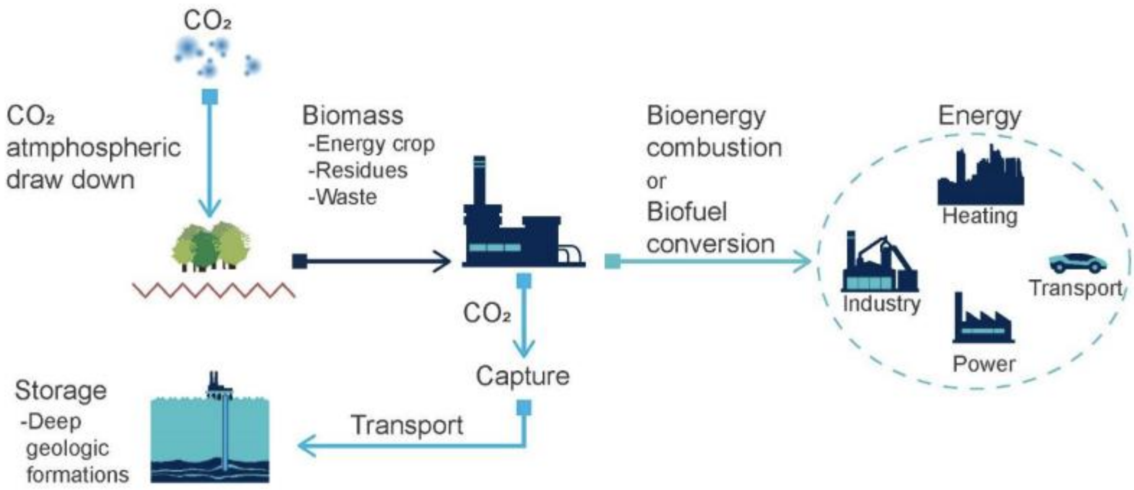


Figure 3.1: Schematic of CCS from Consoli (2019).

The BECCS follows the CCS method, biomass feedstock (trees, algae cultivation, etc) draws the CO2 from the atmosphere via photosynthesis, and the biomass is transported to a conversion facility. The biomass is then combusted or converted to biofuel (via digestion or fermentation processes), and CO2 is produced during these processes. CO2 is captured and stored; negative emission occurs when the amount of Co2 stored is greater than that was emitted during the whole CCS process. In BECCS, this captured CO2 is used for Enhanced Oil Recovery (EOR) in the Oil & Gas industry.

Case Study: Farnsworth Oil Field BECCS, USA

Profile	Farnsworth Oil Field
Location	Texas, USA
Date	2013 - 2018
Injection Size	0.2Mt/yr until total 1 Mt stored
CO2 Source	• Arkalon Ethanol Plant (Liberal Kansas) • Agrium Fertilizer Plant (Borger Texas)
Storage	Enhanced Oil Recovery (EOR)
Project Value	$78,910,800
Partnership	*South West Partnership (SWP),* *New Mexico Institute of Mining and Technology,* *Chapparal Energy, LLC* *Los Alamos National Laboratory,*

	Oklahoma Geological Survey, *Pacific Northwest National Laboratory,* *Utah Geological Survey, University of Missouri,* *University of Utah,* *Sandia National Laboratories,* *Schlumberger Carbon Services*

Figure 3.2: Map of Farnsworth Unit Project in Texas by Adu-Gyamfi et al (2022) with Google Earth Pro 7.3.1.

The oil field is an incised valley-fill coarse sandstone in the Anadarko Basin, it produces more than 19 million barrels of oil and 44 billion cubic feet of gas, 13 CO2 injection wells were created to inject the anthropogenic CO2 underground. Over 600,000 tonnes of CO2 were compressed from the Arkalon Ethanol Plant and Agrium Fertilizer Plant, the emissions were used for the Enhanced Oil Recovery in the Farnsworth Oil Field (Consoli, 2019; Rodosta & Damiani, 2017).

The Farnsworth Unit Project has provided educational experiences for college students and national laboratories, providing information on the BECCS process. The site project has provided a wealth of surface and subsurface data, it serves as a baseline for the simulation and monitoring, verification, and accounting activities for future CCS projects.

Advantages and Disadvantages of BECCS

One of the largest BECCS applications is waste-to-energy (WtE)., burning public solid waste (biomass) to generate heat and electricity, the CO2 is then captured and stored for negative emissions. However, CO2 is also a natural part of the environment, trees absorb it, and cutting down trees to create these storage and machinery will seem counterintuitive. While setting up a dedicated energy crop such as fast-growing willow trees can be considered this would mean additional land must be deforested/cleared out for the homogenous group, affecting the local diversity. Residual products such as sugar cane waste can be used instead as this would be an additional usage rather than more land being taken up however the residual product must be local to the region, and growing sugar cane in colder climates will be more difficult. To meet the target of maintaining the temperature below 1.5 ° increase, climate modellers estimate an area size of India (380 – 700 million hectares) would be needed for BECCS, the carbon capture can potentially lead to soil degradation, therefore, reducing crop yields increasing the already inflated food prices (fern, 2018; Yamagata et al 2018).

Although the EOR focuses on the use of fossil fuel energy, the benefit of this practice is by maximizing the potential of the local oil field, the country (e.g. USA) can reduce reliance on oil imports. The injection of water or CO2 extends the fields' productive life, it displaces the oil up to the production wellbore. This (tertiary) recovery can extract 30% to 60% or more of a reservoir's oil, a primary and secondary recovery would just yield 20 – 40% of the reservoir (DoE, n.d).

Solar Thermal Energy

In 2018, Solar thermal energy accounted for around 7% (1.5 EJ) of global renewable heat, most applications being small-scale thermal systems for domestic water heating. Despite gross annual capacity additions declining since then the Global solar thermal consumption is expected to increase more than 45% over the outlook period, mostly in residentials (IEA, 2019). China is still expected to dominate the market despite the recent housing construction scandals and reduction in new housing builds as rural to urban migrations will keep on raising demands for residential buildings.

Although the solar heat for industrial processes (SHIP) only accounts for 0.02% of the global heat energy demand, the niche market is steadily expanding with 108 systems being commissioned. Increasing the total installed capacity to 567 MW_{th} (IEA, 2019).

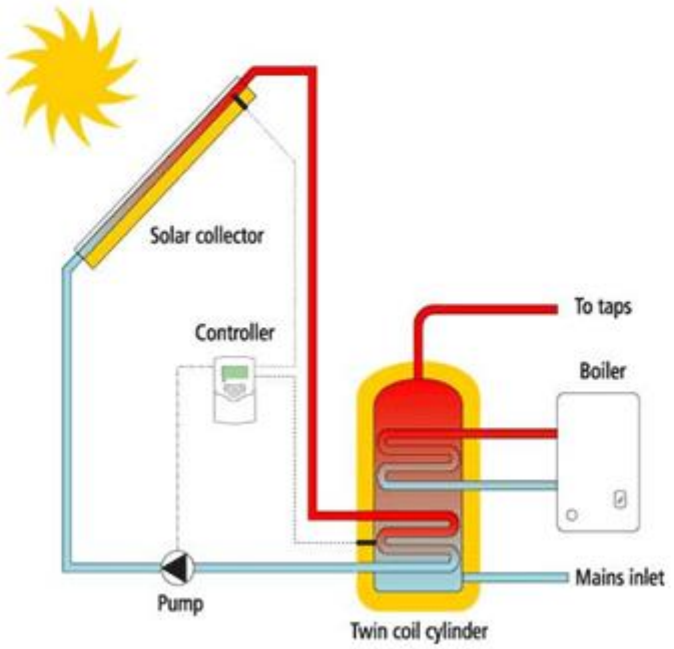


Figure 4.1: Diagram of Solar Energy Heating Water by Enviro-Heat (n.d).

The Solar collectors absorb energy from the sun and transfer it to the control panel, the heated water runs from the collector to the hot water cylinder. The solar energy will then supply hot water to the house for heating, hot water for the bathroom, and other appliances.

Case Study: RED WoLF Hybrid Storage System, North-West Europe

Profile	RED WoLF Hybrid Storage System
Location	Europe
Date	2019 - 2023
Storage	Thermal (+ wind power)
Project Value	€ 7,400,000
Partnership	*Leeds Beckett University*

	Oldham Metropolitan Borough Council *Institute of Technology, Sligo* *Université de Lorraine* *Electricité de France* *VOLTA* *Students Organising for Sustainability – UK* *Néolia* *Cork City Council* *Carbery Housing Association* *First Choice Homes* *eco:novis | Ingénieurs-Conseils* *Sligo Leitrim ITS Regional Development Projects DAC* *Energipark Reiden S.a.* *GLAS Energy Technology* *Bretagne Sud Habitat*

The RED WoLF (Rethink Electricity Distribution Without Load Following) is an EU project proposed to reduce CO2 emissions in households. The trial was conducted on households across EIRE, the UK, and France where the houses were equipped with the Hybrid Storage system that combines batteries with cheaper thermal storage to create a cost-effective storage solution by shifting the household's energy demand from peak to off-peak times (Colantuono, 2022).

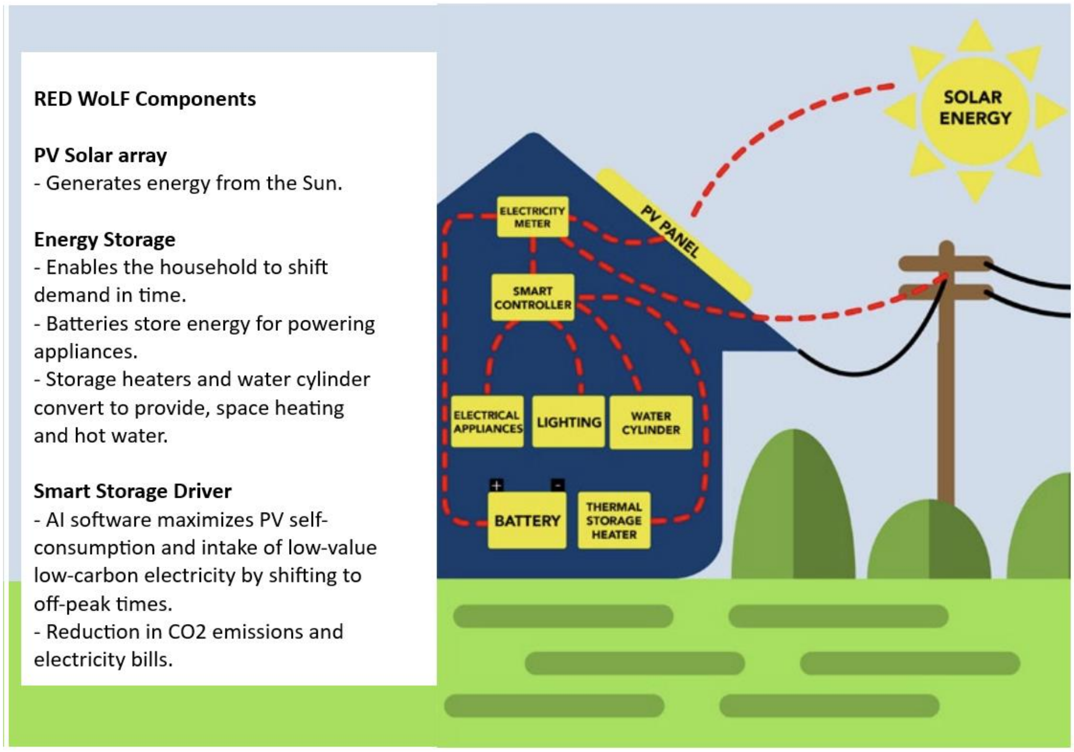


Figure 4.2 Diagram of RED WoLF components in a household, adapted from Colantuono (2022).

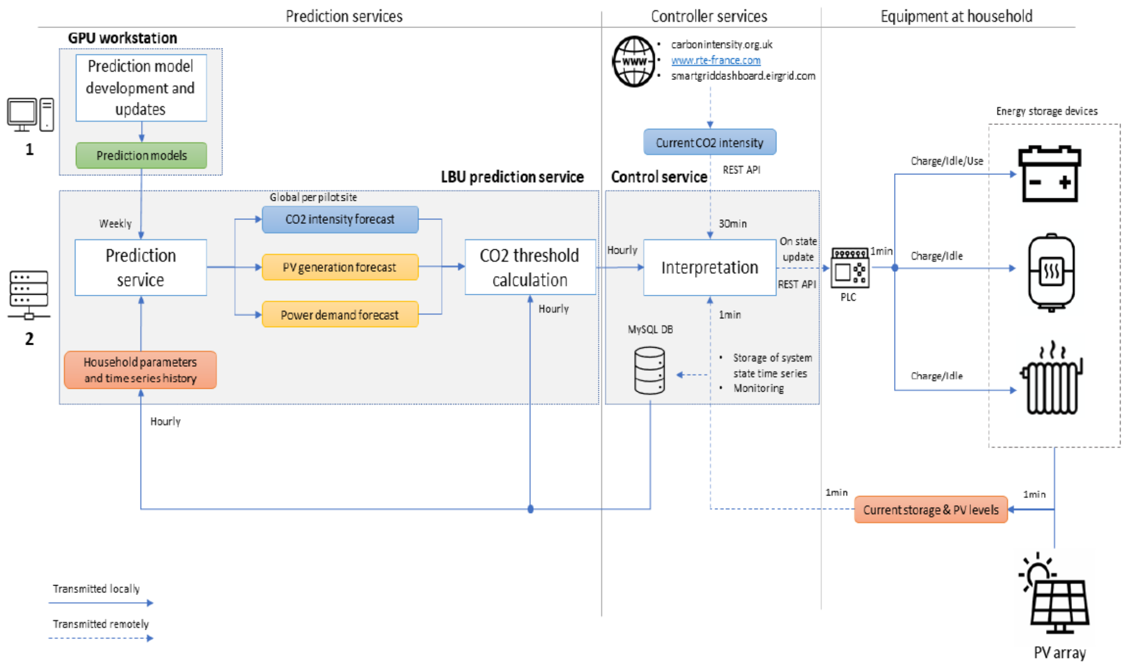


Figure 4.3 Diagram of RED WoLF process from Shukhobodyskiy & Colantuono (2020).

As energy consumption in households are not evenly distributed, additional CO2-intensive generators are used to meet the peak demand. The RED WoLF hybrid storage system works to avoid the peak demands by integrating a higher share of renewables on the power grid. Om co, computer simulations, the algorithm showed a drop in CO2 emission. When using a 7 KWh battery with a 4 kW Photovoltaic array, the CO2 emission dropped by 30% to 100% depending on the season simulated. The Storage heaters (StHs) provide domestic space heating on demand to individual rooms within 24 hr. the Hybrid Storage Systems (HSSs) store houses' Photovoltaic (PV) output and low-CO2 energy (wind/solar) drawn from the Power Grid at times of low demand, removing the generation-demand temporal mismatch that currently limits renewables growth (when demand is low on sunny/windy days, output of solar/wind farms need to also be reduced) (*Colantuono, 2022;* Shukhobodskiy & Colantuono, 2020). The 2023 revised algorithm showed a further reduction in CO2 emissions by 9% comparatively to RED WoLF double threshold approach and by 26% against the RED WoLF single threshold approach (Shukhobodskiy, Colantuono & Zaitcev, 2023).

Although the pilot was conducted on smaller new residential builds there is potential for use in commercial buildings as the hybrid battery has also been trialled to work with other energy sources and in the future at a larger scale.

Integration with Wind Power

The current RED WoLF system implements a hybrid storage system with thermal energy, to aid the overall decrease of CO2 emissions, the additional project examined how the existing RED WoLF algorithm responds to an additional renewable energy source, wind power.

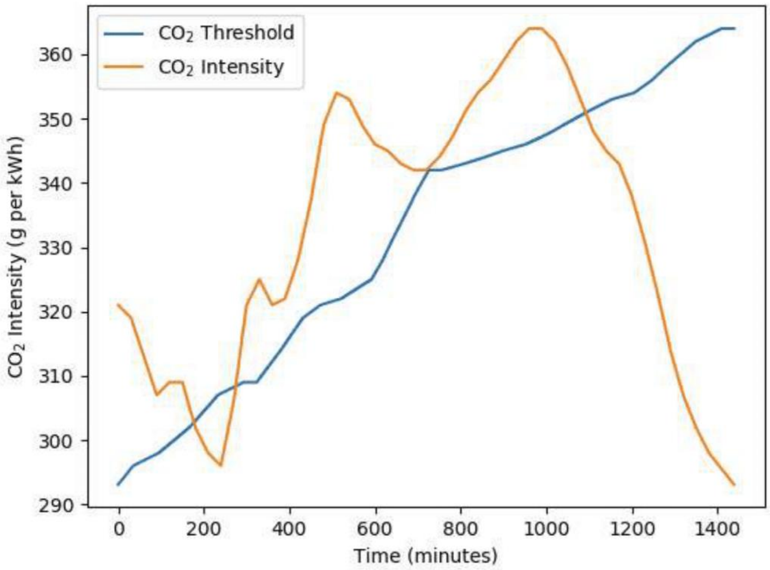


Figure 4.4: CO2 Intensity and threshold over one day with wind energy integrated into the RED WoLF system.

The algorithm is simulated with the integrated of wind source, the figure shows the CO2 threshold increase in duration however to further explore the impact of wind power, the actual wind data was increased though this wind strength maybe difficult to achieve in France (where the original data was extracted from), it helped the team understand that greater wind power did offset the emission as the CO2 intensity showed fluctuations and dips in the observed time. While there is potential for wind power to be integrated into this, the location of the original wind farms may not be sufficient to garner enough strength to offset the emissions (France's average wind speed is 7.8 mph to 11 mph).

Advantages and Disadvantages of Solar Thermal Energy

While solar thermal energy has low maintenance cost however it is still expensive which is why there is lower demand for this, most of the heat energy produced is still through biomass burning. Like wind energy, location is also key in that the area must have a significant amount of sunlight, colder regions or areas within the mid-latitude may not provide sufficient sunlight during the colder seasons, making the energy source inconsistent. In places where there is greater sun exposure such as the desert these places will be optimal however these locations also tend to be sparse in population and other infrastructures, therefore maintenance will become expensive due to the logistics.

Hot water cannot be stored for long periods without loss of its heat however and combination of other renewable energy such as wind energy which can be stored in batteries can work to supplement this loss.

Policies & Programmes

Organisations within the energy sector should consider collaborating with external parties, The RED WoLF program was successful in encouraging the younger generation as they were able to partake in research that can help pave the way for a sustainable future. By building these interests and giving opportunities to work in a professional environment, more people will understand the Importance of reconsidering how energy is produced and used.

Compared to other energy sources, the demand for BECCS remains low therefore a high degree of transparency is required to demonstrate the benefits of investing in this approach. Communities and stakeholders are more likely to approve if there are internationally recognised Carbon Dioxide Removal (CDR) frameworks involving BECCS. In November 2022, the European Commission proposed an EU-wide voluntary framework to certify high-quality carbon removals to recognize certification schemes that can comply with the EU framework by achieving the following criteria:

- Quantification
- Additionality
- Long-term storage
- Sustainability

Denmark's Energy Agency has been involved in investing in CCS technology since 2022. Their Negative Emission CCS (NECCS) Fund of € 350,000,000 aims to subsidies schemes for CO2 negative emissions. Currently, Denmark can remove 0.4 Mt CO2 annually, they aim to remove 0.5 Mt per annum from 2025 onwards (Danish Energy Agency, 2023; IEA, 2023). With a budget of £25,000,000, the UK's Hydrogen BECCS Innovation Programme was also established to support CCS technologies, specifically in producing hydrogen from biogenic feedstocks.

Renewables Portfolio Standard (RPS) is a global regulation adopted by many developed countries to increase the consumption of energy from renewable resources. Such a program is important has it requires countries who will have the highest CO2 emissions to invest in renewable energy, for example, the state of California which produces 6.6% of the US's total emissions must have 20% of its electricity supplied by alternative sources. As of 2017, 1/4th of California's electricity is sourced from RPS-approved resources, the state is on track to meet the ongoing RPS which aims to procure 60% of its energy from renewable sources by 2030. (CEC, 2024; CPUC, 2021).

Conclusion

Net Zero will remain a significant challenge and for the energy sector to strive towards Net Zero, they should invest further into green energy however they must also consider the applications of the technology and the necessary environment and its impact. Wind power production is optimal in areas with at least 9 mph of annual wind speed, thermal energy will be more abundant in areas that see greater light exposure (Middle East, desert environment, etc.). All technology should consider the life in the designated location, approaching reservation lands will require the local communities' approval and where there are endangered species, construction should be avoided to not contribute to potential wildlife extinction. Policies and programmes have also been established to not only encourage but require organisations to consider renewable energy and for the energy sector, they must also invest in renewable technology to meet their customer's needs.

Embracing new technologies such as energy storage solutions can significantly progress the collaboration between government, industries, and communities on the transition to a sustainable future.

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