# SUSTAINABLE ENERGY MARKET TRANSFORMATION AT THE INTERSECTION OF HUMAN EVOLUTION, DIGITAL TECHNOLOGY AND ECONOMICS

by

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## Dedication

Dedicated to my children Sasha S Santhosh and Siddhanth S Santhosh, to give them confidence that we do care about their future.

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I sincerely thank my husband Santhosh Kumar AS, my parents Radha R and B.N Rajagopala for all their unconditional support.

I thank my guide Dr. Luka Lesko in guiding me through this journey.

# ABSTRACT

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Our climate is changing due to increase in temperature which is directly linked to the carbon emitted by our industries, transportation, and modern lives. Primarily this carbon is emitted due to burning of fossil fuels (a major source of Energy) which is considered as dirty fuel.

To address the growing demand for energy and reduction of carbon emissions energy market need to undergo transformation.

While there are multiple greener technologies which can bring down the carbon emissions but there is no research done on what kind of transformations energy market has to undergo at the intersection of economics and digital technologies.

This research aims to address this gap.

The methodology adopted can be divided into two parts.

a) Research on how to reduce the energy demand and decouple the economic growth with energy.
b) Study different green technologies and abatement technologies available for Energy companies to adopt.

The research showed different energy sources like Solar Power, Wind Energy, Nuclear Energy, Battery Technology, Biofuels, Geothermal and Hydrogen which will help reduce the emissions.

To enable consumption of these form of energies the Energy Market transformations needs to happen. Transmission and Distribution network needs to be modernized and expanded to meet the demands. Carbon Capture technologies needs to be adapted along with transportation and storage which is giving rise to new financial markets with carbon as commodity. This helps ensure the balance of emissions and absorption of carbon. Battery Manufacturing needs to be scaled up to meet the huge load of storage of renewable energy. Electric Vehicle (EV) Charging infrastructure needs to be scaled at a very rapid pace to increase the uptake of electricity for mobility and reduce range anxiety.

Having said this the mobility sector also needs to undergo transformation to bring down the cost of the EV vehicles and make it ubiquitous. The sector has to scale Hydrogen powered vehicles to solve the requirements of high power for heavy loads transportation. For customers who are not willing or cannot move to EV or Hydrogen powered vehicles, solutions like Biofuel, Sustainable Aviation Fuels must be provided. There is a need to increase blending plants for Biofuels and Sustainable Aviation fuel and supply greener fuel in the same supply chain network, without modifying the automotive involved. Enabling this is digital technologies which play crucial role in connecting stakeholders across ecosystem, brining insights into operations and recommend actions.

Further research on how to fund this change and the ecosystem to enable this transformation are required.

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CHAPTER I:

INTRODUCTION

## 1.1 Introduction

World has been dependent on fossil fuels for commercial use for three centuries now. Fossil fuels have powered the growth for humanity and today we cannot imagine anything without Energy. Be it manufacturing, transportation, electricity's at home & offices, heating, cooling, agriculture etcetera. Energy has become such an integral part of our lives that we cannot imagine anything without energy. Energy powers everything around us. Having said that we are at cusp of Climate Change.

We have approximately 50 Giga Tones (GT) of Green House Gas emitted into the atmosphere currently. Green House gases primarily constitutes of Carbon dioxide, Methane and Nitrous oxide. As per NRDC (2021) Carbon dioxide (the chief contributor to climate change) is up by 40 percent, nitrous oxide by 20 percent, and methane by a whopping 150 percent since 1750—mainly from the burning of dirty fossil fuels. Methane though small in percentage, causes 25 times more impact than carbon dioxide. NRDC (2021) This prevents heat from radiating from earth's surface into space, creating what's known as the greenhouse effect. Huangpeng et al (2021) Rising greenhouse gases have disrupted the energy balance between the solar and the Earth causing climate changes.

Huangpeng et al (2021) claim in their paper that climate change is causing several environmental problems, such as changes in precipitation patterns, the melting of polar glaciers, and rising sea levels  and the main cause of these changes is global warming.

So what has changed? What is causing this climate change? Data shows that we've emitted more than half of all emissions since 1751 in the last 30 years alone. In 1905 we were barely emitting 1GT /year of Carbon dioxide into the atmosphere. This number touched to around 24 GT by the end of the 20th century. We are in 2022-23 we have already touched around 37GT in terms of Carbon dioxide. Is it population rise? We have grown from 1 billion in 1800 to 7.9 billion in 2020. Just in last century we have added over 6.25 billion people. As per United Nations (2022) The world's population is expected to increase by nearly 2 billion persons in the next 30 years, from the current 8 billion to 9.7 billion in 2050 and could peak at nearly 10.4 billion in the mid-2080s. Our life expectancy on an average has increased from 30 years in 1800s to around 70 years on average in 2020. What does this mean, we have the same resources provided by nature but the people consuming has increased 8 times over 2 centuries. This brings to our problems statement.

## 1.2 Research Problem

Population has increased 8 times over 2 centuries, but carbon emissions have increased close to 50 times. There seems to be a close relation between these two entities though not in the same proportions. While there are enough of studies establishing the relation between population and carbon emission, my research will focus on what within population is causing the carbon emissions. For example, India with a population size of 1.4 billion emits 2.7 GT of carbon. Whereas US with approximately 340 million population size emits 5.5 GT of CO2 emissions. So clearly the size of the population does not have a direct co-relation with the emissions.

So, the question is why some societies are polluting so much and other countries/societies are not? As per UN report Human development Index (HDI) has a direct relation with the Energy consumption. The developed countries are consuming more Energy than the developing countries. More the energy consumption more the emissions. While this fact has been established quite firmly, not enough research is available to understand why the energy consumption is higher. What is driving this higher consumption? And more importantly is that consumption necessary? What role does consumerism play? How can we decouple economic growth powered by consumerism to measure progress? What mindset and market transformation are required to achieve this? Ultimately the goal is how do we reduce the emissions and what role can Energy companies can play in this space?

How can Information and communication technology (ICT)/Digital/Information technology (IT) play a role in achieving Energy security and sustainability? There needs to be a clear understanding of how technology can play a role in this and beyond Energy efficiency and energy conservation.

The answer to these questions will help us transform our Energy market to a more sustainable world.

### 1.3 Purpose of Research

The long-term goal of this research is to find out what Energy market transformations has to happen to ensure we meet our climate goals and also ensure equitable and sustainable quality of life and progress.

This study aims to conduct a systematic review of existing literature and analyze current industry practices related to energy market transformation. By synthesizing these findings, the research will develop a novel conceptual framework that illuminates the key factors shaping the evolution of energy markets.

The study will have the following sub-objectives:

- How to ensure equitable and sustainable quality of life while transforming the Energy markets?
- How do we decouple Energy demand and society progress?
- What are some of the best practices adopted across the world which helps in maintaining the balance between economics growth and environment?
- What transformations are required at the consumer end to achieve these goals?

- What transformations are required in business (industries) to drive sustainability?
- How can technology be a big enabler in this space?

The result of this study will be valuable to the industry practitioners as well as related software providers in developing better practice and tools to solve the climate challenge.

### 1.4 Preliminary Literature Review Objectives

A preliminary literature review shows that past studies are primarily focused understanding the following.

- How can we measure growth of a nation beyond Gross Domestic Product? Kate Raworth (2017) she developed a "Doughnut Model", which includes twelve aspects of our social foundation, as well as nine planetary boundaries and explains that the ideal space of our economy is between these two elements. Kate Raworth (2017) focusses on bringing the attention beyond household, it is about working with resources which are available and overshooting them. But there are some unanswered questions - How to avoid an overshoot when our population is constantly increasing, thereby putting stress on ecological balance.
- How can we decouple consumerism with energy demand? Jin Guo et al (2021) analyzed this energy–economy nexus and explored their decoupling possibilities by using cross-country data over the years 1971–2014. They found that energy use and economic growth tend to follow opposite trends (decouple) in developed countries, with energy use eventually decreasing as economies mature. However, in developing countries, energy use and economic growth have been increasing together. To achieve better decoupling, the author suggests policies that focus on economic restructuring, clean energy adoption, improved energy efficiency, and effective energy management. But here again the fundamental assumption is economy is driven by consumption. He assumes that high

consumption drives economy, it is now a matter of how we power this consumption with renewable sources and more energy efficient systems.

But he doesn't question, is high consumption of energy really need to drive the economy beyond a certain point?

- Marco Buttazzoni (2008) in his research identified one giga tons of strategic CO2 reductions based on a bottom-up approach with concrete solutions. These reductions are equivalent to more than one quarter of EU's total CO2 emissions. Marco Buttazzoni (2008) proposes ten solutions that can deliver 1 giga tons of carbon reduction Smart city planning, Smart Buildings, Smart appliances, Dematerialization services, Smart Industry, Intelligent Optimization, Smart Grid, Integrated renewable solutions, Smart work and intelligent transport. Though he covers broad areas he has not explored each technology that can have profound impact on reducing carbon emissions. How can the Information Communication Technology (ICT)/digital technologies help reduce the energy demand and reduce carbon emissions?

# CHAPTER 2:

# LITERATURE REVIEW

## 2.1 Introduction

World is going through climate changes. There is no denying this fact anymore. Conference of Parties (COP) summit after summit are highlighting this and many countries have started to take actions in this direction. The most accepted primary reason for the increase in the carbon emissions is burning of fossil fuels for Energy needs. All efforts are being made now to reduce the burning of fossil fuels.

There are multiple ways to reduce the burning of fossil fuels. There is no one single silver bullet, instead it has to be multiple solutions coming together to solve this challenge. We need to replace the fossil fuel with more renewable energies and also reduce the overall energy demand. Both needs huge transformation in the society. Energy consumption is not directly proportional to the population. Hannah Ritchie et al (2020) mention in their research in WorldData a significant disparity exists in per capita energy consumption across nations. Countries with advanced economies, such as Iceland, Norway, Canada, the United States, and wealthy Middle Eastern states (e.g., Oman, Saudi Arabia, Qatar), exhibit considerably higher consumption levels compared to their less developed counterparts. This disparity can be substantial, with some estimates suggesting a factor of 100 or more difference in per capita consumption between the most and least energy-intensive nations. This disparity is directly linked to the quality of life – which is driven by consumerism. Consumerism drives the economic growth of the nation which is directly impacting the Gross Domestic Product (GDP). The relation as of now is very clear- more the consumption, higher the growth, higher the GDP, more the energy demand. So that means prosperity is linked to consumption which in turn means, we need more energy. In addition to existing population energy demands we will have population growth, which will further add to more energy demands. So that means to reduce the emissions, we must reduce the energy demand despite the growth in the population at the same time cater to the rising consumption of energy. This is the conundrum.

The question to ask ourselves is how can we decouple Energy with growth? What market transformations are required in Energy market to help achieve this? What should be the mindset to measure the growth and prosperity of human race, is GDP growth the only way to measure progress?

This literature review explores the different ways to measure progress – which is more balanced and wholistic. Recent Russia-Ukraine war has made it very clear to all the countries that Energy security along with sustainability is key. Decisions cannot be made on economics alone – which was the trend observed during last couple of decades. Countries have woken up to the fact that over reliance on other countries to meet their Energy demands can prove to be very costly in long run and can challenge their own security. This research focuses on exploring different options available to reduce the dependence and increase self-reliance of energy needs while ensuring clean energy and how information and communication technology and consumerism can play a crucial role in this.

## 2.2 Measuring growth of the nation

World has never been the same as compared to last centuries. But despite that we continue to measure growth using parameters and mechanism defined in 18$^{th}$-19$^{th}$ century. There has been growing consensus that progress must be measured beyond economic progress.

Brigid Reynolds et al (2009) argue in the book "Beyond GDP: What is prosperity and how it should be measured?" that GDP provides an inadequate indicator of human development or progress for people in any real sense. They recommend that we must turn instead to more appropriate goal of human development by using a much more comprehensive set of variables which place emphasis on sustainability, freedom, capabilities and empowerment within a human rights-based framework.

Brigid Reynolds et al (2009) UN has already attempted in this direction. In its first Human Development Report in 1990 they introduced a composite measure of development called the Human Development Index (HDI). This single statistic combined three goals of development: life expectancy at birth, educational attainment and income adjusted for different purchasing power in different countries. But this does not cover any of the ecological impact or sustainability of resources across generations. Erica Matthew (2007) Around the world, societies are increasingly concerned with their quality of life. A consensus is growing around the need to develop a more comprehensive view of progress – one that considers social, environmental, and economic concerns - rather than focusing mainly on economic indicators like GDP.

The dynamics of 21st century needs newer ways to measure progress which is respecting environment, human evolution, and equality.

Recent pandemic has shown that no one is safe until everybody is safe. We are all interdependent and really need to think as a whole society rather than just focusing on individual needs. This applies to a person and a country at large. Kate Raworth (2017) asks the same question in her book "Doughnut Economics". She criticizes that our economical acts and decisions are based on the economic theories of the 1960s, which are mainly focused on a continuous and infinite growth. She argues that we need an update to the 21st century economy, which accounts not just for our well-being and prosperity, but for that of our planet as well. To make the missing factors in classic economies visible, she developed a "Doughnut Model", which includes twelve aspects of our social foundation, as well as nine planetary boundaries and explains that the ideal space of our economy is between these two elements. Kate Raworth (2017) focusses on bringing the attention beyond household, it is about working with resources which are available and not overshooting them. But there are some unanswered questions - How to avoid an overshoot when our population is constantly increasing, thereby putting stress on ecological balance. In the doughnut model – Energy is shown as one of the needs of human being, but Energy underpins everything. We cannot have food, water, housing, education etcetera. without energy. How do we measure this? And most importantly how can we achieve the de-coupling of energy with human population. Kate Raworth (2017) does not recommend concrete actions, how to transform her theories and to apply them. It is important to understand how to decouple the main polluting source which underpins all human activities from economy.

**2.3 Decoupling Energy demands with population.**

Jin Guo et al (2021) analyzed this energy–economy nexus and explored their decoupling possibilities by using cross-country data over the years 1971–2014. The results indicated that, while energy use and economic growth exhibit a typical inverted U-shaped decoupling relationship for the industrialized countries, they have been rising in tandem for the developing economies. He considers many important decisive factors like economic scale, population size, and energy intensity for this study. He concludes that any global economy–energy decoupling may confront challenges and uncertainty. To better decouple economic growth from energy use, he proposed policies for more structural reforms, a clean energy system, improved energy efficiency, and efficient energy demand-side management. But here again the fundamental assumption is economy is driven by consumption. He assumes that high consumption drives economy, it is now a matter of how we power this consumption with renewable sources and more energy efficient systems. And then there is thin line between need and greed of humans leading to excess consumption.

One would argue – why not look at ways to remove the idea that consumption is primary driver.

Perera et al (2014) in his study suggest that the dominant paradigm of consumerism presents a multifaceted challenge. Firstly, its emphasis on continual acquisition is demonstrably unsustainable from an ecological standpoint, exerting undue pressure on resource availability and ecosystem integrity. Secondly, it risks severing the inherent human connection with the natural world, potentially leading to a sense of alienation from nature that undermines human well-being They concluded that the world needs to find ways and means to protect and conserve the resource for future generations. Also, the transition to sustainable society will require a major improvement in societal organizations, government institutions and citizenry activities of the world. Specially, those organizations should address the issue of consumerism, environmental quality, and ecological sustainability.

Again, this research does not address the "how" part of reducing consumerism. And this is directly related to the kind of lifestyle we choose. Cohen (2017) in his research concludes that adhering of sustainable lifestyles exhibit a shared core principle: consumption is viewed as a means to an end, not the end itself. Success is not measured by material accumulation, but by the pursuit of a fulfilling life, the definition of which is subjective and multifaceted.

We are learning to share auto, cabs, books, clothes, bikes, vehicles even homes when we travel. This is helping us consume less and less thereby putting less burden on the planet at the same time ensuring progressive world. This also reduces the parity, makes our society more inclusive and gives opportunity to everyone to experience the materialistic joys. After all it is easy to rent a vehicle when needed, then to buy.

Other idea emerging is going local. In a study done by Martin et al (2016) that food grown locally has both sustainability and health benefits. The development of urban agriculture presents an opportunity to integrate local food production into regional food systems. This integration has the potential to enhance the sustainability and resilience of food supply chains. Furthermore, it can foster public co-production of novel forms of urban conviviality and well-being.

Having said this there is still no study to analyze how the country's prosperity, by decoupling energy such that there is net zero carbon emissions. Different studies address different aspects of the problem, but one thing is certain, energy is fundamental to human life and will continue to be. Therefore, the question to be asked is how we manage this conundrum of increase energy and decrease carbon emissions or achieve net zero carbon emissions. This means we should de-link carbon emissions with energy as much as possible.

For sake of argument let us consider the following three factors to de-link carbon emitting energy demand and growth

a) Switching to renewable sources of energy which has near zero carbon emissions. Ottmar Edenhofer et al (2012) in their report "Renewable Energy Sources and Climate Change Mitigation" clearly calls out Bioenergy, Direct Solar Energy, Geothermal Energy, Hydropower, Ocean Energy and Wind Energy as renewable sources of energy. But he has not covered the details on how these technologies works and how they can be implemented.

b) Increasing efficiencies in the existing energy systems to bring down the consumption. The term Energy efficiency means using energy more effectively by leveraging advances in science and technology as catalysts to provide services or products that will require the use of less and less energy to achieve same or even higher services delivery. Eric Beinhocker et al (2008) from McKinsey Global Institute ranks energy efficiency as the top priority among measures to mitigate climate change. Jas Singh (2016) in his research found that increased global commitments are already beginning to pay off. In 2011, energy savings in 11 OECD countries reduced demand by an amount that exceeded the total energy consumption of the European Union. He further concludes that Policy &Regulations, commitment from institutions, Information &communication technology (ICT), technical capacity in terms of the energy systems and finally finance are some of the successful levers which helps achieve energy efficiencies. But he has not covered how this will help. This is a gap that needs to be researched.

c) The other way to tackle this problem is to reduce the Energy requirement itself which means conserving Energy. Energy conservation is achieved when you adopt better ways of doing things by using the less amount of available energy to perform more useful work. O U Olughu (2021) in his paper claims that Energy conservation is also a behavioral effort which calls for actions that encourages reduction of commercial, industrial and household energy use. It advocates for the use and application of alternative energy modes, better ways of doing things that save cost of rendering energy services. Some of the Energy conservation methods are reducing usage of virgin materials for manufacturing, adopt more and more recycled material, design building, homes that does not need lights during daytime, fans or air conditioners through the day and night, reduce use and throw plastic, build the mindset “repair and use” rather than going for new ones every time it breaks down etcetera.

Hoexter MF (2010) argues that energy efficiency is arguably the most effective method as compared to energy conservation in saving energy. However, the former requires more monetary investment than the latter due to the fact that energy efficiency requires the intervention of technological equipment in order to reduce energy consumption as mentioned by Parrott K (2019). Laitner J (2000) says one of the solutions is retrofitting the existing energy system which can help to reduce the overall implementation cost. However, Radzi et al (2021) conclude that energy efficiency and conservation should go hand in hand so as to ensure that the magnitude of the rebound effects can be minimized as well as the benefits can be maximized.

Digital technologies are believed to play a big and critical role in ensuring efficiencies and conservation. Marco Buttazzoni (2008) identified one billion tons of potential strategic CO2 reductions through a bottom-up approach with concrete solutions. These reductions are significant, representing more than a quarter of the European Union's total CO2 emissions.  His work proposes ten key solutions that can collectively achieve this 1 GT reduction Smart city planning, Smart Buildings, Smart appliances, Dematerialization services, Smart Industry, Intelligent Optimization, Smart Grid, Integrated renewable solutions, Smart work and intelligent transport. While Marco's study encompasses a broad range of areas, it does not exhaustively explore every potential technology that could significantly contribute to CO2 emission reduction. A crucial area for further investigation is the transformation of the energy sector, which underpins all other sectors. Research is also needed to understand how digital technologies can play a vital role in facilitating this transformation.

### 2.4 Digital Technologies driving the change.

The fundamental premise of digital technologies is making information and insights available at the right time, at the right place to the right decision maker. But thanks to the explosion of internet information is available everywhere. The proliferation of information available online has presented a paradoxical challenge. While access to knowledge has become unprecedented, a growing segment of the population experiences information overload, leading to confusion and difficulty in discerning credible sources. This phenomenon hinders public engagement with complex policy debates (e.g., climate change, migration, economic globalization) due to the perceived threat posed by the issues' complexity and the polarization of "evidence" used by opposing viewpoints. The ease of information gathering has demonstrably outpaced the development of effective information evaluation skills, making the distinction between reliable and unreliable data increasingly challenging. Therefore, the question to be asked is how we can build more trust in the system, that will help people convert this information to knowledge and ultimately knowledge to wisdom to take the right decisions. Therefore, consumer expectations and experience become pivotal in transforming the Energy sector. Norbert Schwieters (2013) in his survey found that 94% of the utilities business predict complete transformation or crucial changes to the power utility business model and 67% of them expect technology and new supply sources to dramatically reduce dependence on oil and gas rich countries. The contemporary energy landscape is witnessing a paradigm shift towards a decentralized model, aptly termed the "Internet of Energy" (IoE). This transformation is driven by the increasing prominence of renewable energy sources like wind and solar, which inherently differ from traditional, centralized systems. The IoE departs from the prior model characterized by a limited number of large, centrally controlled power plants facilitating unidirectional flows of energy, information, and financial resources. Instead, it embraces a distributed architecture with a multitude of geographically dispersed, intermittent renewable energy sources. This decentralized structure necessitates a new ownership paradigm and fosters bidirectional flows of energy, information, and financial resources. The resulting system exhibits remarkable parallels to the internet, with concepts like "uploading" and "downloading" of energy analogous to data transfer, "energy routers" akin to internet routers facilitating communication, and "energy buffers" resembling data storage mechanisms. In this process consumer behavior and expectation is expected to change. Anne Immonen et al (2020) finds that consumers are willing to provide demand flexibility which means they consume more power when it is available from renewable sources and restrict the consumption when power is not coming from renewable sources. Also, consumers are now becoming prosumers as they will start producing power from their own home installations. While this is expected ICT has to provide the necessary infrastructure to support this. Be it supply and demand forecast, ability to literally offload the excess power onto grid and consume power from grid when needed. This also means smart meters and bidirectional smart grids need to be installed to enable this. Anne (2020) research also confirms that consumers are willing to allow a third party to control their devices in order to achieve the benefits.

To achieve this kind of flexibility consumers, need to have trust. Blockchain is set to be that source of trust that can help manage these transactions seamlessly. Burger C (2016) claims that blockchain technologies have the potential to improve the efficiency of current energy practices and processes, can accelerate the development of IoT platforms and digital applications and can provide innovation in Peer to Peer (P2P) energy trading and decentralized generation. In addition, they report that blockchain technologies have the potential to significantly improve current practices of energy enterprises and utility companies by improving internal processes, customer services and costs.

Andoni et al (2018) concludes in her research that blockchain or distributed ledger technologies can clearly benefit energy system operations, markets and consumers. They offer disintermediation, transparency, and tamper-proof transactions, but most importantly, blockchains offer novel solutions for empowering consumers and small renewable generators to play a more active role in the energy market and monetize their assets.

While these covered some of the technology, but more research is required in understanding how other technologies like Artificial intelligence, robotics, automation, metaverse can bring about the energy market transformation.

# CHAPTER 3:

# METHODOLOGY

## 3.1 Introduction

It is well known fact that energy industry is perceived as one of the main reasons for polluting the world leading to the current challenges. While most of the society wants to come out of this challenge, it is not easy like turning on a button. Economic growth is related to energy consumption, which is continuously increasing as we grow. The energy companies must balance the need to increasing energy and at the same time pivot to provide green energy. This research tries to understand the different options available to Energy companies to provide green energy. While there is a need to change the source of generation of energy, there must be change at the consumer side both in terms of bringing down the consumption and ensuring the right mechanism to consume the energy.

While the initial literature review was to understand the above it brought out several limitations.

## 3.2 Limitation of current literature

- Most research papers agree that energy and economic growth are related. Why is this a concern because growth leads to more carbon emissions leading to environmental and social challenges. However, the question that is not directly addressed is it possible to decouple the economic growth and carbon emissions.
- It is not clear from research papers on different energy forms that an Energy company can adopt to increase footprint of renewable and green energy.
- It is not clear how Energy efficiency and Energy conservation can play a role in bringing down the overall carbon footprint.

- Clearly moving to Renewable Energy is not the only way to bring down the emission. There is no research calling out how different abatement technologies needs to be adopted to have wholistic solution.
- Given this what are the energy market transformations that needs to happen to cater to the new realities of the world. There is limited research done on this.
- Finally, it is not clear how digital technologies can enable these market transformations.

Below is the key literature reviewed, which will be augmented by the study done in this research exercise.

| Research Paper | Content summary | Augmentation from this research |
|---|---|---|
| Kate Raworth (2017). Doughnut Economics: Seven Ways to Think Like a 21st Century Economist. Regional and Business Studies | Kate Raworth does not recommend concrete actions, how to transform her theories and to apply them. It is important to understand how to decouple the main polluting source which underpins all human activities from economy. | Address how we can decouple growth with mindless consumption impacting the ecological imbalances. Some practical solutions which can be taken by Energy companies along with societies in general to reduce the impact. |
| Perera, H.s.C & Gunawardana, T.S.L.W.(2014). Modern Consumerist Culture, Its Drawbacks and Benefits | Perera concludes that the world needs to find ways and means to protect and conserve the resource for future generations but | Give recommendations on ways to reduce consumerism and also bring in the concept of Prosumers, consumers who are also producers of the same commodity. |

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| | does not address the how part. | |
| Ottmar Edenhofer, Ramón Pichs Madruga & Youba Sokona. (2012). Renewable Energy Sources and Climate Change Mitigation Special Report of the Intergovernmental Panel on Climate Change | They discuss on different options available to move away from fossil fuel to renewable fuels. But there is no discussion on how to manage the emissions in hard to abate industries. Also, no discussion on how digital technologies can help. | Bring in wholistic recommendations in terms of how to achieve net zero by deploying Carbon Capture technologies and also addressing how Energy companies need to still produce for petrochemicals which forms the back bone of modern civilization. Also touching upon how efficiency and conservation of Energy can play a key role in achieving net zero targets |
| Marco Buttazzoni. (2008). Potential global CO2 emission reductions from ICT use: Identifying and assessing the opportunities to reduce the first billion tonnes of co2 emissions. | Marco gives 10 solutions to reduce the first billion tonnes of CO2. | But there is no deep dive on how digital technologies can play a pivotal role in each of the solution. While we will not delve into all 10 solutions, we will focus on key ones and bring out the digital technologies which will make the impact |

### 3.3 Research Model

This research is primarily secondary research. Several case studies across this topic have been leveraged and have tried to co-relate to the Energy market transformation. The following three principal areas of data has been leveraged.

**Study the relation between growth and emissions.** World Economic Outlook Update, World Bank data, International Energy Agency (IEA), World Economic Forum (WEF) data et cetera. Through this research we have discovered the meaning of real growth and how is emissions related to it. Also, research has tried to establish whether it is indeed possible to have growth without have proportionate emissions.

**Transformation in Energy Market –** To understand the Energy market better. Data collection include open-source data collected from different scientific articles, professional articles, blogs, policies, reports from international agencies for technologies like solar, wind, hydrogen, biofuels and nuclear listed in the below table.

For each of the type of the renewable energy I have researched deeper into diverse types of technologies available to achieve net zero which includes cleaner or abatement technologies as well as carbon capture technologies.

Also researched what are the different Energy companies doing in this space and how they are transforming themselves and hence the Energy Market.

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The case studies referred here provides details on each of the renewable technologies, but do not discuss how in totality it can solve the emissions problems. Also, there is no reference of how digital technologies can help adopt the technology and amplify the impact. This research attempts to provide one stop solution for energy companies to understand the different strategies present to reduce the emissions and pivot to future technologies of green energy leveraging digital technologies.

**Technology perspective:** Have researched on the role technology is playing on Energy and its consumption. Have also tried to understand how technology is helping in achieving the sustainability goals. Some of the secondary data referred to research papers published in ResearchGate, UN, Accenture, PwC, McKinsey et cetera.

CHAPTER 4:

RESULTS

## 4.1 Introduction

The research first focussed first on understanding how Growth and Energy are related and how this contributes to carbon emissions.

Below sections first describes the relationship between **Growth and Energy** and is followed by chapters that captures the key research done in this space, in five main sections

a) Without disrupting the existing ways of consumption of energy. The keyword here is "existing ways" which means no changes in transportation and power sector.

- **Biofuels** – can be blended with existing fuels to reduce the carbon emissions. Does not require change at the consumer end. The existing engine mechanism is good to consume this energy
- **Nuclear Energy** – Energy generated by this can be used to produce thermal power which can be distributed on existing Transmission and Distribution grid.
- **Geothermal energy** – Similar to Nuclear energy

b) Needs changes in the way energy is consumed widely, stored and transmitted. These energies are/can be produced at different places, different mechnism is required to gather, transmit, distribute and also manage the intermittent availability.

- **Solar Power**
- **Wind energy**
- **Hydroelectric Power**
- **Battery technologies** - to store the green power as they are intermittent and seasonal
- **Transmission and Distribution Mordernization** - The infrastructure changes required in the Transmition and distribution to cater to intermitency nature of

renewables, plus the proliferation of small scale generation coming from different sources

- **Hydrogen** – needs new supply chain and Hydrogen engine powered vehicles

c) Research also showed in addition to switching to green energy, there are straegies that needs to be adopted to ensure overall reduction in emissions, but yet meeting the needs of growing population. Under this category the following topics emerged through the research

- **Biological Sequestration and Storage**
- **Carbon Capture Utilization and Storage**
- **Crude Oil to chemicals**

d) Owing to the focus on emissions the research also showed there is evolution of **Carbon Markets** leading to **Carbon trading** as new commodity.

e) Finally research also revealed how concepts like **Consumerism, Circularity** and **Energy efficiency and conservation** play a role in the overall sustainability agenda.

Each of the bolded section above are being described in detail below which includes what energy companies are doing in this space, some of the challenges and how digital technologies are helping in this process.

## 4.2 Growth and Energy

As we progressed, we started questioning what is growth? There are several definitions of growth measured across different parameters like economic growth in terms of Gross Domestic Product (GDP)/year, measure affluence in terms of GDP/per capita, urbanization percentage (Urbanization is the percentage of a country's population who live in urban areas), consumption per capita (the richer the country more the consumption). There are also some social indicators like literacy rate, life expectancy, health care, infant mortality etcetera. The questions now which comes to mind does this measure the growth in terms of wellbeing of the society. After all the society does not exist in isolation. Human beings are social animals, and they survive when they are in harmony with nature and with the creatures in the environments. Morden economic growth indicates endless consumptions of these resources, the more the consumption better the growth, richer the citizens. But is that true?

While there are some social indicators, but does that represent true human growth. Let us see what indicators are available to measure the actual growth- which truly matters to human beings.

### 4.2.1 Growth Indicators

One of the well-known indicators which tries to satisfy the above requirement is Human Development Index (HDI). The Human Development Index (HDI), introduced by the United Nations Development Program in 1990 as noted by Cutler Cleveland (2022), offers a more nuanced perspective on a nation's progress than solely relying on economic indicators like GDP growth or GDP per capita. It emphasizes broader well-being by focusing on three key development goals: health access, education, and access to goods.

The HDI is a composite index that combines three key metrics: life expectancy, educational attainment (both average years of schooling and expected years for future generations), and per capita income. Each nation receives a score between 0 and 1, reflecting a low to high level of development.

This index reveals significant disparities in quality of life across countries and regions. Countries with very high HDI scores (above 0.8) tend to be concentrated in Europe and

North America, while those with low HDI scores (below 0.55) are more prevalent in South Asia and sub-Saharan Africa.

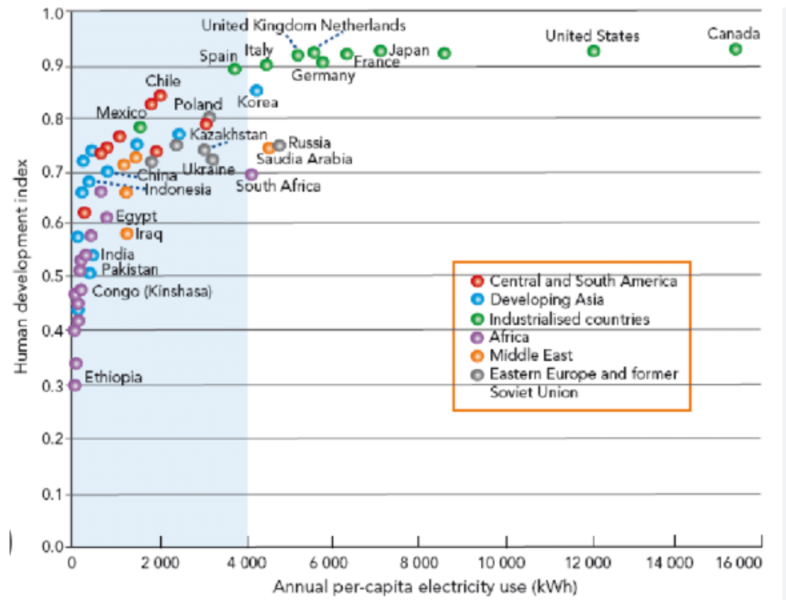

Source: UNDP, Human Development Report (2021-22) (2022) – OurWorldInData.org/human-development-index

*Figure 1:*
*Human Development Index*

While this gives a good indication of quality life, coming to the main topic of this paper, the emissions, let us see how does HDI and emission get related.

### 4.2.2 The Power consumption and Emissions against Growth

Let us stack this up with the power consumption of each country against their development index.




Source: United Nations Development Programme; Our World in Data

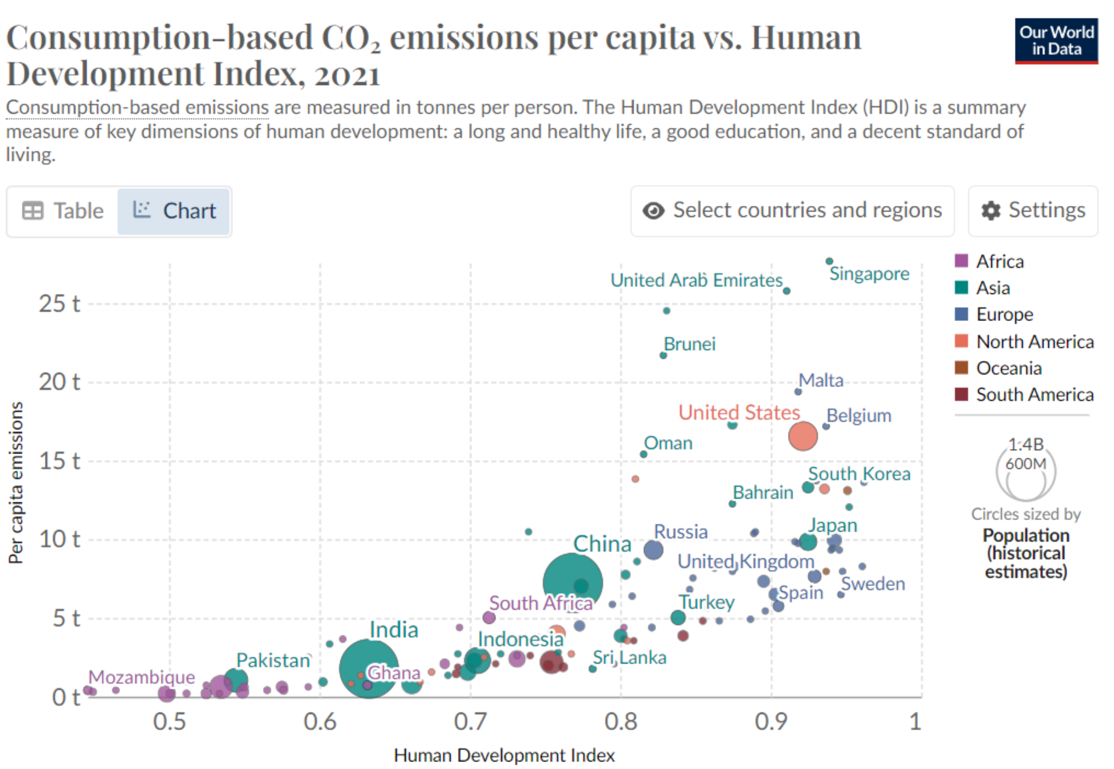
*Figure 2:*
*HDI v/s Annual per capita electricity usage*

Grover, Ravi. (2020) calls out some of the key observation based on the above data

- India -the most populated country has 918KwH consumption for HDI of 0.64
- Whereas Vietnam for the almost same HDI has 76% more consumption of power as compared to India.
- Compare this to US, which has 0.924 HDI but consumes 14 times more power per capita.

A point to be noted, which clearly indicates higher the HDI, higher the consumption of power ie electricity which means more fossil fuels required (in current scenario where over 80% of power comes from fossil fuel), which means more carbon emissions.

We researched on the carbon emissions per capita against HDI.




**Source:** Global Carbon Budget (2023); Population based on various sources (2023); UNDP, Human Development Report (2021-22) (2022)

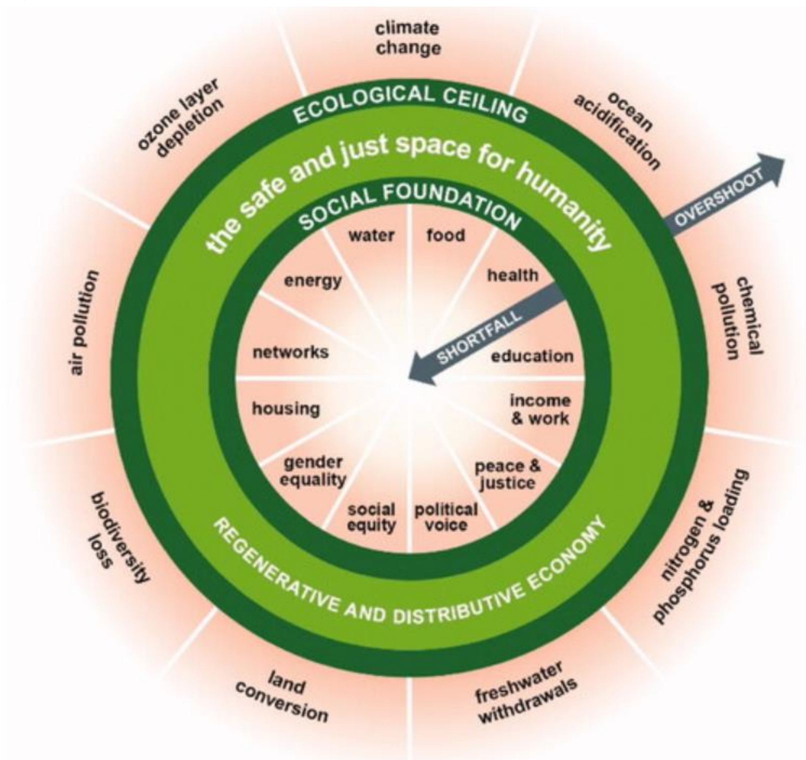
*Figure 3:*
*Per Capita Emissions against Human Development Index*

This graph is not a surprise, lower the HDI, lower the carbon emissions. If you check US, UAE Singapore with almost HDI index of close to 1, clock some of very high emissions. But if you check countries like Sweden, Spain, UK the carbon emissions are much lower compared to the above countries, but still clocking the same HDI. This clearly shows in these countries while the power consumption is high to achieve the HDI, the carbon emissions are low. Which means they are moving more towards greener source of power, perhaps respecting the ecological balance of their environment.

This leads to a question can we start looking at our economy more holistically which respects the ecological/planetary and social boundaries.

### 4.2.3 Measuring growth wholistically

Kate Raworth (2017) in her book Doughnut economics proposes to drastically rethink the goals of economic policy. She suggests drawing the economy as a doughnut and visualizing its social and environmental boundaries. She strongly recommends replacing the fixation with growth of gross domestic product (GDP) with priorities centered on social and ecological needs. Using the doughnut as an orientating metaphor, she points to the need to include multiple social and environmental concerns within economic development strategies.




**Source:** Kate Raworth (2017). Doughnut Economics: Seven Ways to Think Like a 21st Century Economist. Regional and Business Studies, 11(2), 81–86. <https://doi.org/10.33568/rbs.2409>

*Figure 4:*
*Doughnut Economics- Seven ways to Think for 21st economy.*

Ross, Florian. (2020) The inner circle of the Doughnut represents our social foundation, which means all the basic needs we have like water, food, or housing. The outer circle represents our ecological ceiling. If we stay between these two limitations, we are in the safe and just space for humanity, where all people can live in wealth and prosperity and where we do not shoot over the planet’s boundaries. If we fall inside the inner circle, the people will have to suffer because they cannot cover their daily needs. If the use of resources and environmental pollution are so high that they hurt the planet, the economy crosses the ecological ceiling and goes outside the outer circle. As of now we are outside the ecological ceiling. Given the current rate of burning fossil fuels and stressing the ecology around us we are set to cross 3.5 degree rise in temperature as compared to pre-industrial revolution era.

She suggests seven ways to think like 21$^{st}$ century economist, which are listed below:

a) **Change the goal**: Donella Meadows, an American scientist said: “Growth is one of the stupidest purposes ever invented by any culture. We´ve got to have an enough.” Raworth notes, that this 20th century strategy of growth pushed a lot of societies into deep inequality and the world into an ecological collapse. A high quantity of people falls short with their daily needs, but at the same time, we are pushing too much pressure to our planet, which led to climate changes or the breakdown of biodiversity. It is time to get into the sweet spot of the Doughnut and to replace the goal of endless growth for a new one, a 21st century goal. This goal is clear from Raworth´s point of view: To cover both, our as well as our planet’s needs and to live in balance with our environment.

**b)** **See the big picture**: Traditional economics describes the economy always with the same picture, the circular–flow diagram between companies and households. In this the fundamental assumption is that the markets are efficient to run free, trade is beneficial for everyone and society quasi does not exist. She recommends recognize the economy as a complex, dynamic system that is embedded within society and the environment.

**c)** **Nurture Human Nature:** Kate Raworth (2017) says, we must change ourselves from self-interested to socially reciprocating, from fixed preferences to fluid values and from isolated to interdependent ones. That will give us the opportunity to nurture human nature, and due to that, more chances to get in the safe and just space of the Doughnut**.**

d) **Get savvy with systems:** Raworth shows that economy is a complex, constantly changing system and not a simple, stable one like the economists in the 19th century invented. Systematic thinking is more helpful to understand the dynamics of economics, which can be summarized in a pair of feedback loops. Because of that, Raworth says that 21st century economists do not see themselves as engineers who control the economy, but as gardeners who take care and shape it.

e) **Design to distribute:** The basic for that way is the Kuznet curve, which says that when an economy develops, market forces first increase and later decrease economic inequalities. It means that the income per capital first rises to a maximum and causes inequality, until it can decrease it. Raworth criticizes that the economic inequality is not an economical need, it is more a design error. 21st century economists must recognize that a lot of possibilities exist to design economies with the result of more equality when distributing their created values. It means that it is much more, than just distributing incomes, but wealth. Especially when that wealth comes from possessing land, companies, and technologies or from the creation of money.

f) **Create to regenerate:** Kate says that the environmental damage is a result of a degenerative orientation of the industry and that we need a new economical thinking in the next century, which has a regenerative orientation and a more circular approach.

We should change our business model which eats up the planet's resources and spits out just waste into a system, which turns waste back into valuable goods.

g) **Be agnostic with growth:** Kate argues that economic growth will eventually hit a tipping point, it cannot grow infinitely. She suggests that the traditional exponential growth curve has to be replaced by the s curve, focusing on a level where we can cover both, our as well as our planet's needs to live in harmony with our environment.

### 4.2.4 Green Economy

While the above are Kate's view and recommendations, it does make lot of sense in the 21st century. Though she does not address the "How" part of the question.

Another concept evolving is the concept of "Green Economy" United Nation Environment Program (UNEP) defines a green economy as "one that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities. In its simplest expression, a green economy can be thought of as one which is low carbon, resource efficient and socially inclusive."

The Organization for Economic Cooperation and Development (OECD) 2023 Report defines green growth as "fostering economic growth and development, while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies"

Doreen Fedriga et al (2012) The green economy prioritizes investments in clean technologies, natural resources, and social well-being to achieve sustainable growth. This approach emphasizes shifting public and private investments as a key driver for economic development, environmental protection, poverty reduction, and social equality. Policy reforms play a crucial role in facilitating this shift.

A central tenet of the green economy is that social dimensions benefit from these redirected investments. As highlighted in the UNEP's Green Economy Report, strategic investments of just 2% of global GDP into greening ten key sectors can yield significant economic, environmental, and social benefits, provided the right enabling environment exists.
Examples of such enabling policies include fiscal reforms, accurate valuation of natural resources, promoting innovation in green technologies, offering incentives for private sector investment, and fostering stronger collaboration with businesses.

## 4.3 Biofuel

Now that we have established relationship between growth and energy let us now delve into details of fuels powering this growth in a sustainable way. We will first discuss the green fuels which emits less carbon and required minimal modifications to existing systems of transportation, management, and consumption. Let us start with Biofuel.

### 4.3.1 What are Biofuels?

United States Environmental Protection Agency (2018) describes biofuel as any fuel made from organic materials or their processing and conversion derivatives. Tanumoy Bera (2020) explains the term biofuel as liquid fuels used as replacements for or additives to petroleum-based liquid fuel. Biofuel or bioenergy is more commonly used to describe any energy source based on recently produced biomass—everything from food, fiber, wood, grasses, crop residues, and even industrial and municipal wastes.

Biofuels are grouped into three categories based on the type of feedstock used to produce biofuels. Lee et al (2013) describes these categories as **first generation, second generation, and third generation**. Additionally, “Advanced Biofuels” is a term generally used to describe comparatively new biofuel production technologies that use waste such as garbage, spent cooking oil, and animal fats as feedstock.

**Types of Biofuels**

**First Generation**

- Made from edible feedstock like palm, sunflower, Canola, wheat, barley

**Second Generation**

- Made from non-edible feedstock like grasses, crop residues, wood chips, jatropha , jajoba castor, soapnut etc

**Third Generation**

- Made from algae

**Ethanol:**

Ethanol production: Claude Mandil (2010) Currently, ethanol production relies on fermenting sugars from crops like sugarcane, sugar beet, and sweet sorghum, or starches from corn, wheat, and cassava. This process, known as first-generation technology, involves fermentation followed by distillation. While the basic process remains the same in both the feedstocks, the energy required in starchy crops is much more as the starch first needs to be converted to sugar and then to ethanol. Therefore, both from energy required to produce and overall GHG emission sugar-based ethanol are more favorable.

Also producing Ethanol from sugar cane results into many by products which are very useful. A study conducted by OPEC Fund for International Development in 2009, indicates that sugar mills are more self-sufficient in energy. The byproducts generated during the production of ethanol like bagasse, residual fiber is used to co-generate electricity and heat. The excess can be sold on to the consumer electricity grid, which can be additional sources of income.

Ethanol production from starchy crops while the primary product is fuel, a valuable co-product, high-protein distillers' grain, is also generated for livestock feed.

**Where is Ethanol used?** Claude Mandil (2010) up to 10% of Ethanol blend can be used in conventional spark ignition engines. If the engines are modified to suit the biofuels – ethanol can be used 100%. This is practiced in Brazil on a large scale.

While ethanol packs less energy per gallon than gasoline (around 66%), it boasts a higher-octane rating. This translates to improved vehicle performance when blended with gasoline. Additionally, ethanol reduces carbon dioxide ($CO_2$) emissions, a key greenhouse gas. Another benefit is its very low sulfur content, which helps minimize sulfur dioxide ($SO_2$) emissions – a major contributor to acid rain.

However, it's important to note that ethanol use might lead to increased nitrogen oxide ($NO_x$) emissions. These emissions play a significant role in the formation of ground-level ozone, another environmental concern, and contribute to acid rain.

**Biodiesel:**

**Biodiesel production:** Claude Mandil (2010) in his paper explains that unlike ethanol, conventional biodiesel is derived from vegetable oils and animal fats through a process called esterification. Common feedstocks include rapeseed, soybean, palm, and jatropha oils. This process also generates valuable byproducts, such as protein-rich bean cake for animal feed and glycerin, which has applications across various industries.

**Where is Biodiesel used:** Biodiesel offers flexibility. It can be blended with regular diesel or even used in its pure form in compression-ignition engines, without requiring modifications to the engine or fueling infrastructure. While its energy content per gallon is slightly lower than diesel (around 88-95%), the fuel efficiency typically remains comparable. This is because biodiesel improves both lubricity and a property called "cetane level," leading to better engine performance. Additionally, biodiesel use translates to reduced emissions of harmful pollutants like particulate matter and carbon monoxide (CO).

Looking ahead, a more advanced technology known as Fischer-Tropsch (FT) biodiesel is under development. This second-generation technology, also called biomass-to-liquid (BTL) biodiesel, aims to create synthetic biodiesel from biomass sources.

#### 4.3.1 What area of research is required?

There is always a debate between food and fuel. We have a population size of 8.5 billion today and expected to become 10 billion by the turn of this century. This means we will have 10 billion mouths to feed. There is already a huge pressure on the land to cultivate foods. Scientist have started exploring lab grown food to meet the demand. But still it is a long way to solve the huge land requirement for cultivation. Besides this cattle feeding is another area where huge agriculture land is required to grow food for them, which will ultimately land on our plates as animal meat. All this is causing huge stress on the available land and growing potential of our soil. To add to this, we are now talking of growing crops for fuel. All this to save carbon emissions. But is Biofuel really saving on carbon emissions. Growing, harvesting, planting, fertilizing, and watering corn all take up resources. In addition, once corn is harvested, it must be processed to get ethanol, and that ethanol must be transported. This entire process releases large amounts of greenhouse gases. Leah Douglas (2022) reported that Corn-based ethanol, which for years has been mixed in huge quantities into gasoline sold at U.S. pumps, is likely a much bigger contributor to global warming than straight gasoline. The research, which was funded in part by the National Wildlife Federation and U.S. Department of Energy, found that ethanol is likely at least 24% more carbon-intensive than gasoline due to emissions resulting from land use changes to grow corn, along with processing and combustion.

This is the fundamental challenge of Biofuels. However, Tomei et al (2015) argues the food versus fuel argument is a result of the complexity of and interlinkages between energy and food markets. While there is a debate on this, what one miss is the negative impacts of our consumption, forcing us to face the social priorities reflected by the apparent choice between food and fuel. However, even if the demand for biofuel disappears, the issues that the food versus fuel debate has raised will not. Stopping bio-fuel production will not address the need for land to meet growing demand for food, feed, energy, fiber and fertilizer, nor would it tackle our consumption patterns. This area definitely needs to be studied more to have a better understanding of the linkages between food and fuel.

### 4.3.2 What are energy companies doing in this space?

Biofuels are perceived to be used in road transport by mixing with existing fuels. For example, E10 fuels means Petrol mixed with 10% of Ethanol. This is usually prevalent in most of the countries now. India recently announced it will move to E20 blend to reduce it's fuel import bills. In some of the countries, biofuels are predominant fuels. Take for example Brazil. Approx 70% of their vehicles run on flex fuel – with Ethanol being the primary blend. Whereas in China biodiesel is used as primary biofuel. They are running vehicles with 5% blend of biodiesel in diesel vehicles. There is also a push to get vehicles to run on 100% biodiesel.

Recently we are seeing biofuels enter even the marine and aviation industries.

- ExxonMobil (2023) New Bio-Based Marine Fuel Shows Promise in Successful Sea Trial as per their announcement. The biofuel oil is a Very Low Sulfur Fuel Oil(VLSFO), 0.50% sulfur blended with a second-generation Fatty Acid Methyl Ester (FAME) component derived from waste materials and certified sustainable by the International Sustainability and Carbon Certification (ISCC). They demonstrated a 40% reduction of CO2 as compared to traditional fuels.
- Shell and BP are another company which is investing high in biofuels. They are known for rolling our commercial Sustainable Aviation Fuel (SAF) since 2008/2009. This

fuel is made from waste and renewable biomass. It is then combined 50:50 with conventional -oil based fuel. As a result, the fuel can be easily used in the current generation of aircraft delivered via the existing infrastructure.

### 4.3.3 How are digital technologies helping in this process?

Digital Technologies is helping Biofuel industry in the following way as per Aegex (2023)

**Digitalization Enhances Feedstock Material Integrity: Information technology** plays a crucial role in ensuring the quality and origin of biofuel ingredients (feedstocks). These tools enable a more robust auditing process throughout the entire feedstock supply chain, leading to increased value for producers. IT tools capture and record vital data about the feedstock, including its source, the volume collected at the harvesting site compared to the final received amount, and the presence of any unusable material. This creates a transparent and traceable flow of information, simplifying audits. By leveraging digital tools, biofuel producers gain a clear understanding of the feedstock's quality, quantity, and production parameters, leading to better decision-making and improved production efficiency.

**Improved real time Communication with Suppliers**: Advanced IT tools enable instant communication with suppliers, providing real-time location updates. This transparency empowers managers to proactively manage their supply chain, preventing disruptions and optimizing resource allocation. Additionally, these tools offer a comprehensive view of the entire supply chain network, streamlining the sourcing process.

**Predictive Maintenance for Increased Uptime**: As biofuel demand climbs, so does the need for consistent production. Digitalization empowers plant managers to shift from reactive maintenance (fixing problems after they occur) to a proactive approach. This allows them to anticipate and address potential equipment issues before they lead to breakdowns and costly downtime. In fact, a recent report highlights a large-scale biofuel facility that achieved an impressive 80% reduction in unexpected downtime by implementing digital maintenance solutions.

**Increased Productivity:** Digital technology empowers the biofuel workforce to achieve significant productivity and efficiency improvements, ultimately boosting overall business performance. These tools enable factories to adapt quickly to the dynamic and ever-changing nature of the biofuel industry. For example, smart technologies can automate and streamline repetitive tasks, freeing up valuable employee time and energy. This allows teams to focus their efforts on higher-value activities that drive innovation and growth.

**Fueling Innovation:** Digitalization acts as a catalyst for innovation in biofuel product development. By streamlining processes and leveraging real-time data, it significantly reduces the time it takes to bring new biofuels to market. This allows developers to quickly adapt to evolving market needs and consumer demands.

Furthermore, advanced data analysis capabilities provided by digital tools can predict critical trends that will shape the future of the biofuel industry. This foresight empowers researchers to focus their efforts on biofuel solutions that will remain relevant and impactful in the long run.

## 4.4 Nuclear Energy

Now let's understand the next source of green energy. Nuclear energy is not considered renewable because the fuel used to generate the energy is mainly uranium which is finite resource.

### 4.4.1 What is Nuclear Energy

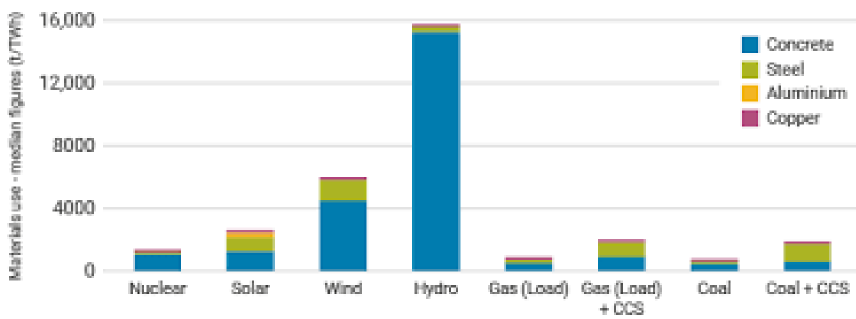
Sir James Chadwick in 1932 discovered neutron, amidst the urgency of second world war. Out of this basic knowledge, came the atomic fission discovery that energy is released when atoms are split. This led in turn to the first controlled chain reaction (1943), the first atomic weapon (1945), and the first production of electricity using nuclear energy (1951). Thus, within a span of twenty years, nuclear energy developed from first principles to practical demonstration.

### 4.4.2 Why Nuclear Energy?

Nuclear Energy has historically been a clean source of energy, currently contributing around 10% of energy in the world and in some advance economies up to 20% of their energy requirement. Besides being clean source of Energy, Nuclear energy also provides the base load energy which is lacking in other renewable sources like Wind and Solar. As long as the atoms are split, heat is continuously generated and thereby generating constant flow of electricity into the grid. Infact, this source of energy coupled with Wind/Solar energy can be one of the best available de-carbonizing solutions. Bruno Comby (2006) calls out over 30 countries more than 400 nuclear reactors provide base-load electric power. This well-proven technology, established for more than fifty years, shows exciting potential for major leaps in the next generation.

Besides this there are several other important factors which really helps Nuclear Energy stand out

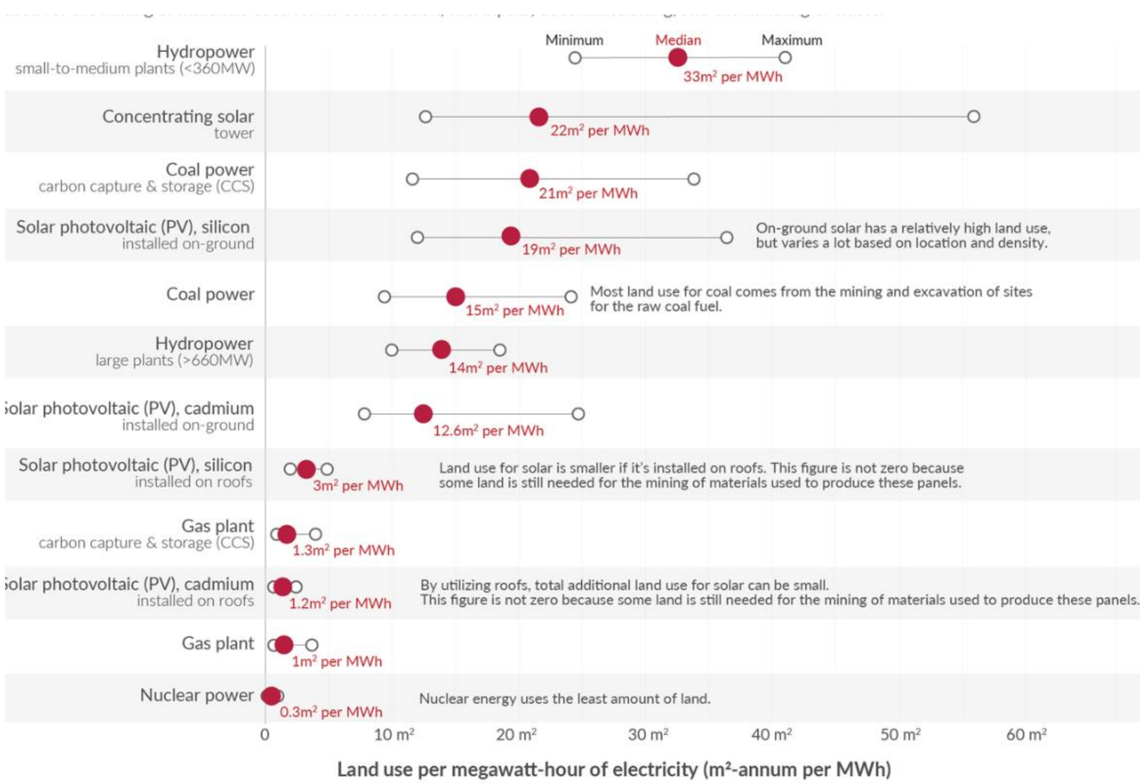
a) Nuclear plants which generate nuclear energy are number one when it comes to efficiently use materials like cement, steel, glass. The below graph from Bright New World (2023) clearly shows the material consumption per TWH is very less compared to other renewable sources like wind, solar and hydro. While Solar takes almost double the material, Wind takes in more than three times and Hydropower takes almost eight times more material to build.



**Source:** Bright New World  Major materials for different generating technologies, ones per TWh

*Figure 5:*
*Material use in different Energy technologies.*

b) Let us look at the land required to generate power. The below chart from Our World in Data shows the range of land required to generate 1 MWh of power. Hannah Ritchie (2022) Land use here is calculated on the life cycle assessment which accounts for land not only for the energy plant but also land used for mining of materials used for construction, fuel inputs, decommissioning, and handling of waste.




Source: Bright New World Major materials for different generating technologies, tones per TWh

*Figure 6:*
*Land use per megawatt-hour of electricity*

c) Very clearly nuclear power stands out as the least land utilizer. To bring in more perspective Bruno Comby et al (2006) gives an example. The author argues that replacing a single nuclear reactor, like the Électricité de France (EPR) in Normandy, France, with even the most advanced wind turbines (standing double the height of Notre Dame Cathedral in Paris) would necessitate a massive wind farm. Imagine rows of these turbines stretching all the way from Genoa, Italy to Barcelona, Spain, roughly 700 kilometers (400 miles). Despite this much land consumption the average yield of power is only about 25-40% of their rated capacity. Compare this with Nuclear power generation, whose yield is 90%+. Clearly Nuclear power stands out here.

d) The other common misconception is the safety associated with nuclear power generation. Let us again look at data from Our World in Data. Hannah Ritchie (2020)

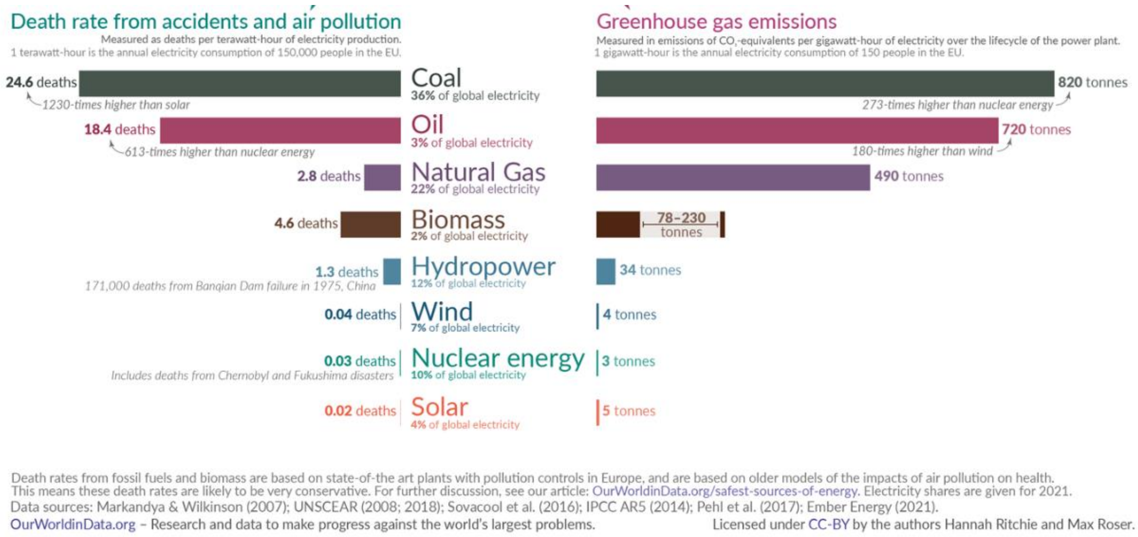


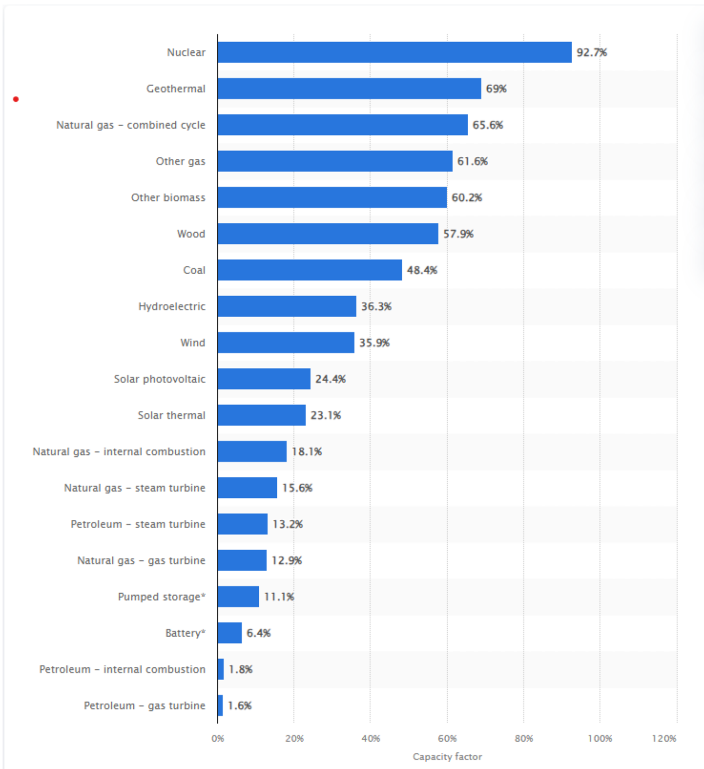

*Figure 7:*
*Death rates from different types of fuels and associated carbon emissions of the fuels*

Clearly Nuclear Energy along with Solar energy stands out in terms of having least death rates and lower carbon emissions. He explains this with an example of a hypothetical town with 150, 000 people called Euroville. Now if we assume Euroville is completed powered by the below sources of energy, it will result in the following premature deaths per year

- Coal: 25 people would die
- Oil: 18 people would die
- Gas: 3 people would die
- Hydropower: 1 person would die
- Wind: In an average year, nobody would die. A death rate of 0.04 deaths per terawatt-hour means every 25 years, a single person would die.
- Nuclear: In an average year, nobody would die – only every 33 years would someone die.
- Solar: In an average year, nobody would die – only every 50 years would someone die.

But when you compare with the yield and energy efficiency of solar and nuclear, nuclear stands out.

e) Capacity factor of each of these sources of energy.




Source : https://www.statista.com/statistics/183680/us-average-capacity-factors-by-selected-energy-source-since-1998/

*Figure 8:*
*Average capacity factors of different energy sources*

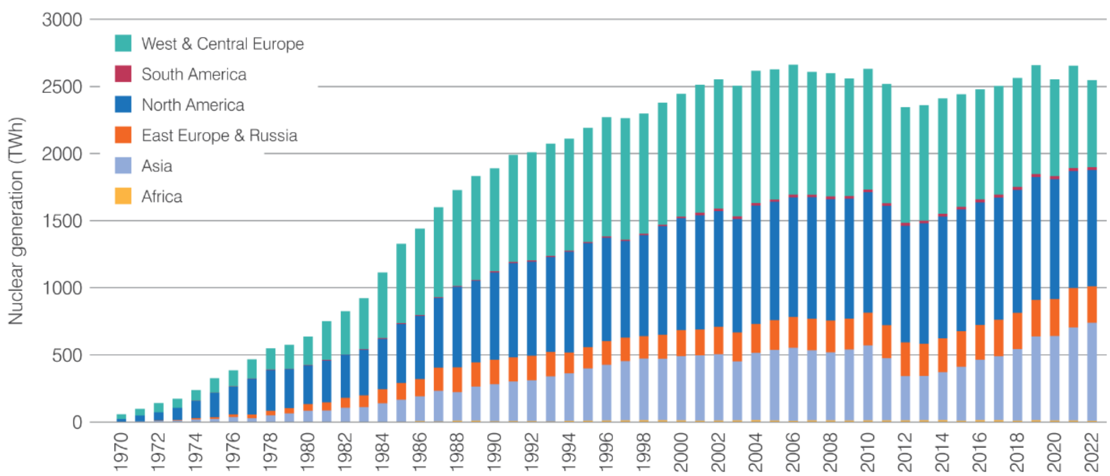
The above data from United States in 2022 clearly calls out that nuclear has highest capacity factor compared to any other energy source. What does this mean? This means nuclear power plants are producing maximum power 92% of the time during the year which is nearly two times more of natural gas and coal units and close to three times more than wind and solar. Now the next question is why is nuclear power plants more reliable?

- Nuclear power plants typically require less maintenance and are designed to operate for longer stretches before refueling (typically every 1.5 or 2 years).

- Natural gas and coal capacity factors are generally lower due to routine maintenance and/or refueling at these facilities.
- Renewable plants are intermittent and are mostly limited by a lack of fuel (i.e. wind, sun, or water). As a result, these plants need a backup power source such as large-scale storage (not currently available at grid-scale)—or they can be paired with a reliable baseload power like nuclear energy.

With so many benefits it is obvious the world is focusing on producing Nuclear Energy

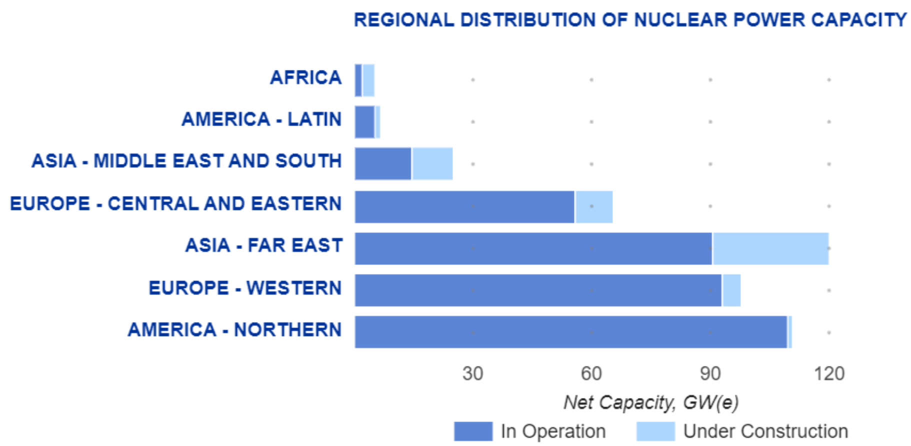
### 4.4.3 How much Nuclear Energy is produced?



Source : World Nuclear Association and IEA Power Reactor Information Service (PRIS)

*Figure 9:*
*Nuclear generation capacity across the globe*

Clearly over last 50 years the energy produced from nuclear generation has grown over thousand times. Almost all geographies except Africa seems to have equal %age of nuclear generation. Let us compare this with the Nuclear power reactors currently available in the world. The below is the data obtained IAEA PRIS – Power reactor information system.




Source: https://pris.iaea.org/pris/home.aspx

*Figure 10:*
*Regional distribution of operation and under construction nuclear capacity*

Africa is lacking the stack where Asia/Europe and America are almost comparable- similar to the nuclear energy being produced. Asia is very bullish on the nuclear power and is investing heavily in building more power reactors.

Having said this there are certain issues with Nuclear Energy as well. Afterall nothing is perfect in this world. Let us understand the issues.

### 4.4.4 Issues with Nuclear Energy

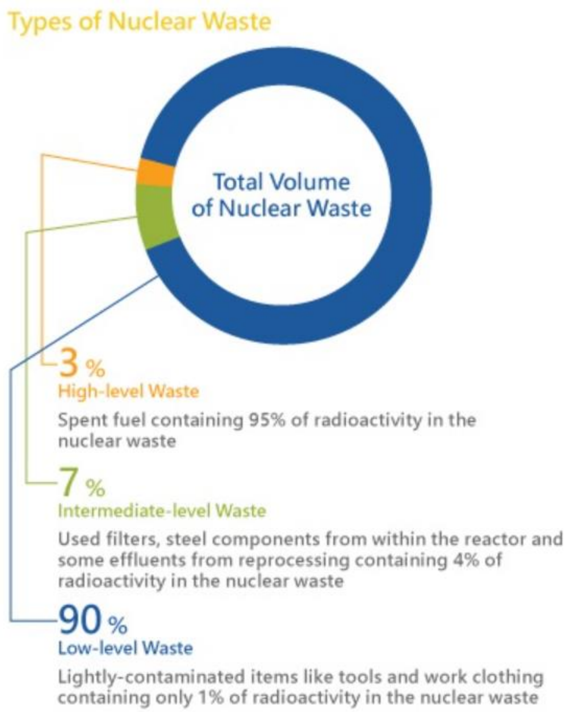
There are primarily two major concerns.

a) Radioactive waste generated - A key environmental concern with nuclear power is the generation of radioactive waste. This includes leftover materials from uranium processing (mill tailings), used nuclear fuel (spent reactor fuel), and other radioactive byproducts. These materials remain radioactive and potentially hazardous for millennia.

b) Proliferation of nuclear weapons – The same technology used to make nuclear fuel for power plants can also be used to produce explosive material for nuclear weapons

While the second issue is more societal and politically driven, the first one is easier to manage and control.

Let us focus on the first issue and understand more in detail. As per World Nuclear Association (2023) the waste from nuclear reactors can be classified according to their radioactivity which are low, intermediate, and high level. The vast majority (around 90%) of the waste is low-level. This low-level waste consists of lightly contaminated items like tools and clothing, but it only holds around 1% of the total radioactivity. In contrast, high-level waste makes up a much smaller portion of the total volume (only 3%). However, it's far more radioactive, containing a staggering 95% of the total radioactivity. This high-level waste primarily consists of used nuclear fuel, also called spent fuel, leftover from nuclear reactions.




Source: https://world-nuclear.org/nuclear-essentials/what-is-nuclear-waste-and-what-do-we-do-with-it.aspx

*Figure 11:*
*Types of Nuclear Waste*

3% of high-level waste is what needs to be managed well.

After use, nuclear fuel is stored in either wet or dry facilities before being recycled or permanently disposed of. This initial storage period is crucial because freshly removed fuel is both hot and highly radioactive. Storing it underwater allows the fuel to cool significantly. After a period of initial cooling, the fuel can remain in wet storage or be transferred to a dry storage facility. This temporary storage allows both the heat and radioactivity to decrease over time, making the fuel safer and easier to manage for future recycling or disposal.

From here onwards two strategies are being used. Some of the countries like USA treat the nuclear fuel as waste, while some of the countries like France, Japan, Germany, Belgium and Russia recycle this fuel to extract plutonium and uranium. These elements are then used in conventional reactors to produce more power. While most used nuclear fuel can potentially be recycled, a small portion (around 4%) requires permanent disposal. These byproducts, primarily fission products, are highly radioactive and need to be immobilized for safe storage. Vitrification is a process that encases these materials in a stable glass form, significantly reducing the risk of leaks or contamination.

#### 4.4.5 What are energy companies doing in this space?

Several Power generation companies are investing, building, and operating several nuclear reactors to augment their power production. For example,

As per Wikipedia (2023) on List of Companies in the nuclear sector

- EDF energy in France operates around 58 reactors across 20+ sites.
- EnBW a subsidiary of EDF, through its subsidiary EnBW Kernkraft GmbH operates the Philippsburg Nuclear Power Plant, Obrigheim Nuclear Power Plant, and Neckarwestheim Nuclear Power Plant.

- Enel - has nuclear activities in Russia, France (a 12.5% stake in the Unit 3 of Flamanville Nuclear Power Plant), Slovakia (66% stake in Slovenské elektrárne), Spain (92% stake in Endesa) and Italy (a joint venture with Edf named Sviluppo Nucleare Italia Srl).

- Tokyo Electric Power Company - Tokyo Electric Power Company, (TEPCO) is the largest nuclear operator in Japan. It operates the Fukushima Daiichi Nuclear Power Plant, Fukushima Daini Nuclear Power Plant, and Kashiwazaki–Kariwa Nuclear Power Plant.

- Duke Energy in United States operates the Catawba Nuclear Station, Oconee Nuclear Station, and McGuire Nuclear Station. It plans to build the William States Lee III Nuclear Generating Station.

- Dominion Resources through its three daughter companies operates the Kewaunee Power Station (556 MW, northeastern Wisconsin), Millstone Nuclear Power Plant (2,103 MW, Connecticut), North Anna Nuclear Generating Station (1,806 MW) and Surry Nuclear Power Plant (1,598 MW) in United states.

- Nuclear Power corporation of India - Nuclear Power Corporation of India Limited is a public sector enterprise generating about 3% of the total electricity production in India. It operates Tarapur Atomic Power Station, Rajasthan Atomic Power Station, Madras Atomic Power Station, Narora Atomic Power Station, Kakrapar Atomic Power Station, Kaiga Atomic Power Station, and Kudankulam Nuclear Power Plant.

### 4.4.6 How is digitalization/IT helping in this process?

Touichi Shida et al (2001) in their paper state that IT has two main objectives.

To improve business efficiency and increase the reliability of plants.

Basic approach is divided into three parts:

- **Data Centralization and Integration**: An Enterprise Resource Planning (ERP) system integrates data from key manufacturers, fostering centralized information management for efficient decision-making.
- **Enhanced Business Connectivity:** Intranet and extranet technologies strengthen communication and collaboration between internal and external stakeholders, optimizing processes and fostering innovation.
- **Knowledge Management for Technical Expertise:** Knowledge management practices ensure the preservation and improvement of technical knowledge related to nuclear power plants, promoting safety and operational excellence.

When it comes to managing the Plat operation different IT intervention can be seen. IEA (2002)

a) **Engineering Document Management**: Think of Engineering data management (EDM) as digital filing cabinet for all engineering documents. It uses computers and storage systems to organize various documents, such as reports, drawings (including CAD), specifications, sales order, and even photos or videos. An EDM system acts as a central hub, allowing users to create, store, edit, print, and manage these documents electronically. This includes features like version control, ensuring you always have the latest version on hand. It acts like a one-stop shop for all your engineering project information. EDM systems can connect to various databases and often include tools for scanning paper documents, editing them electronically, and even printing physical copies if needed. Powerful server computers manage the system, ensuring everything is organized and readily accessible.

b) **Asset Management:** Keeping track of the plant’s equipment is crucial, and an effective asset management system can help. This system categorizes equipment data into two key areas:

a. **Function Data:** This data, typically linked to equipment tags and described in design documents, details what each piece of equipment does in the plant.

b. **Asset Data:** This data focuses on the physical equipment itself (often identified by a serial number) and its role in fulfilling its designated function. The asset management system empowers to:

- **Track Equipment Easily**: Quickly find specific equipment by searching for its tag number.
- **Maintain Status Records:** Keep tabs on the current status of each equipment piece, including its assignment and any downtime.
- **Access Historical Information**: Gain insights into past maintenance records, location history, service logs, and exposure data for each equipment item.
- **Locate Relevant Documents**: Access the latest versions of related documentation, such as design data, supplier information, registration documents, and maintenance instructions.

These are just few examples of where IT is helping in Nuclear Power Plants.

In summary IT is leveraged for large scale simulations right from the optimum mix of fuels, optimum usage of catalyst, optimum carbon emissions in terms of scope 1 and scope 2, ensuring reliable supply chains, matching demand and supply of power, safe disposal of waste, recycling, communications etcetera.

### 4.4.7 Summary

Nuclear power can be one of the best options to rapidly reduce carbon emissions and still meet the ever-growing demands of our people and society at large. With due attention to security and responsible management of waste nuclear energy can solve lot of our modern-day energy challenges.

### 4.5 Geothermal

Having studied biofuels, nuclear energy let's now explore the next source of green energy – geothermal energy.

#### 4.5.1 What is Geothermal Energy?

Geothermal is made up of two words, Geo – means earth and thermal means heat.

It is the heat energy, which is trapped in the subsurface of the earth, which originates from the radioactive decay of material in the core of the earth. The heat is maximum at the core and can reach about 5200 degrees Celsius. The heat decreases as it moves away from the core. The heat can be felt down at 20-30 feet of the earth's surface at around 50-60 degree Celsius.

National Geographic Education (2023) in their article on Geothermal Energy articulates that as we go deeper underground in most places around the world, the geothermal gradient increases by about 25 degrees Celsius per kilometer of depth.

When we think of Geothermal energy immediately Iceland's dramatic landscapes with spouting geysers and wispy steam clouds comes into our mind. While Iceland utilizes this resource remarkably by capturing almost 60% of its energy needs, most geothermal heat lies hidden beneath the Earth's surface. Unlike the dramatic geysers, this heat resides deep within the mantle, slowly radiating outwards and forming pockets of intense thermal energy. This dry geothermal heat can be accessed by drilling and enhanced with injected water to create steam.

IEA (2022) defines Geothermal energy as an energy that is available as heat contained in or discharged from the earth's crust which can be used for generating electricity and providing direct heat for numerous applications such as space and district heating, water heating, aquaculture, horticulture and industrial processes.

It is estimated that 0.1% of earth's total heat content can meet our energy needs for 2 million years according to Arpa-e projects. Besides this there are several advantages of geothermal energy.

Advantages of Geothermal energy as per IRENA (2017) is that it is available year-long, whereas solar and wind energy depends on when sun shines and wind blow- giving rise to high variability and intermittence. Besides Geothermal energy can be found around the globe, giving equity in energy availability. Geothermal power has considerable potential for growth. The amount of heat within 10,000 meters of the earth's surface is estimated to contain 50,000 times more energy than all oil- and gas resources worldwide Shere J. (2013).

Geothermal energy help solve the base load demand as this energy can be generated 24/7 and 365 days. Besides this is completely renewable energy,

Let us now understand how to generate this energy and direct it for consumption.

### 4.5.2 Geothermal Power Generation

The heat content geothermal field will define the power generation capabilities. Obinna Derek Madueke (2021) in his paper lists four main types

- **Direct Dry steam plants**: These plants use steam directly from a geothermal reservoir to operate generator turbines. This type of geothermal power plant requires 150° C or higher quality of steam. Usually, the steam entering the turbine must be at least 99.9 percent dry. The capacity of direct dry steam plants range between 8 MW and 140 MW. This dry steam is vital to avoid turbine and turbine auxiliary scaling.
- **Binary plants**: These plants transfer the geothermal hot water heat to another liquid. The heat causes the second liquid to transform into steam that can be used to power a turbine. The size of binary plants is between 1 MW and 50 MW.

- **Flash plants**: Flash plants are the most common type of geothermal power plant around. They tap into the Earth's heat by using high-pressure hot water from deep underground. This hot water is then rapidly converted into steam, which spins a turbine to generate electricity. The clever part is that once the steam has done its job, it's cooled down and condensed back into water. This water is then pumped back down into the earth, making it an environmentally friendly process. Flash plants come in different sizes. Single flash plants are smaller, typically generating between 0.2 and 80 megawatts (MW) of electricity. Double and triple flash plants are larger and more powerful, producing from 2 to 150 MW.
- **Hybrid plants:** These power plants combine two cycles to maximize efficiency. They use a traditional Rankine cycle (boiler produces heat which converts water to steam which rotates the turbines to produce power), but with a twist! Instead of wasting the leftover heat, they incorporate a binary cycle to generate additional electricity from it. This innovative approach allows them to extract more power from the geothermal source. The size of these hybrid plants typically ranges from a few megawatts (MW) to up to 10 MW.

### 4.5.3 What are Energy companies doing in this space?

Geothermal market is growing. Energy Source in 2022 (2022) A report by Fortune Business Insights Geothermal Energy Companies with Advantages and Disadvantages of the Clean, reveals that the geothermal energy market was valued at USD 52.87 billion in 2020. Furthermore, the market is projected to experience significant growth, reaching USD 83.27 billion by 2028. This represents a compound annual growth rate (CAGR) of 5.9% during the forecast period (2021-2028). Several energy giants like Shell, Chevron, BP, TotalEnergies are investing in this technology. Shell has secured geothermal exploration in Rotterdam, Netherlands along with Eneco. Carlo Cariaga (2023) in her article in Think Geoenergy calls out that TotalEnergies completed a geothermal assessment which integrates right from subsurface to wells to topside elements and provides guidance to include in offshore renewable energy portfolio.

Oil and Gas companies have natural leverage in geothermal space. They can leverage their knowledge of subsurface and drilling expertise to tap into the heat source. The drilling is very similar to vertical and horizontal (fracking) drilling. R. Schulz et al (2023) in his chapter alludes to the fact that all geothermal technologies will realize near term benefits from oil and gas technology spillover which will provide quick wins and achievable learnings projected to deliver 20 to 43 percent in cost savings, depending on the type of geothermal technology.

Besides Energy companies there are several startups and heat pump service providers emerging in this area. For example, Dandelion Energy, a startup based in Mount Kisco, New York is setting up ordinary homeowner's access to geothermal energy from beneath their subsurface. With the help of heat pump technologies, consumers themselves can setup their own cooling and heating facilities in their home (much like roof top solar panels) and reduce the dependency on grid for electricity or oil/gas for heating/cooling.

IEA (2022) in their report on "The Future of Heat Pumps" report describe that heat pump works much like the technology found in refrigerator. The compressor initiates the cycle by mechanically raising the pressure and temperature of the refrigerant. This high-pressure, high-temperature refrigerant then travels to a heat exchanger (condenser) where it rejects heat to the surrounding environment (heat sink). Beyond their well-established function of space heating in winter, many heat pumps offer the additional capability of space cooling in summer, thus providing year-round thermal comfort. In industrial settings, heat pumps find diverse applications, delivering hot air, water, or steam for various processes, or even directly heating materials. Notably, large-scale heat pumps employed in commercial, industrial facilities, or district heating networks necessitate higher input temperatures compared to their residential counterparts.  Fortunately, these elevated requirements can be met by utilizing waste heat from industrial processes, data centers, or wastewater treatment facilities.

There are different types of geothermal heat pump systems. Energy.gov (2023) US Department of Energy calls out four basic types of ground loop systems. Three of these -- horizontal, vertical, and pond/lake -- are closed-loop systems. The fourth type of system is the open-loop option. Several factors such as climate, soil conditions, available land, and local installation costs determine which is best for the site. All these approaches can be used for residential and commercial building applications.

Earlier heating pumps was kind of restricted to individual single house or small buildings as they had easy access to earth surface. But recently there have been evidence of apartment complex installing massive geothermal. Case in point is the report from Diana Olick (2023) where in massive 500ft boreholes are being drilled in Brooklyn that will house the largest residential apartment complex in US. They will be using this for everything from heating the swimming pool, heating domestic water and cooling & heating of every apartment in the building complex. If this is successful and delivers on cost economics, then it can be a game changer in decarbonizing cities from building emissions perspective.

#### 4.5.4 How are digital technologies helping?

Bello et al (2020) calls out in their paper the main drive for geothermal energy exploration and development is to achieve highest level of safety and lowest operational cost while ensuring optimum drilling performance.

Studies indicate that over 58% of geothermal project expenditures are allocated to drilling operations. This phase is inherently time-dependent, characterized by the drilling and subsequent flooding of numerous wells, generating a significant volume of complex data at a rapid pace. However, advancements in technological capabilities, including the Internet of Things (IoT), machine learning, advanced data analytics, and artificial intelligence, offer significant potential for leveraging this accumulated geothermal drilling data. The application of these technologies presents substantial opportunities to optimize drilling processes, reduce costs, and drive technological advancements throughout the entire geothermal project lifecycle.

Having understood the technologies that can be leveraged to produce green energies let's shift our focus now to renewable sources of energy which is another source of energy and is fueled by infinite source from nature.

## 4.6 Solar Power

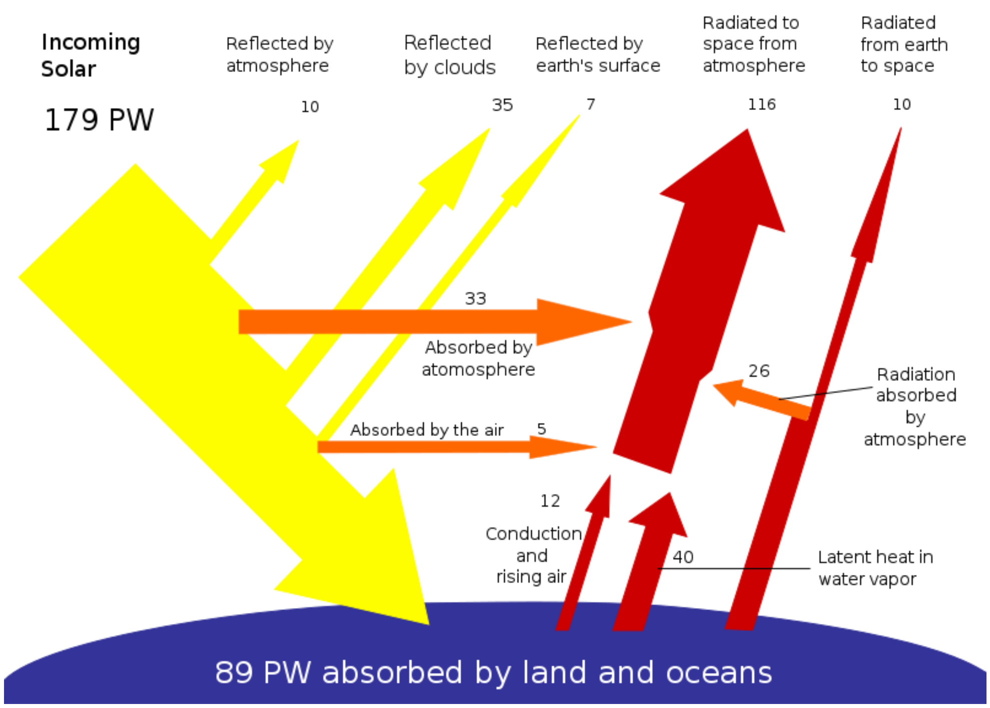
Let us first start with solar power which is powered by the source of all energy - our Sun.

### 4.6.1 What is Solar Power

Solar Energy is abundantly available in nature. Sun is center of our solar system, and everything revolves around sun. It is unlimited sources of energy and easily available. We only need to figure out mechanism to capture the solar energy.

Solar energy is measured in Petawatt. To put in perspective, US grid provide enough energy to power 10 billion 100W light bulbs. Petawatt is 1000 times more power than that. Total amount of energy consumed by humans in all forms like oil, gas, coal, hydro, nuclear etcetera as per International Energy Agency (IEA) (2021) is approximately 23TWh. Compare this to 179PW of solar energy hitting earth. Ram Chandra Poudel (2021) This is around 10,000 times more than the energy consumed by humans. In other words, Every hour, more solar energy reaches the Earth than humans use in a year. It is therefore a great abundant source of energy which should be tapped.

Let us try and understand how this energy behaves when it hits the surface of the earth. Frank van Mierlo (2008) came up with this simple diagram which shows the amount of solar energy hitting the surface and the channels through which it gets reflected. The below diagram clearly shows that about 179PW hits earth out of which around 29% gets reflected by atmosphere, cloud and earth's surface. About 21% gets absorbed by atmosphere and air. Most importantly approx. 50% gets absorbed by land and oceans. This helps in producing water vapor, which ultimately leads to clouds and then rain




Source: Frank van Mierlo. http:yyupload.wikimedia.orgywikipediaycommonsy5y50yBreakdown_of_the _incoming_solar_energy.svg

*Figure 12:*
*Breakdown of the incoming solar energy.*

Let us understand how this energy can be trapped and used.

- **Space Based Solar Power Generation:**

Around 30% (52PW) gets reflected back into space. This gives us a huge opportunity for us to trap this energy and convert into useful energy. This is where the Space Based Solar Power (SBSP) comes into picture.

The idea of collecting solar power in space and transmitting it to the Earth using microwaves was initially proposed in a technical paper by P. E. Glaser in 1968.

P. E. Glaser (1968) This is like building solar panels in space, like what we have on the earth. Solar energy is normally collected by solar collectors or light structures of solar arrays and electronics devices convert it in some other form of energy i.e., microwave or laser for sending it on Earth.

Microwave as energy source is usually considered safer to living beings than other energy resources. Therefore, the idea of generating solar power from space have attracted many space enthusiastic people for doing new innovations.

The main advantage of SBSP is that it beats the very intermittent problem of solar power on earth. Since there is always solar power available in space, it can produce 24/7 solar power and transmit it to earth. It does not rely on seasonality, weather conditions etcetera all of which are major issues on Earth. Also, since energy is transmitted through Microwaves transmission losses are very less compared to traditional transmission.

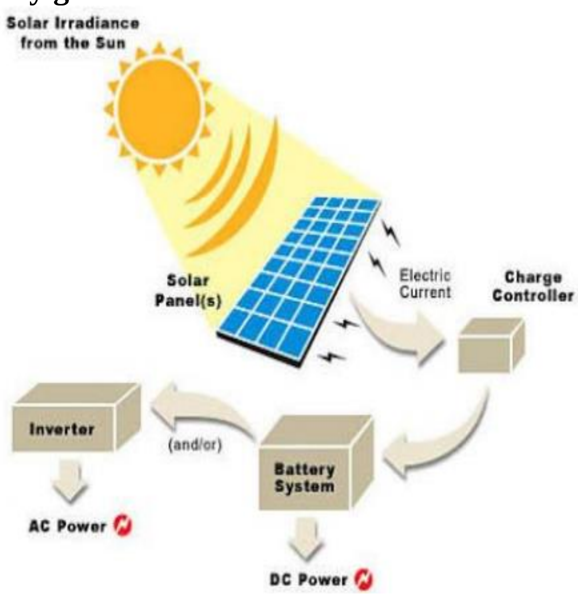
Gosavi et al. (2021) conducted a comprehensive analysis of Space-Based Solar Power (SBSP) and acknowledged its potential for sustainable energy solutions. However, their research also highlighted the challenges associated with SBSP implementation, including not only the slow development of feasible technology but also the significant economic costs involved. Continuous research and technological advancements are crucial to expedite the development and cost reduction necessary for the successful realization of SBSP as a viable energy source.

- **Solar Power Plant on earth:**

  As shown in the above figure Earth receives around 70% of the solar energy. Remaining 30% gets reflected back into the atmosphere. This 70% of the energy can be trapped to produce electricity and heat required for human population.

Let us delve deeper into both these buckets of electricity and heat generation.

### 4.6.2 How is electricity generated?




Source: Electricity generation: Shaikh, Mohd Rizwan et al (2017)

*Figure 13:*

*Power generation from Solar energy.*

The primary component required for generating electricity from Solar Power is thruogh Photovoltaic (PV) cells. They are constructed from various semiconductor materials exhibiting distinct p-type and n-type electrical characteristics. Upon exposure to sunlight, these materials absorb photons, causing the excitation and liberation of electrons from their atomic orbitals. This process generates an electric current within the cell.

Multiple PV cells are encapsulated within an environmentally protective laminate to form a PV module. To meet specific energy requirements, these modules can be interconnected in series or parallel configurations. Series connections serve to increase the overall voltage output, while parallel connections augment the current output of the array. A typical PV module can generate a maximum power output of approximately 180 W under conditions of full sunlight.

The total solar electricity production of a PV system is directly proportional to the total surface area of the deployed array. In simpler terms, larger arrays with a greater surface area will generate more electricity.

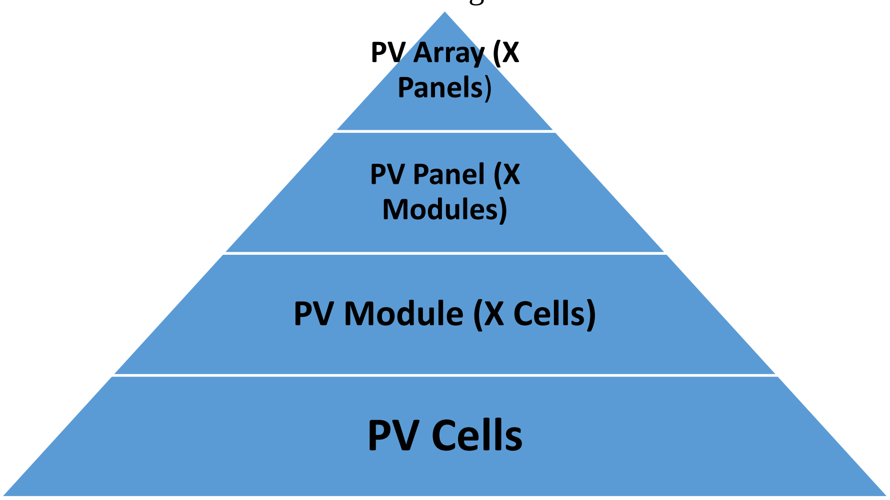



*Figure 14:*
*Hierarchy of the PV configuration*

Having understood how the electricity is produced we looked at how heat is generated.

### 4.6.3 How is heat generated?

Heat Generation: Khan et al. (2013) described Solar Thermal Electric (STE) power generation as a method that utilizes concentrated sunlight to produce high-temperature heat. This heat then drives a heat engine for electricity production. The system collects solar energy in the form of thermal energy using mirrors or lenses that track the sun's movement and focus the concentrated solar radiation onto a receiver. The authors further identified three primary solar collector geometries for STE applications: non-concentrating, concentrating to a line (line-focus), and concentrating to a point

**a) Non-concentrating:** EIA (2024) Solar thermal systems for building applications typically utilize non-concentrating collectors, where the aperture area – the surface area intercepting solar radiation – coincides with the absorption area – the surface area responsible for capturing solar energy. Flat-plate collectors represent the most prevalent type of non-concentrating collector for both domestic hot water and space heating in buildings. Their application is particularly suited for scenarios where temperature requirements are below 200°F (approximately 93°C).

**b) Concentrating to a line:** Shaikh et al. (2017) discussed parabolic trough collectors, which utilize linear parabolic reflectors to concentrate sunlight onto a receiver positioned along the focal line of the reflector. The receiver typically consists of a tube positioned directly above the center of the parabolic mirror and containing a working fluid. As this fluid flows through the receiver, it absorbs the concentrated solar radiation, achieving temperatures ranging from approximately 150°F to 350°F. The thermal energy stored in the heated fluid is then employed as a heat source for a power generation system.

c) **Concentrating to a point:** Parabolic dish systems are the primary technology employed for this collection geometry. These systems resemble large satellite dishes but utilize mirrored reflectors instead and concentrate solar radiation onto an absorber positioned at the focal point. This configuration achieves optical efficiencies of approximately 30%, representing the highest conversion performance among concentrating solar power technologies. Parabolic dish systems are capable of generating heat in the megawatt (MW) range within a solar power plant.

Having said this Solar power is directly used in some of the day-to-day activities. They are used to heat water. Several houses in west Asia have installed solar heaters which uses solar heat to heat the water for domestic use. Similarly solar cookers are used to convert solar energy to heat energy, which is then used to cook food. Usually, this cooker is outdoor to trap the solar energy. Now there have been innovations made in this space which allows to cook food inside. Recently Indian Oil launched world's first indoor solar stove which can be used to cook wide variety of foods.

Now having understood the different ways the Solar power is used to generate electricity and thermal power, we shifted the focus of research to how the panels are produced.

### 4.6.4 How is solar equipment for electricity generation produced?

Main component of solar electricity generation is Photovoltaic cell. Hudedmani et al (2017) articulated that usually PV cells are of two types a) Mono crystalline silicon solar cell b) Polycrystalline silicon solar cell c) Thin-film solar cells.

a) **Mono crystalline silicon** solar cells are fabricated from high-purity silicon ingots. Mallikarjun G Hudedmani et al (2017) These ingots are sliced into wafers with precise dimensions on all four sides, resulting in high conversion efficiency (20-21%). Monocrystalline silicon solar panels offer superior space efficiency and boast power outputs two to three times greater than thin-film technologies. They also exhibit a lengthy lifespan, typically exceeding 25 years. However, their performance is susceptible to environmental factors such as shading, dust accumulation, and snow cover. In severe cases, these elements can interrupt the electrical circuit and significantly reduce power generation. Additionally, while monocrystalline silicon cells perform well in warm temperatures, their efficiency tends to decrease as the operating temperature rises.

b) **Polycrystalline silicon solar cell**: Mallikarjun G Hudedmani et al (2017) This cell manufacturing process utilizes a square mold for casting molten silicon. Following solidification, the silicon ingots are precisely cut into rectangular shapes, minimizing material waste. This approach offers a significant advantage in terms of silicon utilization compared to monocrystalline manufacturing techniques.

c) **Thin film solar cells**: Mallikarjun G Hudedmani et al (2017) This approach deviates from conventional crystalline silicon photovoltaic cell manufacturing. It employs a thin-film deposition process, where layers of photovoltaic material are precisely applied onto a substrate. This technique facilitates large-scale, cost-effective production compared to crystalline silicon technologies. However, these thin-film solar cells exhibit moderate conversion efficiency, necessitating a larger surface area to achieve equivalent power output. Additionally, their efficiency degrades at a faster rate over time relative to mono- and polycrystalline solar panels.

### 4.6.5 What are some of the issues?

Article published by Carbeck, J. (2016) in World Economic Forum articulates the challenges.

Silicon photovoltaic (PV) cells need silicon as base material in its purest form. But this material is rarely found in its purest element form. Our beach sands are tremendous sources of silicon dioxide from where silicon can be extracted but it is very challenging.

- The dissociation of silicon dioxide ($SiO_2$) to obtain pure silicon for photovoltaic (PV) cell production necessitates a significant energy input. This process conventionally involves carbothermic reduction within a high-temperature electric arc furnace, operating at temperatures ranging from 1500-2000 °C. This extreme energy consumption inherently establishes a fundamental constraint on the minimum production cost of silicon PV cells.

Furthermore, the reliance on such energy-intensive processes contributes to greenhouse gas emissions associated with silicon PV cell manufacturing.

- Silicon solar cells are very rigid and weighs heavy. To derive maximum efficiency silicon PV cells should be housed flat in large and heavy panels. But those panels make large-scale installations very expensive, which is in part why you typically see them on rooftops and big solar "farms."

- A significant challenge associated with conventional solar cells is their limited power conversion efficiency. These cells have historically exhibited efficiencies that have remained relatively stagnant at around 25% for the past one and a half decades Lexie Pelchen (2023). According to Lexie Pelchen (2023), citing industry data, the average efficiency of solar panels was previously around 15%. However, advancements in photovoltaic technology have enabled contemporary solar panels to achieve efficiencies ranging from 15% to 22%, with high-efficiency models reaching nearly 23%.

### 4.6.6 What area of research is required?

Given the challenges we need more technological advancements and research in the following area:

- Increase the efficiency and life of solar PV cells. Currently life is stuck around 20-25 years and efficiency around 25%.
- The space required for solar panels is very high. To generate 1MW of output, approximately 5 acres of land is required which is almost 100 times more than fossil fuels. Need designs and solutions which will occupy less space. Garvin Heath et al (2022) suggests further research on increasing the systems longevity of PV Modules and other system components, then the same land can be kept longer. One of the suggestions emerging from this research is usage of contaminated land for setting up

of solar panels. Also, if the efficiency of the solar PV cell is increased then the same piece of land can produce more electricity.

- Storage of energy when sun is not shining. Currently battery solutions are very expensive, and they come with their own challenges of carbon intensive mining, manufacturing, and disposal. India has come out with the idea of One Sun One World One Grid (OSOWOG) which tries to solve the intermittency problem. Hardik Patel (2020) in his paper calls out the main constraint in this development-orientated long-term infrastructure is the lack of source for finance, co-operation across multiple countries and most importantly continuing of current Modi government to carry on the vision.
- Ability to produce electricity even when the temperature is high.
- Re-cycling the solar panels. Though silicon as a material is easy to recycle, but in PV panel metals like cadmium are added to improve the solar panel efficiency. This makes it extremely difficult to recycle due to the hazardous metals in the structure. It is well known fact that it is typically more expensive to recycle a solar panel than it is to construct one.
- The materials which cannot be recycled will again end up in landfills stressing the already stressed waste management system of the world.
- Garvin Heath et al (2022) also talks about colocation of solar energy and agriculture termed as “agrivoltaic systems,”. This co-located agricultural system enhances the total value proposition of these multifunctional sites through the synergistic production of energy and food. However, agrivoltaic implementations may incur yield reductions due to shading effects on crops. Conversely, for specific plant varieties, the microclimate established by the solar panels can demonstrably improve vegetative growth and agricultural output. Moreover, a recent study suggests a potential increase

in photovoltaic panel efficiency when co-located with vegetation, warranting further investigation to substantiate this observation.

### 4.6.7 What are energy companies doing in this space?

There are primarily two types of companies focusing on solar power generation.

Traditional Oil and gas companies who are now trying to provide newer greener source of energy. For example,

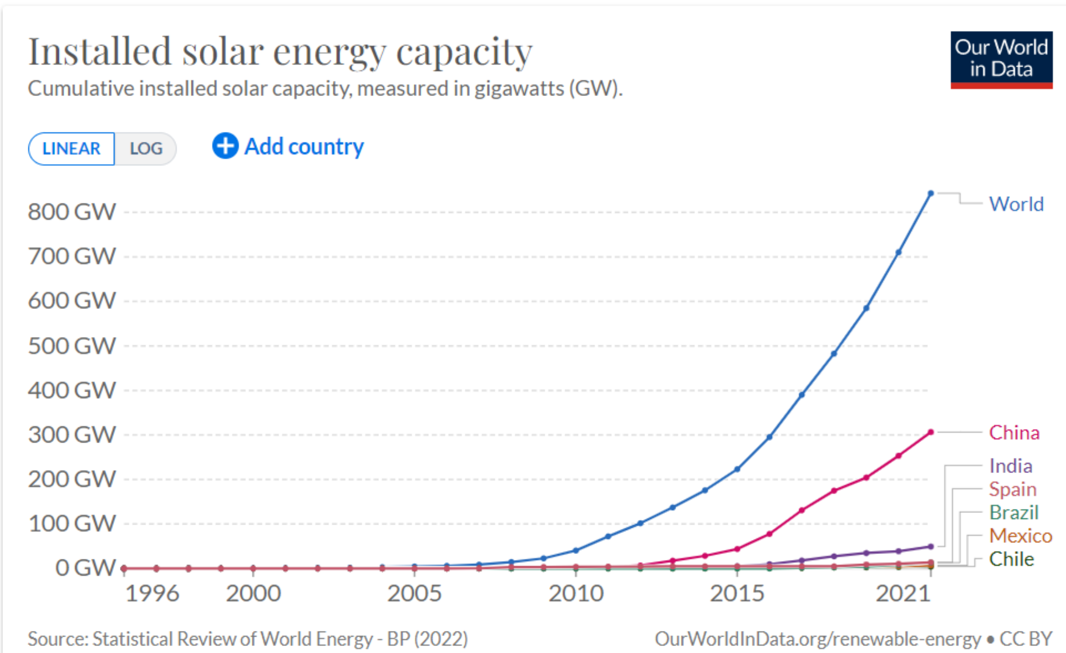
- BP invested 20M AUD in solar provider "5B" which provides technology enabling rapid deployment of solar panels. It consists of up to 90 solar panels mounted on specially designed frames that can be unfolded and installed at speed.
- Shell has introduced Solar BuyBack plans that enables users to leverage power from the grid when sun is not shining. When the solar power electricity is excess, users can put it on grid for which they will receive credits – which will eventually get adjusted in their bills.
- TotalEnergies has invested heavily in distributed power generation using solar PV cell technology. They are powering their operations including the retail outlets using solar power. They are providing both business and hone solutions leveraging solar.

Traditional generation utilities, going beyond coal or gas fired thermal power plants. For example,

- Enel is generating more electricity using renewable resources, then using traditional thermal energy
- EDF has been focused on expanding its investment in solar and storage. The company recently acquired Pivot Power to expand their development into businesses such as battery research, electric vehicle charging space rentals, Smart grid energy efficiency services for buildings.

- Chubu Electric Power Co. commissioned a solar plant that is expected to produce about 2 million kilowatt hours of clean electricity every year.

Thanks to companies like this and many more today we can easily boast Solar generation capacity of more than 850GW, with China leading the pack. India is 2nd.




Source: Statistical Review of World Energy-BP(2022)

*Figure 15:*
*Installed Solar Capacity in the World*

### 4.6.8 How is digitalization/IT helping in this process?

IT can help in the following way.

- Help in land analysis- finding the most suitable land given the solar radiance, temperature, surroundings etcetera. Ehsan Noorollahi (2016) in his report clearly shows in his research that one can identify the suitability of different land terrains on 11 criteria.
  - Solar radiation

- Average annual temperatures
- Distance from power transmission lines.
- Distance from major roads.
- Distance from residential area.
- Elevation
- Slope
- Land use.
- Average annual cloudy days
- Average annual humidity
- Average annual dusty days

- Help in solar power plant design – which includes Photovoltaic modules selection, inverter selection, transformer selection, tracking systems selection, solar power plant design, structural engineering services, security system design etcetera.
- Compare financing options whether to lease or buy. This includes solutions helping calculate project parameters, modeling financial performance, analyze risk profile, profit forecast and finding tailor-made solutions.
- Provide mobile app that enables users to track project installation status, view scheduled events, and monitor energy production.
- Provide personalized solar system that matches homeowner's lifestyle and energy needs.
- Remote site analysis, energy production estimates, and advanced engineering.
- Battery management systems – to provide for functional safety, increased reliability, better performance, diagnostic and coast & warranty reduction.
- Community solar installations management – manage energy bills while building local capacity.

## 4.7 Wind Energy

### 4.7.1 What is wind energy?

Wind energy is derived from wind. Let us start from fundamentals – what is Wind? Wei Tong (2010) in his paper Fundamentals of wind energy says wind results from the movement of air due to atmospheric pressure gradients. Wind flows from regions of higher pressure to regions of lower pressure. The larger the atmospheric pressure gradient, the higher the wind speed. When this wind gets captured and converted to energy by means of wind energy-converting machinery, wind energy gets generated. If you analyze it carefully wind energy is a converted form of solar energy. When the solar radiation hits the earth's surface in an unevenly manner, the place gets heated impacting the atmospheric pressure and accordingly wind gets generated. The Earth's axis of rotation exhibits a tilt of approximately 23.5 degrees relative to the plane of its ecliptic orbit. This axial tilt, maintained throughout the Earth's revolution around the Sun, is the primary driver of seasonal variations in solar radiation receipt. Consequently, it induces a cyclical pattern of uneven heating across the planet's surface, leading to the well-known annual cycle of seasonal weather changes.

Furthermore, the Earth's surface is characterized by a heterogeneous distribution of materials, including vegetation, rock, sand, water bodies, and ice/snow cover. Each of these materials possesses distinct radiative properties, exhibiting varying degrees of solar radiation absorption and reflection. This inherent variability in material composition contributes to significant spatial temperature disparities, even at identical latitudes. For instance, deserts, with their high sand content, demonstrate a propensity for elevated temperatures, while regions dominated by frozen lakes exhibit a markedly lower thermal regime.

Having understood what is Wind Energy, next question to ask is why wind energy. Bernstein et al (2009) determined that wind power boasts a significantly smaller carbon footprint compared to other sources. It generates electricity with 99% less carbon emissions than coal, 98% less than natural gas, and surprisingly, 75% less than solar. It is therefore more prudent to continue investing and building wind energy infrastructure to reduce the carbon footprint and provide more cleaner and greener energy.

Next question is how can the wind energy be trapped and utilized.

Most commonly Windmill and Wind Turbines are used for this process. Let us understand these in bit more detail.

- **Windmill**: Taqi Abrar et al (2010) defined windmill as a machine that captures the energy of the wind and transfers the motion to a generator shaft. This energy is produced mainly by massive three-bladed wind turbines that sits on top of towers and work like fans in reverse. Rather than using electricity to make wind, turbines use wind to make electricity. Generally, windmill is used to convert the wind energy to mechanical energy. For example, to pump ground water, extraction of oil from seeds, milling of the grain’s etcetera. Vipul Todkar et al (2017) First historical references of a windmill were found in Europe dates to 1185 in Yorkshire, Great Britain. Usually, these mills could be spotted during the previous centuries to help humans deliver more mechanical work. It was not surprising to see villages dotted with these mills depending on the purpose of the mill.

Source: https://pixabay.com/photos/windmill-wind-tourism-landscape-1745186/

*Figure 16:*
*Windmill*

- **Wind Turbines**: Abrar Taqi et al (2010) The resurgence of wind power as a viable energy source began in the late 1970s. The first commercial wind farms emerged in California during the 1980s. While wind turbines share a functional resemblance to windmills, they are specifically designed to maximize energy capture. Unlike windmills, which typically have tower heights below 30 meters, modern wind turbines are constructed with significantly taller towers (often exceeding 100 feet) to access stronger, less turbulent wind regimes. These turbines utilize propeller-like blades, typically numbering two or three and mounted on a central shaft to form a rotor. The blades function similarly to airplane wings. As wind flows across the blades, a low-pressure zone is created on the downwind side. This pressure differential generates lift, pulling the blade and consequently the rotor with greater force than the opposing wind resistance (drag) acting on the front of the blade. The combined effect of lift and drag spins the rotor, which in turn rotates a driveshaft connected to a generator, producing electricity.

  Wind turbines offer versatile applications. They can function as stand-alone power sources or be integrated into larger utility grids. Additionally, they can be co-located with photovoltaic systems for hybrid renewable energy generation. Utility-scale wind energy production involves clustering a large number of wind turbines in close proximity, forming a wind farm which constitutes the wind power plants.

### 4.7.2 Wind Power plant classifications.

Andrzej Tywoniuk (2018) clearly articulates different types of power plants classified on three main parameters – Power output, construction size, rotor axis orientation, and some other criteria.

We investigated some of these parameters.

a) Power output

- Micro plant has the output up to 100 W generally used to power off-grid circuits.
- Small power plants with the power output from 100 W to 100 kW, used to power individual households or small enterprises.
- Large wind power plants with the power output of 100 kW and above, used for producing grid-tied energy.
- Utility-scale more than 1 MW

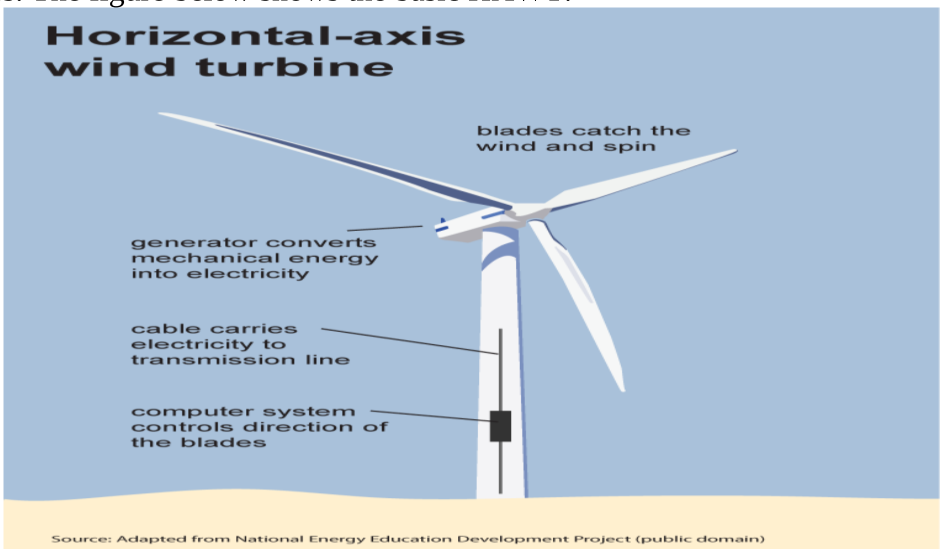
b) Construction size

c) Rotor Axis Orientation

- Horizontal Axis Wind Turbine (HAWT)
- Upwind Turbine
- Downwind Turbine
- Vertical Axis Wind Turbine (VAWT)

While the point a) and b) are self-explanatory we researched to understand the difference between HAWT and VAWT.

**Horizontal Axis Wind Turbine**: Vipul Todkar et al (2017) says the horizontal wind turbine is a turbine in which the axis of the rotor is parallel to the wind stream and the ground. Most HAWTs today are two- or three-bladed, though some may have fewer or more blades. The figure below shows the basic HAWT.




Source: HAWT. https://www.eia.gov/energyexplained/wind/types-of-wind-turbines.php

*Figure 17:*
*Horizontal Axis Wind Turbine (HAWT)*

HAWT can be further divided into two – Upwind turbine and Downwind turbine.

The upwind turbine is a type of turbine in which the rotor faces the wind. A vast majority of wind turbines have this design. Its basic advantage is that it avoids the wind shade behind the tower. In addition, this kind of HAWT also needs a yaw mechanism to keep the rotor facing the wind. Downwind turbine is a turbine in which the rotor is on the downwind side (lee side) of the tower. It has the theoretical advantage that they may be built without a yaw mechanism, considering that their rotors and nacelles (is the part of the turbine where it houses and supports most of the elements of the wind turbine) have the suitable design that makes the nacelle follow the wind passively. Most of the commercial wind turbines are HAWT.

VAWT: Vertical axis wind turbines (VAWTs) can be broadly categorized into two principal designs: the Savonius and the Darrieus. The Savonius rotor operates on the principle of drag forces, akin to a waterwheel. Conversely, the Darrieus employs aero foils similar to those utilized in horizontal axis wind turbines (HAWTs). VAWTs are typically positioned closer to the ground, offering the advantage of collocating heavy components such as the gearbox and generator at ground level, eliminating the need for a nacelle. However, this proximity to the ground coincides with lower wind speeds, resulting in diminished power generation compared to HAWTs with equivalent wind capture areas.

### 4.7.3 How is Wind Equipment Produced?

Christopher Helman(2021) Wind turbines are constructed by using many hundreds of tons of materials like steel, concrete, fiberglass, copper, and rare earth metals like neodymium and dysprosium used in permanent magnets. These materials all contribute to the overall carbon footprint of wind turbine production. Steel manufacturing requires coal fired blast furnace to achieve the high temperatures. Steel and other metals need mining of metals and rare earths which is again energy intensive. And the manufacture of concrete emits lots of carbon dioxide. While producing wind energy may be having zero carbon, but production of the wind turbines and win equipment the carbon emissions are front loaded. This begs a question on how carbon intensive is this process.

What are some of the issues? Venkateswaran et al (2009) argued Wind turbines' carbon footprint is primarily driven by the materials used. Steel, aluminum, and epoxy resins holding everything together are the biggest culprits. Notably, the steel tower itself contributes 30%, followed by the concrete foundation at 17%, and the composite blades made of carbon fiber and fiberglass at 12%. Wind turbines overall carbon footprint is high and this needs to be brought down. This is one of the main challenges. Let us understand these challenges and other related challenges in this space and what area of research is required.

### 4.7.4 What area of research is required?

There are several challenges within Wind Turbine

One of the main issues of Wind turbine especially in Horizontal Axis Wind Turbine, is its height. The gear box, rotor, generator et cetera are all placed on top of the tower, which is usually around 15-20 meters. This leads to lot of assets maintenance issues. While Vertical Axis Wind Turbine, may have the gear box and other equipment near to the ground, their efficiency is low as compared to HAWT. While digitally there are solutions to help in proactive and efficient asset management, the height of the towers creates a hindrance. Research is needed to ensure better asset management, in as non-intrusive manner as possible.

Besides towers at that height also hinder the birds flight and have high chances of killing the birds. Drewitt (2006) Inappropriate location of wind farms can adversely affect wild bird populations. This is even more a problem considering the pace at which Wind projects are being conceived and executed. Wherever possible developers should avoid the areas where there is concentration of bird species. For this one need to understand data on bird numbers, their distribution, movements etcetera to predict the concentration and flight path of these birds. While at onshore there are technologies available to measure and monitor this through video feeds, collision risk models etcetera, offshore assessment is still a challenge. There are attempts being made through aerial survey's but has not proved to be very successful. There is more research needed in developing technologies in this area, perhaps explore more radar and infra-red cameras at offshore to provide information on bird distribution and movements.

One more challenge is the noise produced by the Wind turbines. Shubham Deshmukh et al (2019) Wind turbine noise is found to be more annoying than other community noise sources. It has been linked with annoyance and sleep disturbance. While for offshore wind turbines this might not be as big a challenge, but for onshore the wind noise is a big challenge. There has been lot of work going on reviewing the aerodynamic design to reduce noise sources but still lot of research and work needs to be done in this space.

### 4.7.5 What are energy companies doing in this space?

Listed below are few examples:

- UK is set to become "Saudi Arabia of Wind Energy". Several Oil and Gas majors are increasing their Wind projects in this area. Below are some of the major companies in Energy space taking some concrete actions in Wind Energy space.
- TotalEnergies boasts a substantial wind energy portfolio exceeding 11 gigawatts (GW) across various development stages, including projects in development, under construction, and already in production. Notably, 25% of this portfolio utilizes cutting-edge floating bottom technology, while the remaining projects rely on conventional fixed bottom foundations. TotalEnergies has successfully initiated wind energy production in Taiwan and Scotland, with respective capacities of 640 MW and 114 MW.
- Shell prioritizes offshore wind as a strategic area for business expansion. Their current portfolio encompasses over 2.2 gigawatts (GW) of operational and under-construction offshore wind capacity. Additionally, they possess a substantial development pipeline exceeding 9.2 GW of potential projects spread across North America, Europe, the

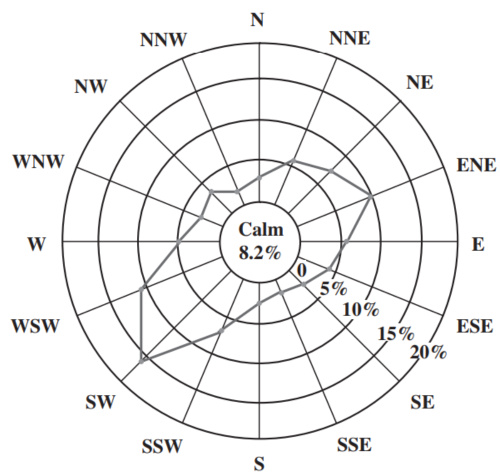
United Kingdom, and Asia (based on Shell's equity share). Furthermore, the company demonstrates a commitment to innovation in wind technology by actively investing in next-generation solutions, such as floating wind turbines.

- Equinor has positioned itself as a key player in the global offshore wind sector, targeting a net installed capacity of 12-16 gigawatts (GW) by 2030. This ambitious target aligns with their commitment to renewable energy production, aiming to achieve a total generation of 35-60 terawatt-hours (TWh) by 2030. Notably, Equinor anticipates that offshore wind will be the predominant source of this projected renewable energy output, contributing two-thirds of the total.

### 4.7.6 How are digital technologies helping?

Digital technologies can help in the following way.

- Conducting Site and Economic Renewable Energy Project Feasibility Assessments
- Technology feasibility and cost analysis
- Wind gust predictions.
- Wind directions prediction.
- Wind shear – meteorological phenomenon which establishes relationship between wind and height above the ground. Greater the height, more the increase in wind.
- Wind rose diagram prediction – This diagram plots wind data related to wind directions at a particular location over a specific time (year, season, month, week, etcetera.).




Source: Operations Sainz, J.A.. (2015)
*Figure 18:*
*Wind Rose Diagram*

- Specialization of plant operations
- Combining operations on a single workstation
- Simultaneous operations
- Increased flexibility
- Automation of material flows and storage
- Inspection online
- Process control and optimization
- Control of plant-level operations
- Better understand the life span of turbine components
- Improve maintenance schedules, reduce costs, and avoid breakdowns.

## 4.8 Hydroelectric Power

### 4.8.1 What is Hydroelectric Power?

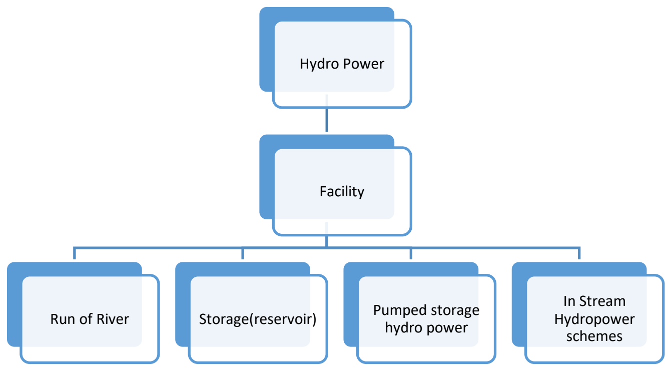
Hydroelectric Energy is generated by harnessing the kinetic energy of flowing water. The kinetic energy is converted to mechanical energy to run the turbine/generator – which in turn generates the electric energy. Sameer Algburi et al (2016) explains that different hydro solutions are built depending on the flow rate and pressure head of the water source. While the basic concept of water falling on the turbine and generating power is same, the scale varies. Small-scale hydropower (SHP) stands out as a highly cost-effective and environmentally sound energy technology for rural electrification initiatives in less developed countries. It is particularly compelling in regions where large-scale hydropower development has reached saturation or faces significant environmental hurdles. SHP systems boast exceptional operational robustness and minimal environmental impact, making them a frontrunner for renewable energy deployment in these contexts.

In stark contrast, the development of hydroelectricity throughout the 20th century was dominated by large-scale dam projects. These endeavors involved the construction of hundreds of massive concrete, rock, and earth dams across river valleys worldwide, resulting in the creation of vast artificial reservoirs. While these large-scale projects facilitated significant and reliable electricity generation, often accompanied by irrigation and flood control benefits, they came at a substantial cost. The construction of these dams necessitated the inundation of extensive tracts of fertile land and the displacement of countless local populations.

### 4.8.2 Types of Hydro Power

Ravi Kiran Karre (2022) classifies Hydro Power into four types:

- Storage or Reservoir
- Run of River
- Pumped Storage hydro power plants
- In-Stream Hydropower




**Storage or Reservoir:** Algburi, Sameer et al (2016) Hydroelectric power generation predominantly utilizes dams constructed across rivers with high flow rates. These dams create upstream reservoirs where water accumulates. The elevation differential between the impounded water and the downstream river establishes gravitational potential energy. As this water flows through a penstock, a dedicated channel within the dam, it exerts force on turbines, converting the potential energy into kinetic energy that is subsequently transformed into electrical energy by generators.

**Run of River (RoR):** Algburi, Sameer et al (2016) Run-of-river (ROR) hydroelectric plants exploit the kinetic energy of flowing water for electricity generation. These systems typically rely on the natural elevation change, or "head," of a stream with consistent year-round flow. Unlike conventional impoundment projects, ROR plants do not require significant alterations to the river course. Water is diverted into a penstock, a dedicated channel, to drive turbines before being returned to the stream. While the power generation capacity of individual ROR plants is typically limited to a few megawatts, they offer the combined advantages of clean hydropower and decentralized electricity production. Furthermore, ROR plants can be categorized into sub-classifications based on their generation capacity: pico (up to 5 kW), micro (up to 100 kW), and mini (up to 1 MW).

**Pump Storage Hydropower Plant** (PSHP): This is not a source of power. It tries to solve the intermittency problem of renewable energy like solar and wind. Typically, when the sun is shining and solar/wind powered electricity is generated, this energy is used to pump water from lower reservoir to higher reservoir - typically on top of a hill. When power is required to be produced the water is released from the reservoir and flows downwards. This water hits the turbine through penstock and generates electricity. This is connected to grid to provide electricity for consumption during off peak hours when renewables are not online. As per DOE Global Energy Storage Database. 2022, PSHs accounted for 96.1% of global electricity storage capacity.

**In-Stream Hydropower** use a rivers natural elevation drop without to dam a river to produce power.

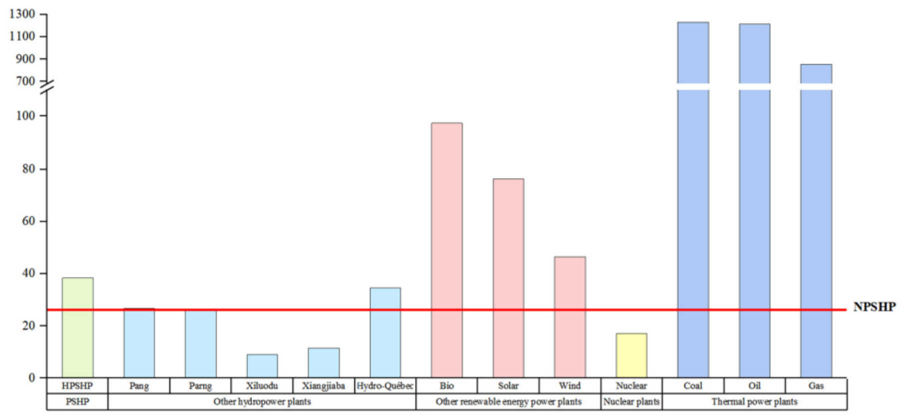
### 4.8.3 How are Hydroelectric Projects setup?

Usually largescale hydro power – storage/reservoir type of hydropower needs huge dams to be constructed. This involves clearing the places, huge loads of steel, cements, wood, metals etcetera to construct. All this is carbon intensive activities. Chu, Y et al (2022) deduced the total carbon emissions in this process is approximately 5828.39 KT in the life cycle of the case system. Breaking down a hydropower plant's lifetime carbon footprint reveals that decommissioning contributes the most (38.4%), followed by construction (34.5%), operation (25.6%), and minimal emissions during preparation (1.5%). Interestingly, nearly all direct emissions (94.8%) come from sediment release at the end of its life and reservoir surface emissions during operation.

However, the bigger picture includes indirect emissions, which are 2.8 times higher than direct ones. These indirect emissions stem from the resources required throughout the plant's lifecycle. Materials used in construction account for 7.1%, followed by machinery

(14.7%), energy used during operation (15.9%), and the services needed to maintain the plant (62.3%).

The below diagram shows the EGOC (electricity generation on carbon emissions)




Source: MDPI: Systems Accounting for Carbon Emissions by Hydropower plant

*Figure 19:*
*Comparison of EGOC of various plants Unit is CO2 equivalent /kWH*

Hydropower plants are perhaps the lowest in terms of CO2 emissions, followed by Wind, solar and biofuels. The only other source- which is comparable to hydro power is Nuclear.

### 4.8.4 What area of research is required?

Algburi, Sameer et al (2016) Large-scale dam construction can trigger significant environmental disruptions within the impacted region. The initial impoundment of water often requires the inundation of fertile agricultural lands, displacing human communities and wildlife populations. Reservoir capacities can encompass hundreds or even thousands of square kilometers, causing widespread habitat loss. Furthermore, the reduced downstream flow rates can have a detrimental impact on the dependent ecosystems and human populations residing along the river's course. Disrupted migratory patterns pose another challenge, as dams can impede the passage of fish species that require upstream travel for spawning. Additionally, the penstock and intake pipes of these dams can cause mortality events for entrapped aquatic organisms. The extensive surface area of reservoirs introduces another environmental concern: elevated evaporation rates that can influence local climatic conditions. Given these challenges we need advanced technological solutions which will help mitigate these issues, including minimizing reservoir surface area to reduce evaporation, implementing fish passageways to address migratory blockages, and employing improved turbine designs to limit aquatic organism mortality.

### 4.8.5 What are energy companies doing in this space?

Interestingly we do not see evidence of any major Energy companies like BP, Shell, Chevron, Total energies taking any steps in Hydro Power Plants. But governments in China, Canada, Brazil, Russia, India and France host some of the world's biggest hydropower producers. Most of these producers are state owned or supported by the state. Not much evidence is found where there are private players completely running independent in this space.

Most of the hydropower fleets were constructed in the last 45-60 years. Report from International energy Agency (IEA) by Piotr Bojek (2022) says that many hydropower plants built in the boom years of the 1960s to 1980s are reaching middle age. Nearly 40% (476 GW) of the global hydropower fleet is at least 40 years old, with an average age of 32. As these plants approach 45-60 years old, significant upgrades become essential to keep them running efficiently and flexibly. Modernization and refurbishment go beyond replacing key parts like turbines and generators. They can also incorporate digital technologies that enhance a plant's ability to adjust to changing power demands. This, along with improved safety features, can address environmental and social concerns. Depending on local regulations, upgrades can also help manage drought and flooding more effectively.

### 4.8.6 How is IT helping in this process?

Bogdan Ristic et al (2021) The digitalization of hydropower plants fosters the integration of technologies like Artificial Intelligence (AI), Smart Energy Systems (SES), Smart Grids, Digital Twins, and the Industrial Internet of Things (IIoT). These advancements empower both individual hydropower plants and entire fleets to operate reliably and efficiently within the electrical grid. Real-time sensor data acquisition from local and remote sources, coupled with historical data analysis, facilitates the formulation of data-driven conclusions for optimization, generation forecasting, and predictive maintenance strategies. The implementation of cutting-edge digital technologies is projected to optimize hydropower utilization, enhance safety protocols, augment annual energy production, and reduce maintenance costs.

Kougias I. (2019) in his paper emphasized that digitalization provides flexibility and the stability of the electrical system, the prolongation of the lifetime of the hydropower equipment and an increase in the overall efficiency. Quaranta E. (2021) estimated that digitalization of the existing hydropower plants would provide around 1% increase in efficiency and around 11% of energy generation achieved by using high quality inflow forecasts.

**Generation**: IT technologies can help predict the reservoir inflow. The flow of water through the turbine depends on the current energy demand, but also on the reservoir inflow. One must ensure adequate and optimum inflow of water through the spillway. For this we need to have a clear sense of upcoming inflow of water. This is a complex function of the incoming streams, precipitation, evaporation, soil characteristics, and other parameters.

Artificial Intelligent methods can be employed to analyze the data and find the optimum combination of inflow of water to meet the energy demand.

**Maintenance:** Maintenance can be done in 4 ways. a) Reactive b) Proactive c) Condition based monitoring d) Predictive e) Prescriptive.

Digitalization ensures the equipment and different assets are all well connected through IT infrastructure. Bogdan Ristic et al (2021) Various health parameters of equipment like temperature, vibration, pressure, flow rate etcetera are measured through sensors. This data can be continuously accessed to access the health of the equipment through satellite or mobile network.

Prior to digitalization there were only two ways to maintain- either reactive or proactive. Reactive was when the equipment has already failed and then the crew is dispatched for repair. This leads to loss of production- in this case loss of electricity generation, financial losses, loss of man hours etcetera and the downtime can cause other challenges. In proactive maintenance – we tend to maintain even if the equipment is in good condition. This may not be optimum use of the budget and resource. Also, proactive maintenance brings down the system – again leading to loss of revenue.

Thanks to digitalization now the health of the equipment is continuously monitored, and the health is accessed. By monitoring the parameters, the AI algorithms are able to predict when the equipment will fail and also give recommendations on what parameters needs to be fixed and adjusted for optimum production. This is proactive and prescriptive maintenance. This helps to prevent losses due to equipment failures, improved efficiency, and increased reliability.

## 4.9 Battery Technology

Battery technologies are set to play a big role in Energy markets. Though not a primary source of energy, but battery technology powers up the system when there is no access to renewable energy due to intermittency. It also plays a hug role in electrifying transportation system.

### 4.9.1 Introduction

Batteries play a very important role in electrification. In simple words when not connected to socket, electricity must be drawn from batteries.

WEF (2019) in their report on sustainable battery value chain in 2030- project that global battery demand is expected to grow by 25% annually to reach 2,600 GWh in 2030.

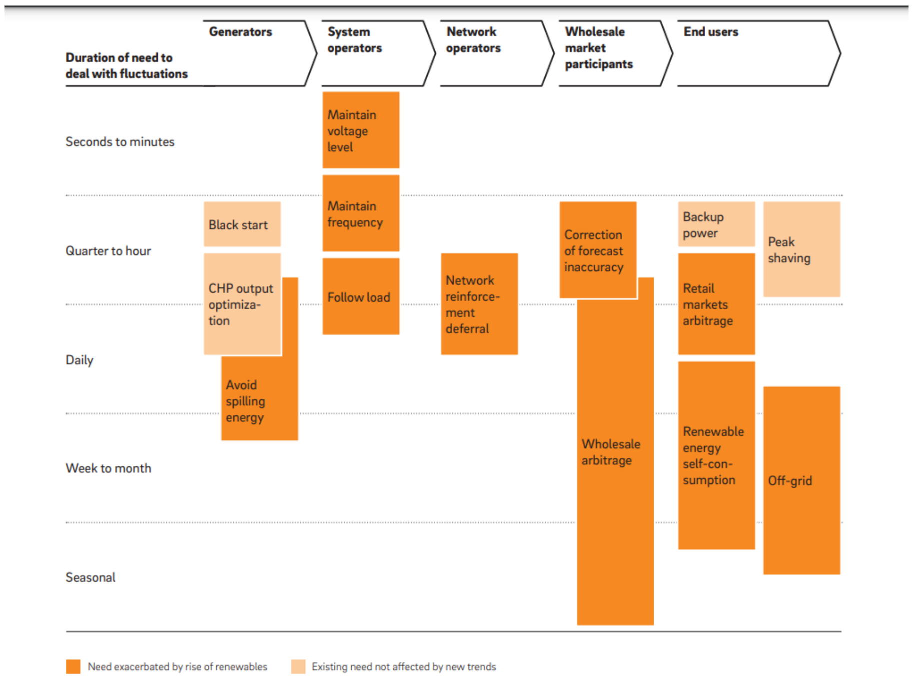
Batteries play an increasingly important role in three areas:

- Electrification of transport helping in decarbonizing
- Maintaining supply and demand balance caused by intermittent sources of electricity.
- Provide access to electricity to off-grid communities.

Batteries act as energy storage in EVs, there is an expectation that more than 34 million EVs which includes hybrid, PHEVs and BEVs will be sold in 2030. They also provide the cushion or buffer in the power system which caters to the intermittency problem of renewables, therefore helping seamless integration of renewable energy generation source.

There are different storage needs along the value chain. Players active in the energy market will have different types of needs related to the more predictable or unpredictable imbalance between demand and supply over various time horizons. The underlying needs differ per time unit and per step of the value chain.

Below diagram from Roland Berger (2017) summarizes the needs.



Source: IEA, Rolan Berger

*Figure 20:*
*Different Battery needs*

Roland Berger (2017) Power storage solutions play a multifaceted role during the electricity generation phase. They enhance grid resilience by facilitating black starts and optimizing the combined output of cogeneration plants. The integration of renewable energy sources necessitates the adoption of energy storage to prevent curtailment (energy spillage). Without storage capacity, excess electricity generated by wind farms (onshore and offshore) would be wasted during periods of low demand. These energy storage requirements encompass cycles ranging from short-term (quarter-hour) to week-long durations.

However, system operators have distinct short-term needs as well. Maintaining grid stability and balancing the intermittency of renewable energy sources is crucial to prevent deviations in frequency and voltage. On a slightly longer timescale, load following becomes increasingly important. This strategy addresses sudden fluctuations in renewable energy output, which may not be readily countered by proportional adjustments to conventional generation capacity.

Network operators, responsible for grid infrastructure, face additional challenges. The rise of renewable energy sources like rooftop solar PV installations can introduce new and unpredictable load points into the grid. Furthermore, the proliferation of distributed generation, where renewable energy sources are connected to the local distribution grid, can disrupt the originally anticipated power flow patterns. In such scenarios, energy storage can potentially defer or even prevent the need for grid refurbishment and reinforcement investments.

### 4.9.2 Different Types of Battery Technologies

P.S Syed (2014) in his paper calls out the below types of battery technologies.

**Primary Battery (or) Primary cells:** P.S Syed (2014) Primary batteries, unlike secondary batteries, exhibit irreversible electrode reactions. The electrochemical processes that occur within these cells cannot be reversed by applying an external electrical current. Consequently, primary batteries undergo a single discharge cycle and become depleted upon exhaustion of their internal reactants. This characteristic renders them non-chargeable. Common examples of primary batteries include dry cells and mercury cells. Due to their limited reusability, primary batteries are not considered a significant contributor to achieving sustainability goals.

**Secondary Battery (or) Secondary cells**: P.S Syed (2014) Secondary batteries, in contrast to primary batteries, exhibit reversible electrode reactions. By applying an external electrical current, the electrochemical processes within these cells can be reversed. This characteristic allows for the repeated charging and discharging cycles, making them rechargeable. Secondary batteries are also referred to as storage cells or accumulators.

Lead-acid storage cells serve as a prime example. Their widespread use in vehicles and high-current applications stems from several advantages: low initial cost, well-established technology, and efficient recycling practices. Nickel-cadmium (Ni-Cd) cells represent another category of secondary batteries. They find application in portable devices like computers, drills, and camcorders due to their ability to deliver consistent power output. Lithium-ion (Li-ion) batteries stand out within the realm of secondary cells due to their exceptional energy density and safety profile. Unlike some rechargeable batteries, Li-ion cells do not exhibit a "memory effect" nor require specific discharge cycles to maintain lifespan. These characteristics have fueled their widespread adoption in electronics (cameras, laptops, mobile phones) and their burgeoning role in electric vehicles and grid storage applications. Consequently, Li-ion batteries play a pivotal role in advancing sustainability goals.

**Flow battery (or) Fuel cell:** P.S Syed (2014) In these cells, the reactants, products and electrolytes are continuously passing through the cell. In this chemical energy gets converted into electrical energy. Example: Hydrogen - oxygen fuel cell.

The next question to ask from here is while this is chemical composition of the batteries, how is batteries pack assembled, what is the composition of battery system?

### 4.9.3 Composition of battery system:

Asian Development Bank (2018) The battery system consists of the battery pack, which connects multiple cells to appropriate voltage and capacity.

There are primarily two systems. The core component of a battery system is the battery pack, which houses multiple cells electrically connected to achieve a desired voltage and capacity. Two critical management systems are employed within the battery system:

- Battery Management System (BMS): The BMS safeguards individual cells from detrimental operational conditions concerning voltage, temperature, and current. This ensures reliable and safe operation by balancing the varying states of charge (SOC) within a series-connected cell configuration.
- Battery Thermal Management System (B-TMS): The B-TMS actively regulates the temperature of the cells within the pack, ensuring adherence to their specified temperature range and minimizing temperature gradients.

For the entire system to function reliably, several additional components are crucial:

- System Control and Monitoring: This encompasses general information technology (IT) monitoring, which may be partially integrated with the overarching Supervisory Control and Data Acquisition (SCADA) system. Additionally, it may incorporate fire protection and alarm units for enhanced safety.
- Energy Management System (EMS): The EMS is responsible for controlling, managing, and distributing the power flow within the system.
- System Thermal Management: This system controls all functions related to the heating, ventilation, and air conditioning (HVAC) of the battery containment system, ensuring optimal thermal conditions.

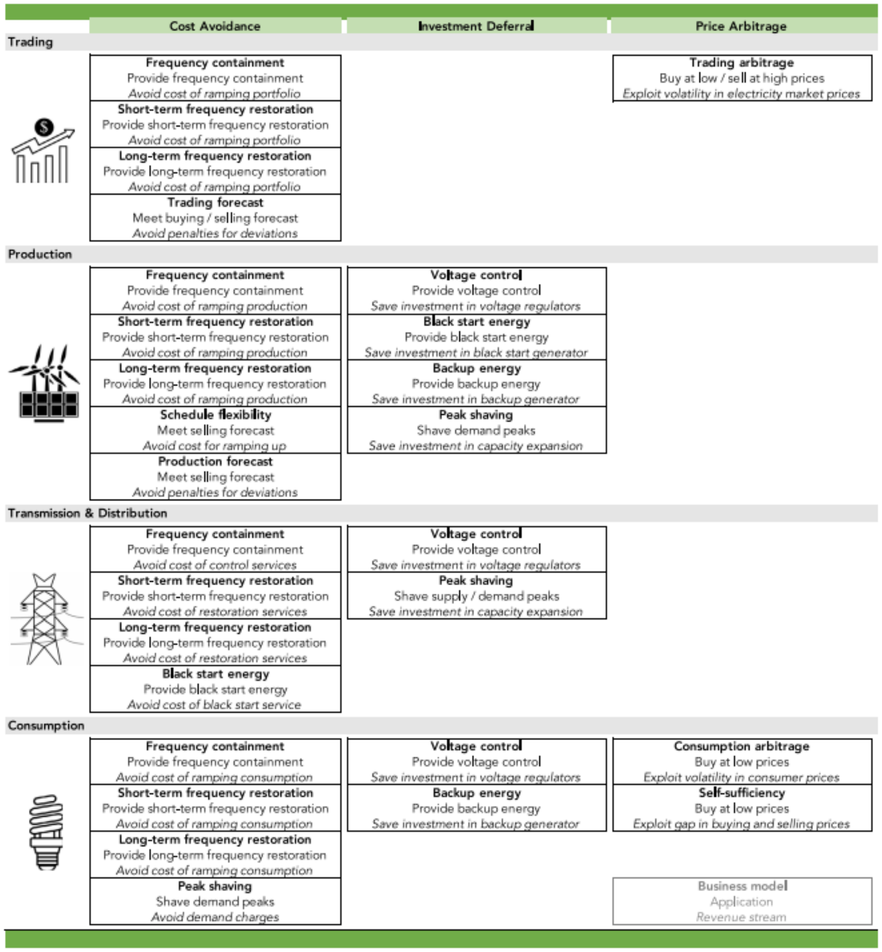
### 4.9.4 What is the business case for battery storage?

Asian Development Bank (2018) The economic justification for battery energy storage (BES) varies depending on the specific application and use case. For instance, prosumers, who are both producers and consumers of electricity (often through rooftop solar panels), can evaluate the return on investment (ROI) of a home energy storage system by considering the differential between the cost of generating and storing their solar power and the cost of purchasing electricity from the grid. In the industrial sector and for distribution network operators, the primary economic benefits of BES stem from reduced peak capacity charges and deferred network expansion needs. These advantages are achieved through peak shaving, which reduces demand during peak hours, and load leveling, which flattens overall demand fluctuations. When it comes to utilizing batteries for frequency regulation, the economic viability hinges on factors like revenue forecasts and the level of competition within the ancillary services market.

So, what role can Utilities or Energy companies play in this? What kind of business models can they adopt?

#### 4.9.5 Business Models in Battery Management system

Felix Baumgarte et al (2020) identifies distinct business models for energy storage technologies based on the combination of parameters which are cost avoidance, investment, and price arbitrage. He divides this against four main roles of Trading, Production, Transmission and Distribution and Consumption. Each business model, represented by a box below, applies storage to solve a particular problem and generate a distinct revenue stream for a specific market role.




Source: Felix Baumgarte et al (2020)

*Figure 21:*
*Different Business Models of Batteries*

Felix Baumgarte et al (2020) Market roles are crucial for business models where the same application applies to several roles and generates the same revenue stream. All three frequency-related applications help the four market roles avoid costs. Market participants in trading, production, or consumption avoid the respective costs of ramping their portfolio, production, or consumption. Operators of a T&D grid would avoid costs of the control/ restoration services offered by other market participants, provided they are allowed to do so by regulation. If an investor, that is a person or an organization, wants to provide one or more frequency-related applications simply for the price paid for this service, the investor would effectively pursue the business model Trading arbitrage. As the names suggest, Trading/Consumption arbitrage apply to trading and consumption, where energy storage enables the respective investor to sell at high prices and/or buy at low prices to take advantage of temporal fluctuations in electricity market prices. A version of price arbitrage may intuitively be assumed to also apply to producers, but they would then effectively act as traders and pursue the business model Trading arbitrage.

#### 4.9.6 What are some of the key challenges?

Some of the key challenges are.

Battery production has a significant GHG footprint and ESG Risks. While the life cycle carbon footprint of battery technology, encompassing both production and use phases, is demonstrably lower than that of traditional vehicles, significant CO2 emissions are associated with the battery production process itself. Mitigating this production footprint presents a crucial opportunity and ethical obligation. By minimizing these emissions, the environmental benefits of transitioning to battery applications can be further strengthened, solidifying the case for their adoption.

As per Jakob Fleischmann et al (2022) in their report have identified 21 risks along ESG.

- Environmental: Jakob Fleischmann et al (2022) Several environmental concerns are associated with the upstream stages of battery production, encompassing the extraction and refining of raw materials as well as cell manufacturing. These processes can potentially lead to significant ecological disruptions, including land degradation, biodiversity loss, hazardous waste generation, and contamination of water, soil, and air. Furthermore, improper or even illegal battery disposal practices pose a serious threat of toxic pollution.

- Social: Jakob Fleischmann et al (2022) The absence of stringent oversight throughout the battery value chain presents potential risks of adverse social impacts on regional communities, particularly in emerging economies. These risks may include violations of labor regulations, the use of child or forced labor, and the infringement upon indigenous rights.
- Governance: Jakob Fleischmann et al (2022) Stakeholders within the battery value chain may be exposed to conflicts of interest or find themselves collaborating with entities that exhibit inadequate social governance practices. To ensure alignment with the evolving expectations of ethical business conduct, companies must demonstrably avoid financial entanglements associated with corruption, bribery, facilitation of armed conflict, and tax evasion.

Below diagram summarizes the same


Source Battery 2030: Resilient, sustainable, and circular. Jakob Fleischmann et al (2022)

*Figure 22:*

*Challenges in Battery production across Environment, Social and Governance parameters*

Other challenge is the viability of battery-enabled applications is uncertain. WEF (2019) Presently, prevailing battery costs pose a significant barrier to profitability across various applications, including the automotive sector. This is exemplified by the considerable pressure faced by electric vehicle (EV) manufacturers in maintaining profit margins. Several key factors contribute to this lack of profitability:

- High initial costs associated with large battery packs: The upfront expense of large battery packs represents a substantial hurdle for widespread EV adoption.
- The "chicken-and-egg" conundrum: Limited availability of charging infrastructure disincentivizes EV adoption, while conversely, low EV adoption rates hinder the economic justification for expanding charging infrastructure. This cyclical challenge creates a barrier to market growth.
- Consumer preference for internal combustion engine (ICE) vehicles: Limited customer acceptance of EVs compared to ICE vehicles remains a significant obstacle.

Furthermore, rapid expansion within the EV industry may prioritize speed over optimization, leading to inefficiencies in production processes that further exacerbate cost pressures. Unless advancements are made in battery cost reduction, the development of purpose-built EV designs, a substantial increase in charging infrastructure, and the exploration of novel business models, the long-term profitability of EVs for car manufacturers remains uncertain.

#### 4.9.7 What are energy companies doing in this space?

Some of the examples of what energy companies are doing in this space are as below referred from YSG Solar (2022)

- NextEra Energy: NextEra Energy isn't just a giant in the U.S. utility market, powering over 5 million Florida homes. They're also a global leader in renewable energy, generating more wind and solar power than any other company in the world. Plus, they're at the forefront of battery storage technology.

- Fluence Energy: Fluence is a leading name in energy technology and services. They understand that different customers have different needs. That's why they offer three pre-configured systems designed for specific applications and user types.
- Eversource Energy: A major player in the Northeast energy market, Eversource provides electricity, natural gas, and even water services to 4 million customers across Connecticut, New Hampshire, and Massachusetts. In recent years, Eversource has expanded its offerings to include the growing energy storage market.
- Xcel Energy: Xcel Energy is a major energy player across the West and Midwest, serving 3.4 million electricity customers and 1.9 million natural gas customers in eight states. Beyond traditional offerings, their portfolio is expanding rapidly to include energy storage solutions.
- Duke Energy: A major Southeast and Midwest electricity provider, Duke Energy (headquartered in Charlotte, North Carolina) serves 7.4 million customers. Beyond its core business, Duke Energy is actively involved in developing renewable energy and battery storage projects across the nation.
- DTE Energy: DTE develops and manages a diverse range of energy-related businesses and services across the country. Its portfolio includes several battery energy storage projects.
- Avangrid: Avangrid which a subsidiary of Spanish energy company Iberdrola, has created two separate segments to bring in the focus on renewables. It has created Avangrid Networks and Avangrid Renewables. The Avangrid Renewables segment is focused on renewables plus includes a number of energy storage projects.

### 4.9.8 How are digital technologies helping in this process?

As per the survey done by DNV.GL (2019) the following technologies were identified by energy storage respondents as being important for their organization to invest in.

**Cyber Security:** The focus on cyber security in the energy storage sector has been growing. There have been instances in past where they demonstrated the ease with which its experts could break into commercially available PV inverters, used to communicate with storage systems or solar panel arrays. This can have hackers manipulate power outputs, damaging batteries or even bringing down a local grid system.

**Data Visualization:** This technology's importance can't be overlooked in the energy storage sector. Trying to manage how storage interacts with grids will become ever more complex as renewable generation grows and the interaction of load, price and available supply becomes critical. Using data visualization to understand load, supply, and battery dispatch for grid and behind the meter applications will enable the right decisions to be made and value to be maximized.

**Automation and Digital Workflow:** The increase of storage assets in the energy system makes automation vital for connecting, managing, securing, proving value, improving efficiency, and ensuring continuity.

**Value Stacking:** Traditionally, energy storage and generation solutions have been designed with singular functionalities. However, advancements in software are enabling these systems to perform multiple tasks concurrently, unlocking significant economic potential through a concept known as value stacking. Value stacking essentially refers to the ability of a single storage unit to provide a multitude of services, thereby creating new revenue streams for the industry. A prime example of this approach can be found in the electric vehicle (EV) sector, where the same battery system can be utilized for grid balancing and EV charging, maximizing its return on investment. EVs acts as storage by allowing flow from EV to network namely Vehicle to Grid and also enabling flow of power from grid to EV to store/utilize in the vehicle. Using software batteries applications can be increased.

## 4.10 Transmission and Distribution Modernization

Study showed that while battery technology enables storing and disbursement of energy, transmission and distribution network will play a key role in Energy market. Let us understand the details in this space.

### 4.10.1 Introduction

International Electrotechnical Commission (IEC) defines “Power Transmission” as the large-scale movement of electricity at high voltage levels from a power plant to a substation. Whereas “Power Distribution” is the conversion of high voltage electricity at substations to lower voltages that can be distributed and used by private, public, and industrial customers. As per Wikipedia (2023) Distribution substations serve as the interface between the high-voltage transmission system and the lower-voltage distribution network. These substations utilize transformers to step down the incoming transmission voltage to a medium voltage level, typically ranging from 2 kV to 33 kV. The medium voltage power then travels through primary distribution lines to reach distribution transformers strategically located near customer premises. These distribution transformers further reduce the voltage to the utilization voltage level, which is the voltage directly used by lighting, industrial equipment, and household appliances. Notably, a single distribution transformer can supply power to multiple customers via secondary distribution lines. For commercial and residential customers, connection to these secondary lines is established through service drops. Customers with significantly higher power requirements may be connected directly to the primary distribution level or even the sub-transmission level, bypassing the voltage reduction stages provided by distribution transformers.

So, without transmission and distribution network electricity cannot be provided to the end consumer. No wonder IEA (2020) in their report on Sustainable Recovery- Electricity calls out that electricity networks are the backbone of a secure and reliable power system: there are nearly 7 million kilometers (km) of transmission lines and 72 million km of distribution lines worldwide. The transmission lines are usually over ground supported by large poles. However, due to space constraint and environmental issues like harsh weather, aesthetics etcetera the transmission lines may be underground as well. But this comes with an increased cost and difficulties in repairs and maintenance. In Distribution networks it is observed that urban distribution is mainly underground, sometimes in common utility ducts. Rural distribution is mostly above ground with utility poles, and suburban distribution is a mix.

So now given the need of the hour to switch to renewable sources of energy is our existing transmission and distribution grid capable of handling this new source of electricity generation and the subsequent changes in the ecosystem.

Unfortunately, in the current scenario of where Renewable sources of electricity are coming online and consumers are becoming producers of electricity as well – conventional grids are not able to cater to new demand of seamless integration into main grid and provide ability to circumvent the intermittency problem of renewable energy. Also provide abilities to customer to sell excess power on grid, ensure supply whenever demanded, reduce outages, be more proactive in communications, manage storm and other outages seamlessly. No wonder World Economic Forum (2020) calls transmission and distribution are the clean energy transition's secret weapons.

At the same time Transmission Efficiency is a challenge. As per IEC (2023) - Electrical transmission over extended distances inherently incurs energy losses. These losses can be attributed to several phenomena occurring within the transmission infrastructure, including overhead lines, conductors, transformers, and power cables. Three primary effects contribute to these losses:

- **Joule effect**: This effect describes the conversion of electrical energy into thermal energy (heat) within the conductor itself. Copper wires, commonly used in transmission lines, are susceptible to this phenomenon.
- **Magnetic loss**: Energy dissipation occurs within metallic components exposed to permeating magnetic fields.
- **Dielectric effect**: Insulating materials used in transmission systems can absorb a portion of the electrical energy.

The Joule effect is the dominant source of loss in overhead lines and power cables, typically accounting for 2-5% of the total transmitted energy. Transformer losses, on the other hand, range from 1-2%, depending on the specific type and capacity of the transformer. It is noteworthy that a 1% reduction in energy losses from a 1000 MW power plant translates to an additional 10 MW of available power for consumers. This recovered energy is sufficient to supply electricity to an estimated 1000-2000 additional homes. The same effect is observed in Distribution network.

To cater to this new reality Traditional Grids needs to be upgraded or modernized to convert it to Smart Grid. So now the question comes what are Smart Grids?

### 4.10.2 Smart Grid:

Smart grids are traditional electric grids which employ innovative technology and services together to provide intelligent monitoring, control, communication, and self-healing technologies. Which means these grids uses digital technologies, sensors, different types of software to enable bi-directional flow of electricity, match the demand and supply, find optimum path for transmission and distribution, isolate networks in case of downtime/accidents and ensure minimum disruption in supplies.

The European Technology Platform Smart Grids, a European Commission initiative which focuses on research into the technology, has come up with one of the most widely accepted definitions for smart grids: “An electricity network which can intelligently integrate the actions of various entities connected to it like generators and consumers and in some cases the prosumers (entities who can produce and consumer) so as to efficiently deliver sustainable, economic and secure electricity supplies.

As per “Energy.gov” – Office of Electricity - “Smart grid” helps build a smart, self-aware systems. They use advanced tools like

- Super-sensitive sensors (PMUs) that help monitor grid health.
- Smart meters that give you more control over your energy use and automatically report outages.
- Automatic switches that reroute power around problems, keeping your lights on.
- High-tech relays that can automatically detect and fix issues within substations.
- Big batteries that store extra energy when demand is low and release it when needed, keeping the grid balanced.

This needs huge amount of investment. For example Ralph Roam (2020) in his PwC report “Grid Modernization for gas and water utilities – A strategy for success “estimate that US will have to spend up to $2 trillion on grid modernization by 2030 – just to maintain the electric grid’s reliability.

**Why are Smart Grid so important?**

IEC (2023) A significant portion of the current electrical grid infrastructure originated in the 1960s or even earlier, nearing the end of its operational lifespan. This aging infrastructure experiences significant stress during periods of peak demand. Furthermore, steadily rising electricity consumption and the integration of intermittent renewable energy sources, such as wind and solar power, place additional strain on existing grids. The growing need to incorporate renewable energy sources and distributed generation presents its challenges never seen before for the conventional electricity grid. Smart grids can be an answer to these challenges. They offer a solution by:

- Facilitating the seamless connection and operation of diverse electricity generation sources, regardless of size or technology.
- Empowering users to actively participate in optimizing overall system efficiency.
- Equipping consumers with greater information and control over their energy usage, fostering informed choices.
- Reducing the environmental impact associated with electricity production and transmission.
- Enhancing the reliability and security of electricity supply.

By addressing these critical aspects, smart grids emerge as a comprehensive solution capable of meeting the evolving needs of the electricity sector. They pave the way for the efficient delivery of sustainable, affordable, and secure electricity.

While smart grids modernize the T&D networks, smaller grid networks are making its presence felt which will play a significant role in transformation of energy market. Let us delve deeper into this.

#### 4.10.3 Microgrids

First question is what is microgrid? Victoria Masterson (2022) in WEF paper “What are microgrids – and how can they help with power cuts?” say microgrids are local power grids that can be operated independently of the main. Victoria Masterson (2022) Microgrids can be used to power a single building, like a hospital or police station, or a collection of buildings, like an industrial park, university campus, military base or neighborhoods. Groups of microgrids that are linked together can also power bigger areas, like towns or cities. Microgrid can draw power from local solar or wind turbine and when required can draw power from main grid to provide power. When there is excessive production of power the power from microgrid can be sold back to main grid or stored in the battery storage connected to the microgrid.

When there is failure on main grid, microgrid can disconnect from the grid and continue provide the power. This process is called “islanding”. Microgrids support decentralized production of power like local solar, wind or hydropower. Microgrids can be arranged in three ways:

a) **Remote microgrids**: These microgrids, also referred to as "off-grid microgrids," are deployed in locations geographically distant from the main electricity grid, rendering connection impractical. They primarily rely on renewable energy sources for power generation and operate in island mode permanently, meaning they function independently of the main grid.
b) **Grid-connected:** This type of microgrid maintains a connection to the main electricity grid. However, it possesses the capability to disconnect and operate autonomously (island mode) during power supply disruptions on the main grid. This functionality ensures continued power availability for local loads even in the event of grid outages..
c) **Networked microgrids:** They are groups of microgrids that are connected to serve a wide geographic area, like a community or city.

Some of the examples Elisa Wood (2022) where microgrids are being setup are:

- San Diego is pursuing eight microgrids along with Shell New Energies for city facilities which includes solar, storage and electric vehicles.
- Big tech, including Google and Meta (Facebook), are embracing microgrids.
- Engie is developing microgrid for their customers in California. ENGIE's newest microgrid installation at the district includes 4.2 megawatts of solar across 14 district locations and six microgrids with 3.8 megawatt hours of battery energy storage for backup power and peak demand charge reduction.
- Centrica, a utility company in UK is working on a unique approach with SNR Smart Grids to provide micro-grid as a service which includes design, financing, build and operate the privately owned micro-grid.

Studies showed that while microgrid focused on setting up of local grids, there is increase proliferation of generation energy resources across different locations aggregated at different unit levels. This is significant importance given the nature of renewable energy. Let us delve deeper into this aspect of generation.

#### 4.10.4 Distributed Energy Resources (DER)

DERs are nothing but are small-scale electricity supply or demand resources that are interconnected to the electric grid. Cummins (2021) They are power generation resources and are usually located close to load centers and can be used individually or in aggregate to provide value to the grid. DER can be both physical and virtual assets. Physical assets are nothing but arrays of solar generators, small wind farms, battery storage, generators etcetera. They are usually owned by utilities or some independent players. Utility directs their operation very similar to large central plants, requesting start and stop as needed.

In contrast, Virtual Distributed Energy Resources (VDERs) represent an aggregation of geographically dispersed physical assets. Through this aggregation, these assets are combined and presented to the utility as a single, dispatchable resource, akin to a power plant. This approach unlocks the vast potential of distributed energy resources that are currently underutilized. A multitude of potential DERs exist, including electric vehicles, residential solar panels, and commercial backup generators. By leveraging an aggregator under an appropriate regulatory framework, these distributed resources can be "harvested" and integrated into the grid. Notably, under such a framework, aggregating one hundred megawatts of DER capacity can be a more efficient, cost-effective, and time-sensitive solution compared to constructing a traditional power plant of equivalent capacity. Some of the companies have started this for example Portland General Electric (PGE) has launched a pilot program to aggregate up to 4 megawatts of residential lithium-ion storage units across 525 homes. The utility will have direct control over the batteries; and have the option to use them for any number of services, such as voltage control, frequency control and peak shaving.

DER is also giving rise to newer business model. Recently e-on, Costain and SSEN are planning to provide Resilience as a Service (RaaS) which uses services provided by a Battery Energy Storage System (BESS) together with local Distributed Energy Resources (DER) to swiftly, automatically, restore power to customers in the event of a fault.

### 4.10.5 How are digital technologies helping in this process?

Jiaqi Shi et al (2022) below are some of the key technologies which is playing a major role in modernization of grids and providing more predictable services to customer both in terms of power and water.

**Artificial Intelligence (AI) technologies:** AI offers a promising approach to mitigate the challenge of limited predictability within the electricity grid. This is primarily achieved by enhancing the accuracy of wind and solar generation forecasts, alongside predictions of user demand for electricity. AI algorithms excel at pattern recognition through the analysis of vast datasets. By examining historical data encompassing metered electricity usage, solar radiation levels, wind speed, temperature, and potentially even future electricity prices, AI models can identify complex correlations that inform more accurate predictions. AI also demonstrates significant potential in failure detection within the grid. Performance indicators obtained from sensors on devices and network elements often exhibit gradual degradation prior to catastrophic failure. AI processors can leverage historical sensor data from past failures to establish patterns and predict future equipment issues. This predictive capability empowers maintenance crews to proactively schedule interventions, preventing unplanned outages and enhancing overall grid reliability. By integrating this information into improved user interfaces for grid control rooms, operators are better equipped to ensure a reliable and resilient electricity supply.

**Energy Management systems (EMS):** For several decades, grid operators have relied on Energy Management Systems (EMS) to monitor grid operations and support dispatch decisions. However, EMS technology has remained largely unaffected by the integration of demand-side resources. EMS are complemented by various on-site management systems, collectively known as xEMS, where "x" represents the specific application domain. These systems include Factory Energy Management Systems (FEMS) for industrial facilities, Building Energy Management Systems (BEMS) for commercial buildings, Home Energy Management Systems (HEMS) for residential applications, and Microgrid Energy Management Systems (MEMS) for distributed generation networks. Despite their domain-specific functionalities, all xEMS variants share core functionalities: comprehensive monitoring, management, and operation of on-site equipment. Most xEMS offer some degree of environmental control, with Building and Factory variants managing larger Heating, Ventilation, and Air Conditioning (HVAC) and lighting systems compared to the more modest capabilities of home systems. Backup power, provided by on-site generation or energy storage, is another common feature. However, each xEMS variant possesses distinct specializations: FEMS prioritize industrial process interfaces, BEMS optimize large-scale building maintenance, HEMS focus on consumer appliances and electronics, and MEMS specialize in managing isolated electrical grids.

**Use of unmanned aerial vehicles (UAVs), satellites, and other remote sensing technologies** to improve management of rights-of-way, including: 1) identification of threats to lines from dead and dying trees; 2) identification of incompatible vegetation, including invasive species; 3) quantification and verification of successful implementation of ROW management; 4) identification and quantification of pollinator habitat.

Erik Haites (2007) This market runs on credits for reducing greenhouse gas emission reductions and allowance - rights to release greenhouse gas emissions. This credit/allowance approximately equals to 1 metric ton of CO2 equivalent (1 tCO2e).

## 4.11 Hydrogen

So far, the study focused on understanding green and renewable energy and transformation required to cater this form of energy.

Studies showed another promising energy source hydrogen which cannot be clearly categorized as green or renewable but is definitely going to play a very crucial role in Energy market given its nature of the fuel. When hydrogen burns water is the side effect and not carbon, helping in achieving net zero carbon emissions.

### 4.11.1 What is Hydrogen Fuel?

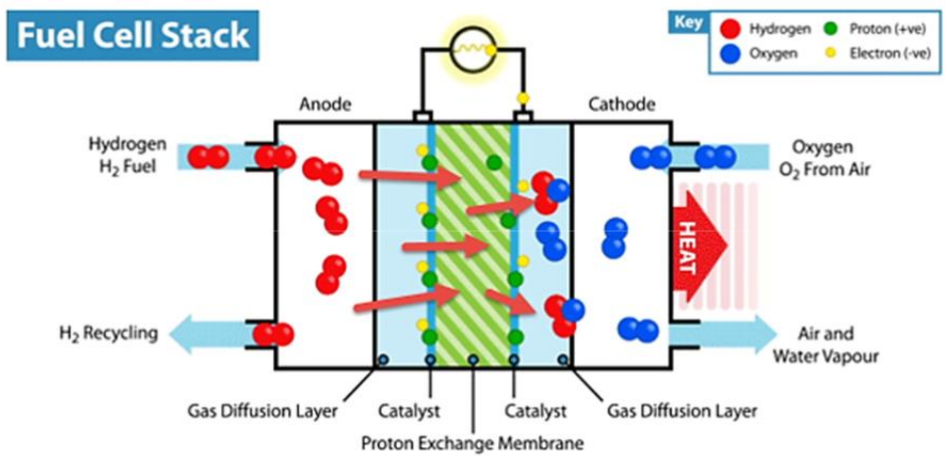
Hydrogen is widely pitted as one of alternate green fuels which will help addressing carbon emissions challenge. Burning of hydrogen as fuel leads to water as byproducts which is not harmful to the environment. It also releases Nitrogen in small quantities which can be reduced to zero if used in fuel cells. Generally, usage of Hydrogen as fuel is seen as much better alternative to fossil fuels. Besides it addresses the time constraint for re-fueling. Unlike battery operated vehicles which takes hours to charge, hydrogen fueled vehicles can refilled like traditional vehicles. The next question is how is hydrogen used as fuel in transportation?

### 4.11.2 How is Hydrogen used as fuel?

Hydrogen traditionally has been used mainly in petroleum refining processes such as desulfurization and cracking of oil, in chemical industries as a raw material or syngas for synthesis of key chemicals, among others. Most recently advancements have been made to use hydrogen as fuel.

Baharudin (2017) Hydrogen can be used as fuel in two ways.

a) **Fuel Cells:** Baharudin (2017) Hydrogen fuel cell powered vehicle is powered by hydrogen fuel cell that are gathered to the fuel cell stacks. One stack is designed to contain enough energy to provide necessary power for the automotive application. The energy is produced as long as fuel is available, and it is similar to the combustion engine.




Source: Fuel Stack used in Hydrogen fuel vehicles Baharudin (2017)

*Figure 23:*
*Fuel Stack used in Hydrogen fuel vehicles*

b) **Hydrogen Combustion Engine:** Sudi Apak et al (2012) Hydrogen due to its non-polluting properties is used in internal combustion engines as fuel, similar to engines operated with petrol and diesel. Luqmanulhakim Baharudin et al. (2013) Hydrogen-based vehicles, encompassing both hydrogen internal combustion engines (HICEs) and hydrogen fuel cell electric vehicles (FCEVs), are gaining traction as a potential pathway to mitigate greenhouse gas emissions and decrease reliance on petroleum. FCEVs, in particular hold significant promise for offering a sustainable transportation solution due to their ability to utilize renewable energy sources for hydrogen production.

However, it's important to distinguish between the environmental benefits of HICEs and FCEVs. While hydrogen's unique physical and chemical properties allow its use in modified versions of traditional spark-ignited engines, this approach offers limited environmental advantages compared to FCEVs. The primary benefit of FCEVs lies in their electrochemical conversion of hydrogen into electricity, resulting in water vapor as the sole tailpipe emission. Conversely, HICEs, despite modifications, still involve combustion and generate pollutant emissions. Milan et al (2019)- For hydrogen combustion nowadays is nothing but modified version of conventional four-stroke petrol piston engine. This kind of engine works on cyclic principal, that is described by Otto cycle.

Other areas of Hydrogen use:

IEA (2019) - Future of Hydrogen in June 2019 clearly articulates usage of hydrogen in addition to transportation and industries.

- IEA (2019) Blending hydrogen into existing natural gas networks presents an opportunity for decarbonization, with multifamily and commercial buildings in dense urban areas offering the most favorable conditions for implementation due to their higher energy demands and proximity to infrastructure. In the longer term, direct use of hydrogen in dedicated hydrogen boilers or fuel cells within buildings could be explored.
- IEA (2019) Within the power generation sector, hydrogen emerges as a frontrunner for storing renewable energy. This capability facilitates the integration of intermittent renewable sources and enhances power system flexibility. Furthermore, both hydrogen and ammonia demonstrate potential for application in gas turbines, contributing to a more adaptable grid. Additionally, ammonia presents a promising avenue for mitigating emissions from existing coal-fired power plants.

### 4.11.3 Production of Hydrogen

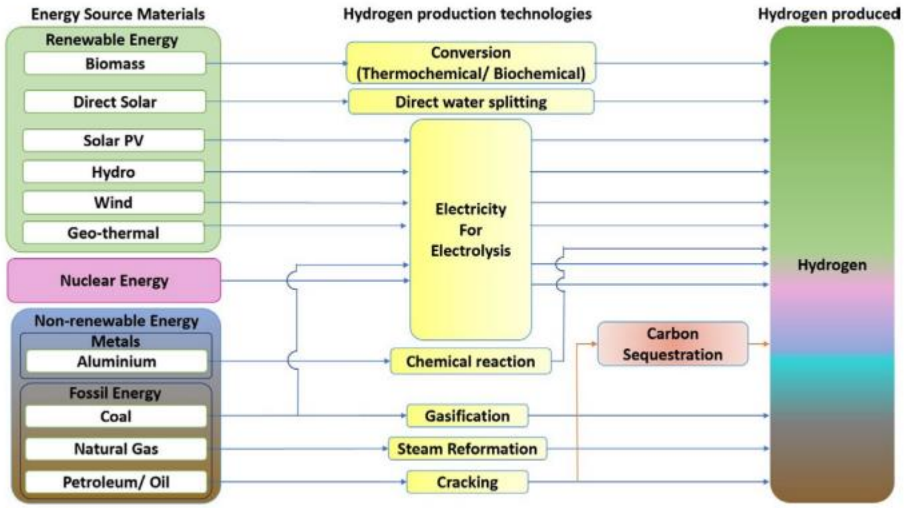
Based on how Hydrogen as a fuel is produced the classification of the fuel is established. Generally, Hydrogen fuel is distinguished by the way it is produced and the feedstock used for production. Two main feedstocks are water or traditional sources like Coal, Methane and energy required to produce.

Based on the source of Energy and the management of associated carbon (if any) we generally see below classifications

- **Grey Hydrogen:** It is produced by using coal or methane as feedstock. Coal is subjected to lignite gasification process or methane undergoes steam methane reformation process to produce hydrogen. These tend to be mostly carbon-intensive processes. Many debate whether this hydrogen really addresses the problem of carbon emission.
- **Blue Hydrogen:** In this the process remains the same as grey hydrogen, but the associated carbon is captured by combining with carbon capture storage (CCS) or carbon capture use (CCU) technologies. This helps reduce the carbon emissions and hence the name.
- **Green Hydrogen:** It is produced using electrolysis of water with electricity generated by renewable energy. The carbon intensity ultimately depends on the carbon neutrality of the source of electricity which means more the percentage of renewable energy in the electricity fuel mix, the "greener" the hydrogen produced. If nuclear energy is used it is known as pink hydrogen.

While electrolysis of water is one way, there have been references of generating hydrogen by dissociation of water into hydrogen and oxygen using concentrating solar collectors. Carmen at al (2018) calls out in his paper that to do this directly we would require very high temperatures, over 2000-degree Celsius, but with more complex process using extra chemical compounds the same result may be achievable at temperatures of under 7000C. But these processes have not yet been developed on a commercial scale. This needs more area of research.

Below diagram from L.M. Eh et al (2022) depicts the different types of fuels very effectively.




Source: L.M. Eh et al (2022)

*Figure 24:*
*Different Types of Fuels used for Hydrogen Production*

### 4.11.4 Transportation of Hydrogen Fuel

There are different types of transporting hydrogen.

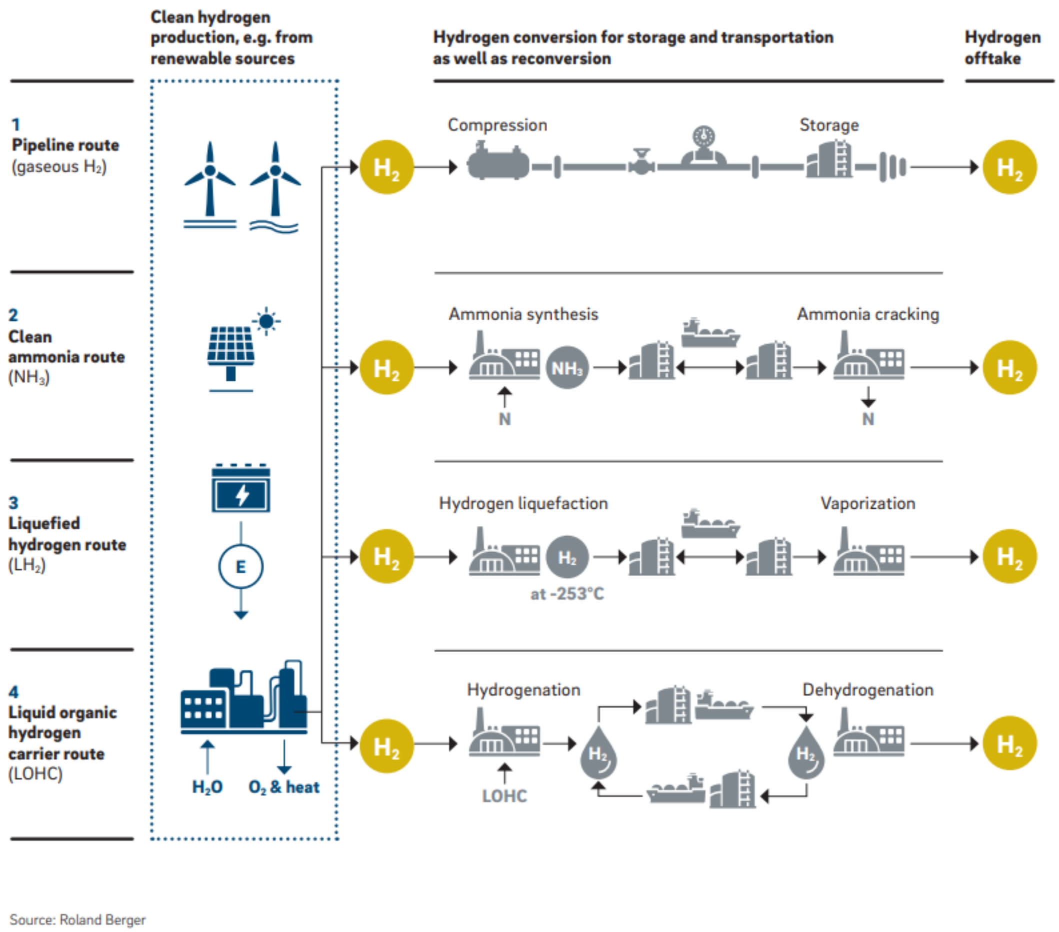
a) **Maintaining its true state:** This follows similar transportation as that of natural gas. Just like how natural gas is compressed, liquefied shipped in large carriers and then gasified at the receiving terminals. This gas is then pumped into pipelines or transported through trucks and trains. But this has several challenges.

- **Physical properties:** As per author Paul W. Parfomak (2021) in his paper published by Congressional Research Service says that Hydrogen's tiny size presents a challenge for infrastructure. Unlike methane (the main component of natural gas), hydrogen molecules are so small they can slip through leaks, cracks, and seals more easily. They can even permeate some pipeline materials faster than methane. This leakage risk is further compounded by hydrogen's ability to weaken steel pipes, welds, valves, and fittings through a process called embrittlement and other mechanisms. Because of this, pipelines need to be upgraded to suit the hydrogen chemistry. In many places natural gas pipeline is being used to transport by blending 20% hydrogen and 80% natural gas. This is perhaps the maximum what can be safely transported using existing pipeline network. Anything beyond this the pipelines needs to be upgraded.

- **Safety concerns**: Paul W. Parfomak (2021) also calls out the safety concern. He argues that hydrogen catches fire much more quickly compared to methane, and he cites the facts for this. For example, Hydrogen is 93% lighter than air and 88% lighter than methane. Besides. Hydrogen flammability range is between 4% and 75% much wider than methane between 5% to 15%.  Having said this the author also points out that the fire from- hydrogen emits less heat, but the fire is so pale that they are almost imperceptible in daylight or artificial light. As a result, visibly detecting can be a challenge. Also in confined spaces, hydrogen poses even more challenge due to higher energy content and higher flammability.

b) **Converting to ammonia:** In this mechanism the hydrogen is combined with nitrogen to convert it into liquid ammonia (NH3). The liquid ammonia can then be transported in refrigerated tanks. Once it reaches its destination, the ammonia is broken down into its components, nitrogen, and hydrogen, through an endothermic cracking process. The resulting gas mixture is then purified, and the nitrogen removed and released back into the atmosphere. Roland Berger (2021) in his paper clearly articulates the impacts of ammonia on soil and human safety because of its toxic nature. Because of this generally authorities do not permit usage of ammonia in populated areas.

Below is the summary depicted by Roland Berger (2021)




Source: Roland Berger (2021)

*Figure 25:*
*Hydrogen Transportation*

### 4.11.5 What are some of the challenges which needs to be addressed?

L.M. Eha et al (2022) lists following categories of challenges.

- **Cost Management**

Green Hydrogen cost is one of the main challenges. Today the cost of green hydrogen is approximately between 3-4$/kg. Blue hydrogen costs are escalating due to the cost associated with building and running Carbon Capture Utilization and storage infrastructure. Grey hydrogen may be comparatively cheaper now, but considering the carbon tax that will be levied, prices are expected to go high. Bernd Heid et al (2022) in their McKinsey report observe that as the cost of renewable power reduces the cost of green hydrogen will settle at approx. $2/kilogram. At this point clean hydrogen will become cost competitive in many applications.

- **Transportation and storage infrastructure**

One of the major hindrances of hydrogen adoption is developing newer pipelines, connecting to production hubs to demand areas. Besides a whole new infrastructure needs to be setup to provide refueling services to vehicles. As per IEA report (2022) there are about 51600 fuel cell vehicles and 730 worldwide hydrogen refueling stations in 2021. Greene, David et al (2020) Most of the fueling stations are supplied by trucks and some of them through pipeline. Pipeline typically connects major demand hub from the manufacturing site. In some cases, hydrogen is produced on site by setting up a small scale onsite water electrolysis or steam methane reforming. Hydrogen is dispensed to vehicles as a compressed gas at pressures 350 or 700 bar. While attempts are being made to bring down the costs, costs continue to be one of the major challenges. Besides demand must catch up accordingly to justify the huge investments required. IEA (2022) in their paper Global Hydrogen Review indicates that perhaps repurposing some of the natural gas pipelines for the transmission of hydrogen can cut investment costs 50-80% in comparison to developing new pipeline. There are projects under development to repurpose thousands of kilometers of natural gas pipes to 100% hydrogen. However, practical experience is limited, and significant reconfiguration and adaptation will be necessary.

Ahmed (2023) in his paper classifies storage of Hydrogen into two main types:

- **Physical-based storage**

By compressing Hydrogen in four kinds of vessels

  - Completely metal pressure containers constructed using aluminum or steel.

    - Wrapping glass fiber on steel pressure vessel- they have great stress endurance.
    - Composite construction with internal metal frame
    - Fully composite – In this High-Density Polyethylene (HDPE) is applied as a lining material. Carbon fiber or carbon-glass components are used to sustain the operational load. Even though it is the lightest, the cost of this kind of containment vessel is very expensive.
- **Liquid/cryogenic H2 storage**
    - By storing in liquid form by liquefying H2 at low temperature 250 degree Celsius
    - Cyro-compressed H2 storage – at low temperature and low pressure
- **Material-based storage**
    - Chemical sorption – by detaching hydrogen into their constituent atoms absorbing that into chemical composition of the sorbent.
    - Physical sorption - Storage solutions based on porous materials could be utilized to build dependable containers with a lot of space.

All these technologies are in different stages of maturity. Overall storage of hydrogen in a cost-effective manner, still needs lot of research and focus.

There are also several safety and environmental concerns which needs further research in these areas.

### 4.11.6 What are energy companies doing in this space?

Energy companies are investing both in terms of building the hydrogen plant and also the electrolyzers required for production of hydrogen. They are investing across green, blue and grey hydrogen. Few examples are:

- Reliance – an oil and gas major from India is trying to solve the cost problem associated with Hydrogen production. It has come up with a vision 1-1-1 which is producing under 1$, 1kg of hydrogen within 1 decade.
- Shell has committed to constructing Holland Hydrogen I, Europe's anticipated largest renewable hydrogen production facility upon its 2025 operational launch. This 200-megawatt (MW) electrolyzer, situated on the Tweede Maasvlakte within the Port of Rotterdam, will generate an estimated daily output of 60,000-80,000 kilograms of renewable hydrogen.
- Another noteworthy project is the China M4 electrolyzer, a 20 MW power-to-hydrogen installation coupled with hydrogen refueling stations in Zhangjiakou. Commencing operations in January 2022, this facility leverages solar and onshore wind power to produce eight tonnes of renewable hydrogen daily. Notably, during the 2022 Winter Olympics held in Zhangjiakou, this project supplied approximately 50% of the total decarbonized hydrogen used to power over 600 hydrogen fuel cell buses.

### 4.11.7 How are digital technologies helping in this process?

As per World Economic Forum -Sylvie et al (2021) says there are four main digital technology solutions which can help in expediting green hydrogen transition.

a) **Digital Twins** – Digital twins can be used to optimize returns of the shareholders. Right from capex allocation, optimization of energy, electrolyzer, storage, transportation optimization etcetera. Digital twins can model multiple design and scenarios such as weather, demand volatility, supply disruptions, policy impact etcetera. World economic forum estimates indicate that digital twin analysis can optimize capital expenditure (CAPEX) by 10-15% whilst reducing risk by 30-50%, along with a marginal change in operating expenditure (OPEX).

b) **Monitoring and Control** – Information Technology (IT) systems can help monitor plant performances, production rate, day to day operations of plant etcetera. When IT combines with Operational technologies (OT), remote monitoring of plants and transportations becomes seamless. This helps in monitoring operations and fine tune them to adjust the operations. This technology when augmented with advanced analytics helps to proactively manage assets from corrosion, asset performance etcetera. This can be operated at asset level, plant level and enterprise level.

c) **Certificates of Origin** – Blockchain technology can help to trace end to end traceability along the life cycle of green hydrogen from cradle to grave. This can help increase the confidence of customers and also helps in auditing, which avoids multiple counting green credits.

So far we discussed different green and renewable fuels which can help in achieving sustainability goals. But having said this we still cannot do away with fossil fuels in certain industries like cement, steel, iron, refineries industries as they need generation of high temperature for their process. Also within marine and aviation industry is still not electrified, nor they can operate on complete green fuels. In such industries fossil fuels will burn and emissions will happen. The question therefore to ask now is how do we manage these emissions. In the next section we discuss these options.

### 4.12 Biological Sequestration and Storage

Raghad Adam et al (2023) Instead of relying on machines, in this method we turn to Earth's natural solution for capturing carbon dioxide. This method utilizes plants, trees, and marine ecosystems. Through biological processes like photosynthesis, these systems absorb CO2 from the atmosphere and transform it into organic material, effectively storing the carbon for extended periods.

Let us look at various biological sequestration and storage methods as discussed by Raghad Adam et al (2023)

- **Afforestation and Reforestation:** Raghad Adam et al (2023) Planting new forests or reviving damaged ones creates a natural weapon against climate change. Trees act like giant carbon vacuums, sucking in CO2 during photosynthesis. This captured carbon gets locked away for years to come, stored safely in the trees' roots, trunks, and leaves.
- **Forest Management:** Raghad Adam et al (2023) Beyond creating new forests, effective forest management is crucial to maximize how much carbon forests can store. By stopping deforestation, implementing sustainable logging practices, and protecting old-growth forests, we can supercharge their ability to capture and store carbon dioxide.
- **Agrofostery:** Raghad Adam et al (2023) Agroforestry is a clever technique that combines agriculture with tree planting. This isn't just about aesthetics; it's a powerful tool for a healthier planet. Trees on farms help capture more carbon dioxide, while also improving soil quality and helping farms better withstand the challenges of climate change.
- **Soil Carbon Sequestration:** Raghad Adam et al (2023) Soil serves as a critical reservoir for carbon storage. The implementation of soil carbon sequestration practices, including cover cropping, reduced tillage, and agroecological farming methods, demonstrably enhances soil organic carbon (SOC) content. This enrichment in SOC leads to the effective sequestration of atmospheric carbon dioxide ($CO_2$).
- **Wetland Restoration:** Raghad Adam et al (2023) Wetland ecosystems, encompassing marshes, swamps, and other saturated environments, function as vital natural carbon sinks. Restoration and preservation efforts directed at these ecosystems contribute to

the maintenance of their carbon sequestration potential. This approach not only promotes biodiversity but also offers mitigation strategies for the rising sea level.

- **Blue Carbon Ecosystems:** Raghad Adam et al (2023) Blue carbon ecosystems, including mangroves, seagrasses, and salt marshes, offer substantial carbon sequestration benefits. These coastal habitats sequester large amounts of carbon in their sediments, making them valuable allies in the fight against climate change.
- **Biochar:** Raghad Adam et al (2023) Biochar, a recalcitrant carbonaceous material produced via the pyrolysis of organic biomass, offers a promising approach for long-term carbon storage. When incorporated into soil, biochar enhances its carbon sequestration capacity by promoting the stable storage of captured atmospheric carbon dioxide ($CO_2$).
- **Carbon Farming:** Raghad Adam et al (2023) The adoption of carbon farming practices, encompassing crop rotation and controlled grazing strategies, presents a viable approach for transforming agricultural lands into efficient carbon sinks. Integration of these methodologies with established farming practices demonstrably enhances the potential for carbon sequestration.
- **Marine Alga and Phytoplankton:** Raghad Adam et al (2023) Marine environments, particularly the vast oceans, represent a significant reservoir for carbon sequestration. Specific types of marine algae and phytoplankton exhibit a high capacity for $CO_2$ absorption through photosynthesis. This biological process plays a critical role in capturing atmospheric carbon dioxide and contributes to the overall health and productivity of marine ecosystems.

## 4.13 Carbon Capture Utilization and Storage (CCUS)

Sara Budinis et al (2023) explains CCUS involves the capture of $CO_2$, generally from large point sources like power generation or industrial facilities that use either fossil fuels or biomass as fuel. If not being used on-site, the captured $CO_2$ is compressed and transported by pipeline, ship, rail or truck to be used in a range of applications or injected into deep geological formations such as depleted oil and gas reservoirs or saline aquifers.

Raghad Adam et al (2023) At a broad level there exists three main types of carbon capture processes, namely, pre-combustion, post-combustion, and oxy-fuel combustion (which includes chemical looping)

- **Pre-combustion $CO_2$ capture:** Imagine capturing carbon dioxide ($CO_2$) from fossil fuels before they're even burned! That's the idea behind pre-combustion $CO_2$ capture. One way to do this is through gasification. In this process, a fuel source (like coal) is heated with steam and air, creating a mixture of gases called syngas (mainly hydrogen and carbon monoxide). This syngas still contains some $CO_2$ (between 15-50%). This $CO_2$ is then captured, stored, and transported, preventing its release into the atmosphere.
- **Post-combustion $CO_2$ capture**: This deals with removing $CO_2$ from the effluent flue stream. Post-combustion is the simplest technology to use and capture $CO_2$ among the currently available technologies of CSS. This process is widely used amongst the applicable technology. It is widely used because of its minimal impact on existing systems. However, it consumes a large amount of energy in the process of separating $CO_2$ gas from the exhaust gases in the air separation unit (ASU). In fact, this process reduces the efficiency of power plants by 8–12%, making it not economically feasible.
- **Oxy-fuel Combustion**: Steven M. Carpenter (2017) Oxy-fuel combustion offers an alternative approach to conventional air-fired combustion in coal-fired power plants. This technology involves combusting hydrocarbon fuels within a near-pure oxygen

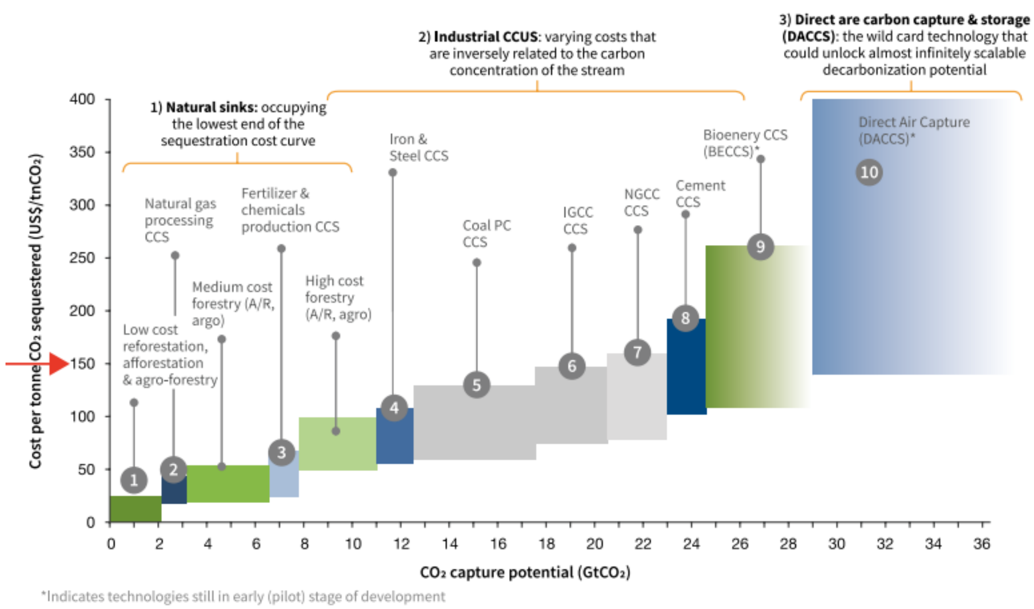
environment, rather than utilizing air. To regulate combustion temperature, a portion of the flue gas, devoid of nitrogen, is used to dilute the oxygen stream. The primary objective of employing oxy-fuel combustion lies in the generation of a flue gas with exceptionally high concentrations of CO2 and water vapor. This characteristic facilitates CO2 capture through readily achievable low-temperature dehydration and desulfurization processes. Notably, oxy-fuel combustion presents several advantages, including a significant reduction in NOx emissions, a high degree of CO2 purity in the captured stream, and a reduced flue gas volume due to the increased density of the oxygen-diluted gas mixture.

CCUS is more of point capture mechanism, which involves installing special devices at fossil fuel plants to absorb the emissions. Raghad Adam et al (2023) there are few other technologies like Biomass Energy with Carbon Capture and Storage (BECC) and Direct Air Capture and Storage (DACS).

UNECE in their paper Technology brief carbon capture use and storage talk about BECC. In this process CO2 is taken out of the atmosphere by vegetation, then recovered from the combustion products when the biomass is burnt as fuel.

Katie Lebling et al (2022) in their paper define Direct Air Capture as a technology that uses chemical reactions to pull carbon dioxide out of air. When air moves over these chemicals, they selectively react with and trap CO2, allowing the other components of air to pass through. Once carbon dioxide is captured from the atmosphere, heat is typically applied to release it from the solvent or sorbent. Doing so regenerates the solvent or sorbent for another capture cycle. The captured CO2 can then be injected deep underground for sequestration in certain geologic formations or used in various products and applications. DACS is currently categorized as “technology readiness level” 6 (on a scale of 1 to 9), meaning it’s still in the large-scale and prototype phase, not yet ready for full commercial deployment.

DACS - Katie Lebling et al (2022) despite the benefits and flexibility, direct air capture is more costly per tonne of CO2 removed compared to many mitigation approaches and natural climate solutions as it is energy intensive to separate carbon dioxide from ambient air. The range of costs for DAC vary between $250 and $600 today, depending on the technology choice, low-carbon energy source, and the scale of their deployment; for comparison, most reforestation costs less than $50/tonne. The below graph from Goldman Sachs also indicates on the same lines. However, depending on the rate of deployment, which could accelerate through supportive policies and market development, costs for DAC could fall to around $150-$200 per tonne over the next 5-10 years.




Source: Goldman Sachs, Equity Research 2020

*Figure 26:*
*Carbon sequestration cost curve and the GHG emission abatement potential*

Natural Sinks solutions offer lower cost/tonne, but it requires large amount of afforestation sites.

Katie Lebling et al (2022) Direct air capture (DAC) technology offers a significant advantage in terms of siting flexibility. Unlike approaches that rely on land-use change, such as afforestation, DAC does not necessitate the utilization of arable land. This characteristic minimizes potential negative impacts on food production and other established land-use practices. The specific land area required for large-scale DAC deployment depends on two key factors: the chosen DAC system type and the energy source powering its operations. When renewable energy sources are employed, they will constitute the most significant contributor to the overall land footprint. Notably, DAC exhibits a lower land requirement per tonne of CO2 sequestered compared to other prominent Carbon Dioxide Removal (CDR) strategies, such as reforestation. Estimates suggest that capturing one million tonnes of CO2 using a DAC plant would necessitate a land area of 0.4 to 66 square kilometers for the plant itself and the associated energy source. In contrast, capturing an equivalent amount of CO2 through forest-based approaches would demand an estimated 862 square kilometers.

### 4.13.1 Transportation of captured Carbon

Jess Ralston (2021) Following capture, the transportation of CO2 is typically achieved via pipelines for its designated utilization or storage. To facilitate pipeline transport, the captured CO2 undergoes compression into a liquid state, enabling its movement through pipelines, ships, or road tankers. The concept of 'industrial clusters' is gaining traction as a strategy to optimize CO2 transportation infrastructure. These clusters involve the shared use of pipelines by multiple emissions sources, such as power plants and industrial facilities. This collaborative approach offers the benefit of consolidating emissions into a single pipeline network, leading to cost reductions and achieving the necessary scale for the economic viability of Carbon Capture, Utilization, and Storage (CCUS) projects.

### 4.13.2 Storage of Carbon

Rosa M. Cue´llar-Franca et al (2015) $CO_2$ storage in geological formations is at present probably one of the most promising options owing to the previous experience by the oil and gas industry. As oil and gas industry has good understanding of the structural characteristics and behavior of depleted oil and gas reservoirs and the existing well-drilling and injection techniques can be adapted for carbon storage applications. Deep saline aquifer formations are also a possibility for storage with a large storage capacity estimated at 700–900 Gt $CO_2$. However, very little is known about coal bed formations and further explorations are required before they can be considered a safe storage option. Ocean storage relies on the principle that the ocean bed has a huge capacity to store injected $CO_2$ at great depths. Yet, ocean storage has never been tested on the large scale even though it has been studied for over 25 years. The main concerns with $CO_2$ storage are its possible leaks and the related damage that a concentrated $CO_2$ stream would cause if it escaped into the environment. The annual leakage rates reported in the literature range from 0.00001% to 1%, depending on the permeability of the geological structure and its faults or defects.

### 4.13.3 Use of Captured Carbon

Jess Ralston (2021) Captured $CO_2$ presents a valuable resource with diverse utilization pathways. One promising application lies in its conversion into construction materials, such as concrete. Additionally, $CO_2$ can serve as a carbon feedstock for the production of plastics. Beyond material conversion, $CO_2$ finds direct application in various commercial processes. In the food and beverage industry, $CO_2$ plays a role in carbonation, food freezing and chilling, and even packaging. The horticultural sector utilizes $CO_2$

enrichment in greenhouses to stimulate the growth of $CO_2$-fixing crops through photosynthesis.

Currently, the dominant application for captured $CO_2$ is in Enhanced Oil Recovery (EOR). This technique involves injecting $CO_2$ into depleted oil and gas reservoirs to displace residual hydrocarbons, thereby increasing ultimate recoverable reserves. The additional revenue generated from these extracted fuels assigns an economic value to the $CO_2$ utilized in the process. To compete effectively with EOR, alternative $CO_2$ utilization pathways will need to demonstrate comparable economic viability.

### 4.13.4 What are energy companies doing in this space?

Climeworks, Carbon Engineering, Global Thermostat are some of the companies with developed technologies who are playing prominent role in DAC. Together these companies have 18 plants of varying sizes (1 $tCO_2$/yr. up to 4,000 $tCO_2$/yr. capacity, the largest plant in operation today) capturing a total of just under 8,000 $tCO_2$/yr. Around half of that is sequestered permanently — similar to the annual emissions from 870 cars — while the other half is sold for use in various products.

Companies like Oxy are investing heavily in DAC technology. As per Sabrina Valle et al (2023) Oxy aims to build 100 plants using direct air capture (DAC) technology that strips carbon dioxide ($CO_2$) from the atmosphere to bury underground or for use in making products such as concrete and aviation fuel.

Nick Jones (2023) in his article has summarized some of the new projects launched by Energy companies as of Sep 2023.

- TC Energy and TVA are launching two new projects to capture carbon emissions from Natural Gas Power Plant in USA.

- Exxon Mobil, Qatar Energy and TotalEnergies are launching project Ras Laffin CCS Expansion in Qatar to capture from LNG liquefaction Plant.
- ADNOC is updating Habshan CCS facility to improve efficiency of capturing from Natural Gas plant processing.
- ENEOS has resumed operation in Petro Nova CCS setup along the Coal Power Plant.
- Climeworks and Great Carbon Valley are setting up DAC in Kenya to be operational in 2028.

### 4.13.5 How are digital technologies helping in this process?

Digital technologies play a crucial role in advancing and optimizing carbon capture technologies in several ways. Here are some ways in which IT contributes to carbon capture:

**Simulation and Modeling:**

- **Computational Models:** IT enables the development and use of complex computational models to simulate and analyze various carbon capture processes. These models help researchers and engineers understand the behavior of different materials and technologies, optimizing the efficiency of carbon capture systems. Alex Procyk (2023) in his paper calls out that to sanction a carbon capture and storage (CCS) project one requires a good understanding of two key things: how much CO2 the underground reservoir can hold and where the captured CO2 will eventually move within it. Scientists use fine-scale computer simulations based on geological data to predict how the CO2 will react with the rock formations and estimate the storage capacity. However, creating detailed simulations for such large areas can take an impractical amount of time. However as per author Apoorva Chawla et al (2022) leveraging digital technologies one can represent the physical conditions of the pipelines and different equipment involved in the operation, will help predict the behavior of the entire CCUS operations. This predictability gives the power to the process designers to design and test process which are robust and cause Zero harm /loss.

- **Machine Learning:** Machine learning algorithms can analyze large datasets generated from experiments and simulations to identify patterns and optimize carbon capture processes. This can lead to more efficient and cost-effective solutions.

**Monitoring and Control:** Apoorva Chawla et al (2022) Large-scale carbon capture and storage (CCS) needs to be safe and dependable. To achieve this, a robust health monitoring system is crucial. This system ensures two things: a smooth flow of captured carbon dioxide (flow assurance) and early detection and prevention of any leaks that might occur anywhere in the CCS process (throughout the value chain).

- **Sensors and IoT Devices:** Information Technology facilitates the integration of sensors and Internet of Things (IoT) devices in carbon capture facilities. These devices monitor parameters such as temperature, pressure, and gas concentrations in real-time, allowing for better control and maintenance of the carbon capture process. IoT monitoring and automation systems could help scale carbon capture programs to a point where they may feasibly undo the damage already caused by CO2 emissions within the past century.
- **Automation**: IT enables the automation of carbon capture systems, improving the precision and speed of operations. Automated systems can respond to changes in conditions and adjust parameters for optimal performance.

**Data Analytics:** Marco Pirrone et al (2022) in their paper talks about integrated combination of data-driven methods (like machine learning) and traditional modeling techniques improves our characterization of reservoirs for carbon capture projects. This approach uses data analysis to estimate the proportions of different minerals in the rock, based on samples taken from the core and well-logging data. These estimated mineral volumes, along with other well-logging measurements, are then fed into established models to obtain a comprehensive understanding of the reservoir's properties.

Remote Monitoring and Maintenance:

- **Remote Sensing**: IT allows for remote monitoring of carbon capture facilities, reducing the need for physical presence. This can lead to more efficient maintenance practices and timely identification of issues, minimizing downtime and improving overall system reliability.
- **Diagnostics and Predictive Maintenance**: IT supports the implementation of diagnostic tools and predictive maintenance algorithms. By analyzing performance data, these tools can predict when components might fail, allowing for proactive maintenance to prevent disruptions.

While we discussed some of the mechanism to capture the carbon from hard to abate industries we also discovered that some of these industries are undergoing transformations which will help shorten the processing cycle thereby reducing the carbon generation in this process. One such process is Crude Oil To Chemicals. The next section covers the details.

## 4.14 Crude Oil To Chemical (COTC)

We all know the crude extracted from the subsurface of the earth is processed in refineries to produce useful products like Diesel, Gasoline, Kerosene, Jet Fuel, Liquid Petroleum Gas (LPG), Naptha, Methane, Ethane etcetera.

The 40-50% of the output from the refinery is transportation fuel like Gasoline and Diesel. <10% of output like Naptha, heavy residual oil etcetera goes in as feedstock for Petrochemical production.

As the world is transitioning to low carbon economy, and the influx of Electric Vehicle the demand for these fuels will come down. At the same time the demand for petrochemicals like polymers will continue to grow with the rising wealth of people. This means refiners will now have to focus on producing less of transportation fuel and more of feedstock for petrochemicals.

Even better is to start producing chemicals so that they can derive the benefits of integrated value chain and pass on the benefits of scale and value to end consumers.

There are different ways to achieve this.

Grosclaude et al (2021) in their paper discussed that some of the engineering companies like Technip Energies believes that to achieve Crude to Chemicals value chain , it requires a dramatic change in the way refiners have traditionally designed their projects and, in particular, it should encompasses:

- Fresh approaches to crude selection and processing scheme based on the target market.
- New novel method of integrating and optimizing refinery units, leveraging the existing Fluid Catalytic cracker, hydrotreater, coker etcetera.
- Focus on circularity with recycle of low-value streams as internal fuels.
- Design new benchmarks in terms of complex size.

Tim Fitzgibbon et al (2022) – senior expert from McKinsey says in his article there are three ways to achieve this.

a) Change in individual process units.
b) Change the mix of process units.
c) Build more direct crude to chemical plants.

Further research showed.

**a) Change in individual process units.**

**High-Severity Fluid Catalytic Cracker (FCC):** This is a breakthrough technology that allows refiners to produce petrochemicals from heavy oils. JX Nippon Oil and Energy Corporation, King Fahd University of Petroleum and Minerals, Axens, and Saudi Aramco developed this technology. S-Oil of South Korea became one of the first companies to commercialize this technology.

**Steam Cracking:** This is a petrochemical process in which saturated hydrocarbons are broken into unsaturated hydrocarbons using Naptha, LPG, propane, butane etcetera. Several petrochemical companies use this process to produce petrochemicals. For example, Reliance Petrochemical in India boasts of leveraging this technology.

**b) Change the mix of process units.**

Some of the refineries are looking at increasing the production of petrochemicals by changing the mix and arrangement of refinery process units. Some of the processes which can play a bigger role in petrochemicals production is increasing hydrocracking, maximizing aromatics reforming etcetera.

**c) Build more direct crude to chemical plants.**

While technology is available what parameters should be considered to shift to higher petrochemical yields. Our research showed below.

### 4.14.1 What are some of the considerations required to shift to higher petrochemical yields?

First and foremost, it makes sense to upscale refineries to petrochemical plants for the following reasons.

- Refineries are usually located near markets with good port and transportation facilities. These can be leveraged with no extra capital costs.
- Utilities available in refineries like water, power, fire water system integration etcetera can be repurposed very easily.
- Sourcing of feedstock becomes very cheap and easy since the feedstock will be produced in the same facility.
- Managing the supply and demand is easier as we have better control on the feedstocks.
- Effluent and environmental safety can be easily extended from the existing facilities.
- Most importantly manpower can be repurposed with little training and coaching.
- Having said this the refineries will have to undergo some configuration changes to produce more petrochemical. This can be increasing the capacity of Fluid Catalytic Cracker, steam cracking, hydrotreater etcetera.

**Geography considerations:** Geography plays an important role in the choice to shift to Crude Oil to Chemicals (COTC). As per the blog on FutureBridge (2019) - for example for US and Middle east there is availability of cheap crude oil and therefore can easily embark on this. Companies like ExxonMobil COTC, Saudi Aramco COTC, SABIC COTC etcetera have already taken this plunge. However, for geographies like Europe and Asia the adoption of the COTC project will be governed by the capital availability and efficiency. Having said that there is great demand for petrochemicals in Asia being the rising middle class of the world and representing 60% of the world’s population.

### 4.14.2 What are energy companies doing in this space?

As per Statista (2021) we have around 700+ refineries in the world, out of which Asia constitutes to around 300+ refineries. This capacity is expected to grow by 5.67% during 2023-27. China is expected to have highest CDU capacity followed by India and South Korea.

- Aramco – Crude Oil to chemicals (2024) Aramco together with SABIC is working to commercialize innovative crude to chemicals technologies, positioning them as a preeminent player in the global petrochemicals industry.
- Reliance India – BSE India (2022) Reliance India's Crude Oil to Chemicals (COTC) business segment encompasses a diversified portfolio of products, including transportation fuels, polymers and elastomers, intermediates, and polyesters. This segment leverages a network of world-class assets, strategically integrating refineries, crackers, and downstream facilities. This unique integration is further bolstered by best-in-class logistics and supply chain infrastructure. The resultant, highly integrated COTC business structure fosters a collaborative decision-making approach. This approach optimizes the entire value chain, from crude oil acquisition and refining to petrochemical production, ultimately serving both B2B and B2C customer markets.
- China's Hengli group recently built integrated refinery and petrochemical plant which in record time of 19 months and operationalized in 6 months. Key products produced in this complex include purified terephthalic acid (PTA), xylenes, ethylene glycol (EG), ethylene, ethylene oxide (EO) etcetera.
- Exxon Mobil Corp. is investing in a multi-billion-dollar petrochemical complex in Huizhou, China that's the cornerstone of its growth strategy in China.

### 4.14.3 How is IT helping in this process?

As per the article published by Deloitte David Yankovitz, et al (2019) – digital technologies can help petrochemical industries in three main segments:

a) Growth and Innovation

- Provide data and insights to companies to develop new business models and markets. For example, based on the customer demands, and the input crude mix, optimum products can be produced which ensures maximum margin and least carbon emissions.
- Create new value chain interaction: The supplier and vendor ecosystem can be seamlessly connected to ensure dynamic adjustments to any change in the market conditions – example fluctuations in demand, logistic disruptions, price rise et cetera.
- Reduce time to market – with end-to-end systems connected seamlessly, decisions are made quickly, bottlenecks reduced, and hence new products can be rolled out quickly.

b) Performance Optimization

- Improve asset efficiency by continuously monitoring the value chain.
- Optimize reaction outputs and molecule management through advanced analytics.

c) Sustainability and circularity

- Reduce waste by capturing untapped opportunities by harvesting insights from new data streams.
- Ensure recycling of the chemicals/water/heat etcetera used in the process by tracking and optimization.
- Simulate the performance of clean technologies and predict carbon footprint of new products.

## 4.15 Carbon Market

Beatriz Fonseca et al (2022) International carbon market started to gain momentum when Kyoto Protocol was signed in 1997. Höhne et al (2015) -This was the time when countries came together and agreed on reducing their emissions by bringing in several offset projects in developing countries who would not have such obligations but could opt to reduce their own emissions and sell credits to the developed ones.

This protocol gave rise to three mechanisms to help countries reduce their emissions.

**- Emissions trading** – this cap-and-trade mechanism. Beatriz Fonseca et al (2022) It provides a fixed cap which limits the amount of emissions from all the entities engaged for example companies, organizations etcetera.

**- Clean Development Mechanism (CDM)**– Beatriz Fonseca et al (2022) This mechanism is to promote more of green projects. It allows developed countries to fund GHG emissions-reducing projects in developing countries and claim the saved emissions as part of their own efforts to meet international emissions targets.

**- Joint Implementation (JI)** – This is also a project-based mechanism, but the difference is in CDM the investment must be done in developing country whereas in this case developed country can themselves carry out emissions reduction or removal enhancement projects in other developed countries.

Beatriz Fonseca et al (2022) Kyoto represented the first step in establishing a solid carbon pricing framework at the international level, which set the scene for the present structure under the Paris Agreement.

### 4.15.1 Type of carbon market

Regulatory compliance and voluntary markets are two types of carbon market generally observed.

Erik Haites (2007) explains- them as

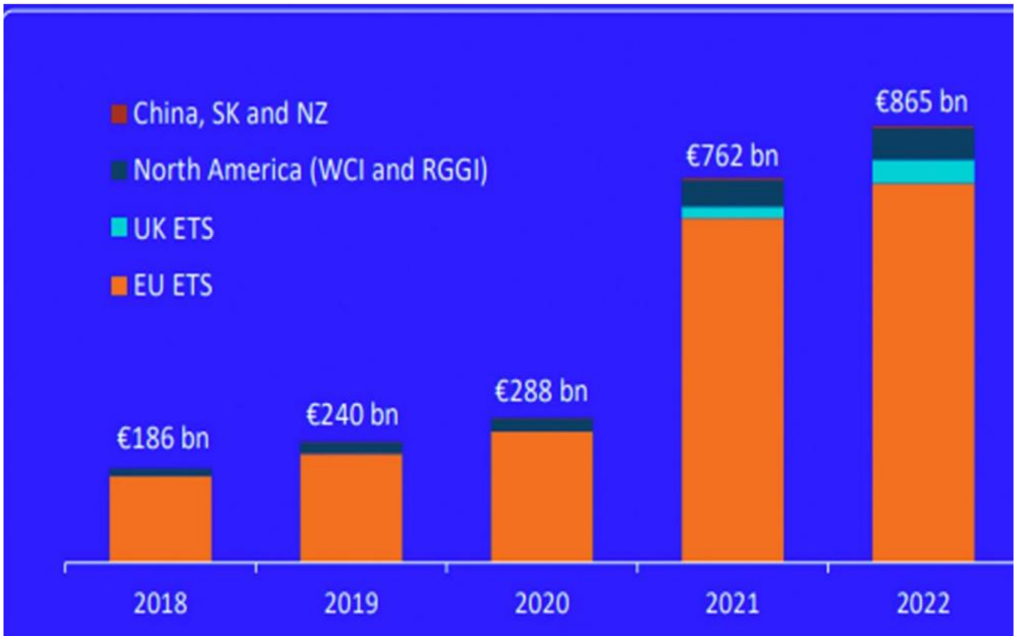
- **The regulatory compliance** - This is generally used by corporates and governments. By law they must account for their emissions. Usually, it is mandated either at regional or national or at international levels. As per Accenture (2023) - Harnessing the power of voluntary carbon markets, governments typically use this to limit the emissions at industry level. They are also called as Emission Trading system (ETS) or cap and trade schemes. Every participant in that industry group is assigned an allowance or quota which can be absolute number or a relative number. If they emit below that limit, they create a surplus of allowances which can be sold to those participants who emit above their allowance thus creating a market for sale and purchase of allowances. This is first type of category as per the report The Board of the International Organization of Securities Commissions. The second category is called the "baseline-and-credit system", there is no fixed limit on emissions but carbon emitters that reduce their emissions more than they would otherwise be obliged to earn allowances that they can sell to others who need them.
- **The voluntary markets** –This market is driven on voluntary basis. As corporates who want to go beyond their set targets of emissions but strive to achieve net zero targets. Accenture (2023) To meet these targets, they often purchase carbon credits, offsetting their emissions with emissions avoided, reduced or removed elsewhere in the world. In voluntary market, companies invest in carbon-reducing or removing initiatives and projects, which then generate credits. These projects can be divided into two buckets.
    - Emission avoidance and reductions
        - Avoiding deforestation and forest degradation.

    - Improving forest management
    - Investing in technology driven projects like setting up renewable energy facilities, cleaner cook stoves, using less polluting fuels like hydrogen, biofuels etcetera
- Emission removals
    - By engaging in afforestation, soil carbon sequestration, direct air capture et cetera
    - These markets tend to be more global in nature whereas the compliance markets tend to operate at regional, national, or subnational level.

Hamilton et al (2009) The size of the two markets differs considerably. In 2008, on the regulated market US$119 billion were traded, and on the voluntary market US$704 million.

### 4.15.2 A view on international carbon market:

Erik Hates (2007) The global landscape of carbon pricing features a network of interconnected carbon markets, each stemming from a distinct greenhouse gas emissions trading system (ETS). These ETS programs establish a cap on allowable emissions for specific sources within their jurisdiction. By the end of a designated compliance period, each emitting entity is obligated to surrender allowances or offsets corresponding to their actual emissions. The governing body of each ETS defines the regulatory framework encompassing the issuance, trading, and utilization of these allowances and offsets. As per the report The Board of the international organization of securities commissions below is how the markets looked across countries in during 2018-2022: total value by segment, total volume.




Source : Refinitiv Feb 2022

*Figure 27:*
*International Carbon Market*

So far around 29 compliances markets have been implemented globally. As per the report IOSCO (2023) Compliance Carbon Markets some examples include the European Union (EU), the United Kingdom (UK), New Zealand, South Korea and Canada. China launched its national ETS (a baseline-and-credit system) in July 2021, after several cities and provinces had been operating pilot ETS programs for several years. In the Americas, Mexico became the first country in Latin America to establish a national ETS in 2020 while Colombia is currently developing one and Brazil and Chile are considering their implementation. The United States does not have a regime in place at the federal level. However, among U.S. states, California operates a compliance market at the state-level, which is linked with Quebec in Canada to form the Western Climate Initiative; and the Regional Greenhouse Gas Initiative (RGGI) operates within about a dozen states along the East Coast of the US. Canada also currently lacks a national compliance market, but regimes are in place in the provinces of Quebec and Nova Scotia.

### 4.15.3 Role of Derivative in Carbon Market

As per ISDA (2021) derivatives in carbon markets provides an effective tool to manage exposure and hedge risk. By facilitating the transfer of risks from counterparties that do not wish to have risk exposures to those that are willing to do so, derivatives offer an effective tool to hedge physical and transition risks by reducing uncertainty over future prices. It also supports investment activity in emissions-reduction projects. Firms use derivatives to enable external capital to be channeled towards sustainable investments and net-zero-emissions activities.

Accenture (2023) - Harnessing the power of voluntary carbon markets, based on their proprietary model anticipate the carbon market to evolve into a substantial physical market exceeding $2 trillion by 2050. When derivative financial instruments are factored in, the projected market size surpasses $10 trillion. These figures are predicated on an assumed carbon price of $120 per tonne, a total market volume of up to 16 GtCO2e (gigatonnes of carbon dioxide equivalent), and a ratio of four derivative trades for every physical trade. A carbon market of this magnitude would be quadruple the size of the global physical oil market value in 2021.

ISDA (2021) Derivative markets play a crucial role in bolstering transparency within the carbon market by providing forward-looking information on the underlying carbon assets. This transparency fosters long-term sustainability objectives. Commonly traded carbon derivatives include futures, options, and swaps. Futures and options represent standardized contracts traded on exchanges with central clearing mechanisms. These exchanges enhance market liquidity, promote price discovery through transparency, and act as financial intermediaries for each trade. Additionally, exchange-traded contracts mitigate counterparty risk via clearing mechanisms, as the exchange acts as the counterparty for both buyers and sellers. Furthermore, exchange listings provide market makers with an avenue to hedge their positions.

Swaps, another prevalent type of over-the-counter (OTC) derivative, involve non-standardized agreements or a series of agreements for the exchange of allowances, offsets, or cash flows at predetermined times or over a defined period. Offset-allowance swaps allow companies to manage their compliance obligations. Companies with excess allowances can sell them to entities that require additional offsets to meet their quotas, capitalizing on price differentials. Conversely, entities with surplus offsets can utilize swaps to acquire allowances they may lack. Swap contracts are typically settled through cash payments rather than physical delivery of allowances or offsets.

#### 4.15.4 What are energy companies doing in this space?

Petrobras – a Brazilian Oil and Gas major in their sustainability report clearly call out high quality carbon credits as complementary strategy.

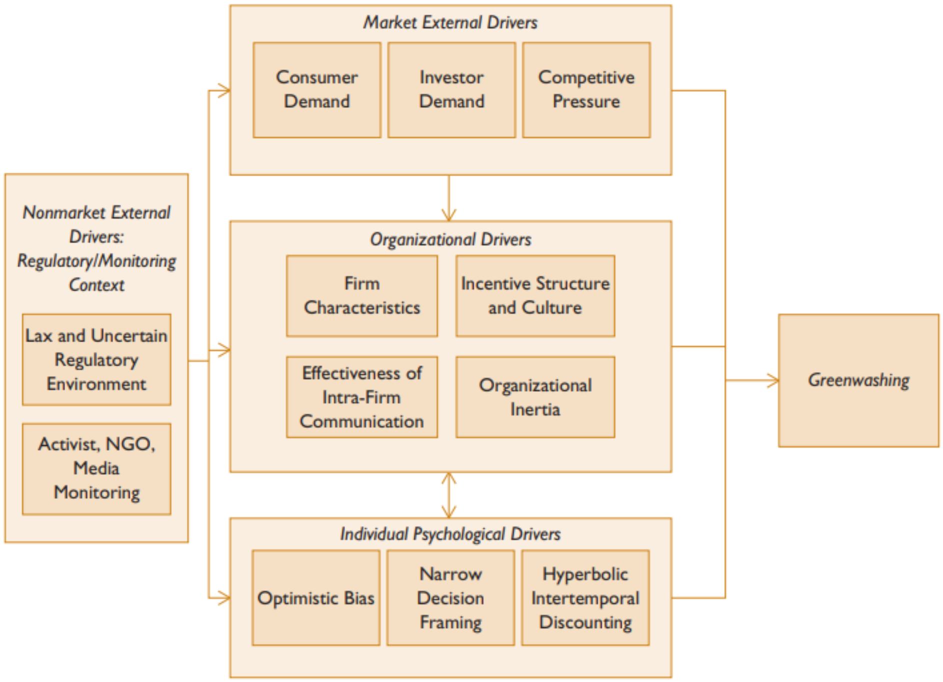
Shell an European Oil and Gas Major offers customers the option to combine product purchases with high-quality, independently verified carbon credits. These carbon credits stem from projects that demonstrably reduce or neutralize the greenhouse gas emissions associated with product use. For instance, at Shell retail outlets, customers can opt for a "carbon neutral" driving experience through Shell. To achieve this carbon neutrality, Shell procures carbon credits generated by a global portfolio of projects specifically focused on forest protection and regeneration.

BP, a prominent European oil and gas company, actively participates in the low-carbon trading (LCT) sector. This strategic engagement leverages established carbon markets to incentivize a global reduction in greenhouse gas emissions (GHG) across diverse geographical regions and industrial sectors. By participating in these markets (LCT), BP acts as a bridge, connecting itself and its customers to the realities of carbon pricing. This multifaceted approach not only supports the efficient functioning of regulatory trading programs designed to curtail emissions but also facilitates the development of projects in other sectors through the strategic purchase of carbon credits.

### 4.15.5 The arguments:

Voluntary emission disclosure by corporates have been mired by several climate activist as greenwashing. What is greenwashing? Magali A. Delmas et al (2011) defines greenwashing as the act of misleading consumers regarding the environmental practices of a company (firm-level greenwashing) or the environmental benefits of a product or service (product-level greenwashing). Increasingly corporates are being accused of greenwashing. They are now being questioned.

Mateo-Márquez et al (2022) in their paper analyzed the impact of regulative pressures related to climate change on the likelihood of companies engaging in greenwashing by studying sample of firms from 12 countries. The results show that the number of regulations related to climate change negatively influences the propensity of firms to engage in greenwashing. The drivers are summarized in the diagram below.




Source: Mateo-Márquez et al (2022)

*Figure 28:*
*Drivers of Greenwashing*

To solve this problem Mateo-Márquez et al (2022) advocates for a multi-stakeholder approach to mitigating greenwashing in the current regulatory environment. Such an approach would convene key actors, including corporate managers, policymakers, and non-governmental organizations (NGOs). Collaborative efforts should focus on three key areas: enhancing transparency in the reporting of environmental performance by firms; facilitating the dissemination and comprehension of knowledge pertaining to greenwashing practices; and fostering effective alignment between internal corporate structures, processes, and incentive systems to prioritize genuine environmental sustainability.

### 4.15.6 Challenges in Carbon Markets

There are several challenges faced in carbon markets. Evîn Cheikosman et al (2023) calls out the following challenges.

- Lack of transparency, integrity and confidence in the monitoring, issuance, sale, retirement and benefits distribution of carbon credits, as well as in third-party certifications
- Insufficient scale to meet climate commitments.
- Inaccessibility, inequity, and lack of participation in carbon markets by women, local communities, smallholder land stewards, Indigenous people and other vulnerable populations.

### 4.15.7 How are digital technologies helping in this process?

Evîn Cheikosman et al (2023) To solve some of these challenges WEF recommends

- Enhance governance by
  - Championing inclusive, equitable, and transparent governance structures.
  - Integrating vulnerable populations and fostering women's empowerment within governance and benefit-sharing mechanisms.
  - Building capacity for participation at local and global levels, while fostering industry comprehension of these participatory processes.
- Develop an accessible marketplace, product definition and clarity amongst all stakeholders. For this purpose, one needs to
  - Ensure carbon markets adopt a common baseline taxonomy to provide clarity.
  - Use an "end-to-end" digital environment, including Distributed Ledger Technology, to enable efficient data capture, analysis, and auditability.
  - Use digitally native credits to support more automation in validation and verification.
  - Use technologies such as advanced remote sensing, artificial intelligence and machine learning and IoT sensors, incorporating auditable records written by DLT. These combinations help achieve scale.

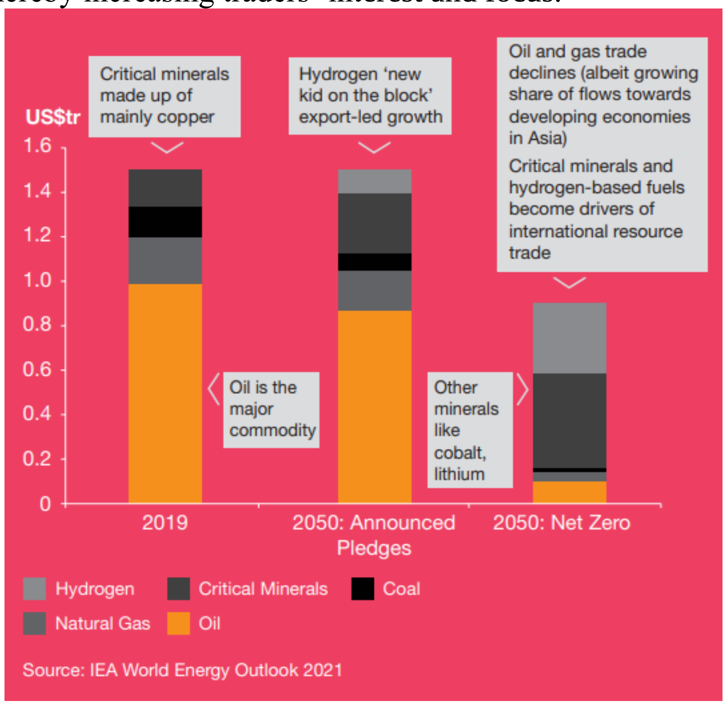
- Reduce friction between buyers and sellers. Connecting buyers and sellers together on DLT reduces the number of intermediaries by providing an immutable record of credit provenance.
- Implement digitally networked carbon credit systems. Application Programming Interfaces (APIs) offer a powerful mechanism for establishing connections between consumers, devices, and services within the Internet of Things (IoT) framework. This technology can be leveraged to enhance transparency through the effective deployment of sensors, drones, and other monitoring tools. Within a crowded carbon credit market, sellers can utilize data collected by IoT devices to differentiate their offerings. This approach empowers buyers to access real-time data, such as visual representations of forests or soil sensor readings, which can be used to verify the amount of carbon sequestered.

### 4.16 Trading Carbon

As per PwC and IETA report Energy traders/Energy trading companies are poised to reap great benefits of transition to low carbon economy and growth in clean energy markets.
They have listed four key emerging trends in this area.

- **Growth of Carbon Markets:** As per report from MarketsAndMarkets carbon credit and carbon offset market is expected to be worth USD 1602.7 billion by 2028, growing at a CAGR of 31% over 5 years from now.
- **The growth of clean power markets:** Corporates are increasingly getting into Renewable Power Purchase Agreements to decarbonize their operations. This is giving rise to clean power trading. They are also investing in greener asset to increase their green quotient.

- **"New energy" commodity markets** are emerging with critical minerals and hydrogen potentially displacing the dominance of conventional hydrocarbon. The below graph from IEA Energy Outlook shows how the critical minerals will occupy significant market value, thereby increasing traders' interest and focus.




Source: IEA World energy Outlook (2021)

*Figure 29:*
*Energy Commodities Market*

a) **Oil and Gas companies seek sustainable operations**: The role of trader increasingly is becoming of that balancer who not only hep companies produce molecules, but also help finding mechanisms to allow them to do in a way that addresses the company's ESG elements. Because if traders don't address this then access to finance will become limited and O&G companies may find it difficult to find and produce more fossil fuel, which is definitely required in the medium term and thereafter as base pay load.

In addition to this companies are increasingly seeking guarantees of the origination, integrity, and quality of carbon certificates. This is giving rise to products with different shades of green from light to deep green shade. The later color is what is most sought after by different entities. The variation of shade describes the perceived quality of carbon credit. For example, automotive original equipment manufacturers (OEMs), producing electric cars are performing additional due diligence on the provenance of the metals being traded and, in some cases, may also visit mining related operation for ensuring ethical and ESG complaint sourcing.

Circularity of materials is another key driver in trading. The Circularity GAP Report (2023) Rising material extraction has shrunk global circularity: from 9.1% in 2018, to 8.6% 2020, and now 7.2% in 2023. This leaves a huge Circularity Gap: the globe exclusively relies on new (virgin) materials. This means that more than 90% of materials are either wasted, lost or remain unavailable for reuse for years as they are locked into long-lasting stock such as buildings and machinery.

The above summarizes the drivers for low carbon trading.

Now let us understand different types of trading associated with low carbon.

### 4.16.1 Different Types of Trading

**Carbon Trading:** Jennifer L (2022) calls out Carbon trading as the process of buying and selling carbon credits. Some of these credits allow a company or other entity to emit $CO_2$, and some of these credits represent one ton of $CO_2$ emissions that's already been offset. Together, they form a market-based system aimed at reducing $CO_2$ emissions that cause global warming.

PwC et al (2023) The European Union's Emissions Trading System (EU ETS), launched in 2005, stands as a pioneering program in carbon emission reduction strategies. Notably, it was the first global initiative to establish a mandatory carbon market targeting high intensity emitting industries. Currently, participants within the EU ETS account for a significant portion (40%) of Europe's total greenhouse gas emissions. Recognizing its success, the European Commission has proposed expanding the program's scope to encompass additional sectors, including road transport and shipping. This proposed expansion underscores the program's central role in mitigating climate change, as evidenced by the documented 35% reduction in emissions achieved within the participating industries. Given its historical significance and ongoing development, the EU ETS serves as a valuable template for establishing a coordinated global approach to carbon pricing. However, challenges persist. A recent survey by PwC highlights the lack of standardized accounting practices for emissions amongst participating companies. This inconsistency presents a barrier to clear communication with key stakeholders, such as investors and consumers. The standardization of carbon allowance accounting is therefore crucial. It would empower business leaders to transparently communicate the financial implications of their emissions and the effectiveness of their reduction efforts. The global landscape of carbon markets continues to evolve, with established exchanges now operating in three European locations, two within the United States, and additional exchanges in New Zealand and South Korea. This proliferation reflects a broader trend of increasing adoption of net-zero emission targets by countries, industries, and individual companies.

**Renewable Energy Trading/Green Power Trading:** Renewable Energy trading can be said as part of Power Trading. Based on the article from Renewable Watch it is articulated that this trade is generally motivated by the need to improve grid operations, develop renewable energy sources, achieve energy security, enhance market efficiency, and sustainably fulfil the rising demand for electricity. Green power trading provides a mechanism to accelerate the deployment of renewable energy sources and develop a greener, more resilient power sector. It also enables different sources of energy to be effectively integrated into the grid, resulting in a steady and balanced supply of electricity. Green Power trading also enables the movement of surplus electricity from areas with excess generation to areas with higher demand, maximizing the use of the transmission and distribution infrastructure that is already in place. This raises the overall effectiveness of the power system, minimizes transmission losses and increases grid stability.

**Peer to Peer Energy Trading**: This is another variant of Power Trading but focused on consumers who can also become producers knows as prosumers (example homeowner with roof top solar panels). This trading allows such players to buy and sell power based on their needs, which means sell excess power when not needed and ability to buy power when their generated power is not sufficient to meet their requirements.

As per UtilitiesOne in their article "The Growth of Peer-to-Peer Energy Trading in Electric Utility Markets" they have articulated that this trading gives ability to users to reduce reliance on solely on centralized power plants and encourages them to generate energy locally using renewable sources such as solar panels or wind turbines. This decentralization of energy production reduces dependence on traditional power grids and fosters a more sustainable and resilient energy ecosystem.

Some of the key advantages and features:

- Empowers individuals and businesses to become energy producers.
- Reduces reliance on fossil fuels and promotes renewable energy sources.
- Enhances grid stability and resilience.
- Enables a distributed energy network.

To promote this trading, existing regulatory framework has to be tweaked to encourage P2P trading. Traditionally the regulatory framework was built to support central production of power. In addition to this the process to connect to grid for P2P prosumers should be made seamless, to facilitate easy flow of energy, ensuring stability and reliability of the grid. This easy access and support from regulatory bodies will promote more participation, increase competition and drive down cost for consumers.

P2P trading also needs advanced technologies like Distributed Ledger Technology, Smart Meters etcetera to ensure transaction real-time monitoring, and efficient energy distribution. Overcoming technological barriers is crucial to ensure seamless operations and user experience.

**Green commodities Trading:**

In addition to the above trading, there is increasing trend of commodity trading in Sustainable Agriculture Products, Green Build Materials, Green Bonds, Electric Vehicle components, Recyclables, Sustainable Forestry Products etcetera. The focus here is to ensure the products traded are greener and are able to meet the ESG requirements of the buyer.

### 4.16.2 How is IT helping in this process?

As per FasterCapital (2024) Digitalization has a key role to play in Energy/Carbon trading. Listed below are some of the benefits listed by FasterCapital.

**a) Increased Efficiency and Transparency**

FasterCapital (2024) The digital revolution has significantly transformed the operational landscape of energy trading houses. By leveraging digital platforms, these entities have achieved enhanced operational efficiency and streamlined trading processes. Automation facilitated by such platforms minimizes manual errors and expedites transaction execution. Real-time data accessibility empowers energy trading houses to make informed decisions with greater agility. This data-driven approach fosters increased transparency within the energy trading industry, enabling stakeholders to effectively monitor their energy consumption patterns and identify opportunities for optimization.

**b) Cost Savings**

FasterCapital (2024) The digital transformation has yielded significant cost reductions for energy trading houses. Automation of trading processes, facilitated by digital platforms, minimizes operational expenditures, including labor costs. Digitalization also empowers these entities to optimize their energy trading strategies, leading to reduced energy acquisition costs. For example, digital platforms enable energy trading houses to conduct real-time monitoring of energy price fluctuations and identify the most cost-effective sources of energy.

**c) Reduced Carbon Footprint**

FasterCapital (2024) Digitalization help drive the decarbonization efforts of energy trading houses. By leveraging digital platforms, these entities can monitor their own energy consumption patterns, thus enabling the identification and subsequent reduction of inefficiencies. This data-driven approach translates to a measurable decrease in overall energy consumption and, consequently, a diminished carbon footprint. Additionally, digitalization empowers energy trading houses to optimize their trading strategies, leading to a reduction in energy waste and the associated greenhouse gas emissions**.**

**d) Digital Platforms for Energy Trading**

FasterCapital (2024) There are various digital platforms available for energy trading houses to enhance their operations and optimize their energy trading. Blockchain technology offers a secure and transparent platform for energy trading. This coupled with AI and machine learning technologies help analyze data and identify patterns, enabling energy trading houses to make informed decisions quickly.

## 4.17 Consumerism

UNEP (2021) United Nations environment programme in their report Mid Term Strategy 2022-2025 call out three interconnected crises.

a) Pollution and waste
b) Climate Change
c) Biodiversity and nature loss

One of the reasons called by them is Expanding human activity and increasingly unsustainable patterns of consumption and production which are testing Earth's environment. In the past 50 years, we are observing 2-3-5-10 trend.

- 2 times increase in global population.
- 3 times increase on Energy production and material extraction.
- 5 times growth in global economy
- 10 times growth in global trade

Despite this around 820 million people still suffer from hunger.

To add to this Human consumption is set to increase further as population will grown, more people will migrate to cities leading to increase in urbanization and also will see increase in per capita income. Per capita consumption in developed countries generally far exceeds that in developing countries.

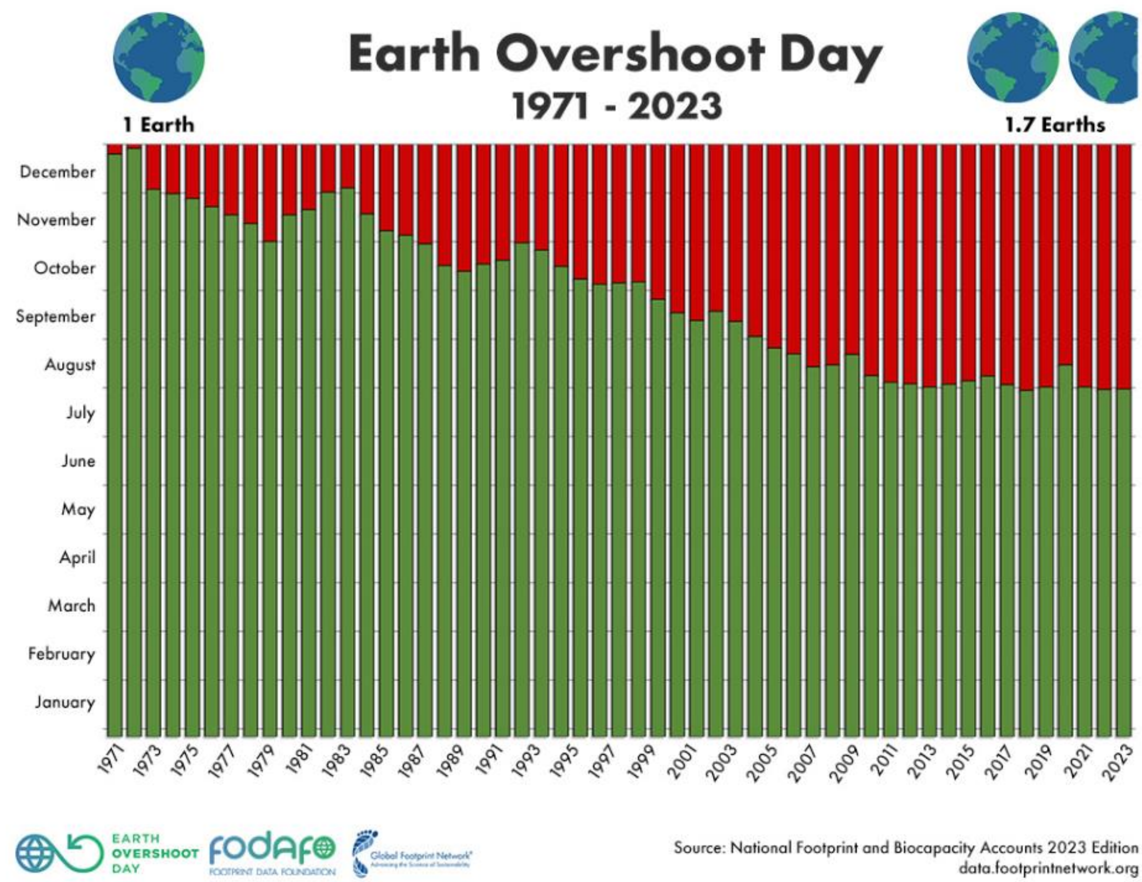
The Earth's vital ecosystems, including land, freshwater bodies, and oceans, are experiencing overexploitation to support food production, infrastructure development, industry, and human settlements. This unsustainable strain manifests in the annual release of up to 400 million tons of pollutants – heavy metals, solvents, toxic sludge, and industrial waste – into global waterways. A concerning synergy exists between these accumulating chemical and waste pollutants, climate change, biodiversity loss, ecosystem degradation, desertification, land degradation, and drought. These factors reinforce each other, accelerating environmental decline.

Agricultural practices contribute significantly to this ecological stress. Excess fertilizers entering coastal ecosystems have resulted in the formation of over 400 ocean 'dead zones,' encompassing a combined area exceeding 245,000 km2, surpassing the landmass of the United Kingdom of Great Britain and Northern Ireland.

Here are some additional key observations:

- Marine plastic pollution has exhibited a tenfold increase since 1980, highlighting the severity of plastic pollution in our oceans.
- Air quality remains a significant public health concern. Only four out of 45 megacities with available data met the World Health Organization's air quality guidelines.
- Pollinator decline poses a substantial threat to global food security, jeopardizing an estimated annual commercial crop output valued between US$235 billion and US$577 billion.
- The current rate of greenhouse gas emissions places us on a trajectory to reach a global temperature increase of 1.5°C by the early 2030s, highlighting the urgency of climate change mitigation efforts.

On same lines Earth Overshoot Day serves as a critical indicator, marking the annual date on which humanity's ecological resource demands and service utilization surpass the Earth's regenerative capacity within that same year. Analogous to a bank statement reconciling income and expenditure, the Global Footprint Network employs a framework to assess the ecological footprint of a population in relation to the biocapacity of its surrounding ecosystems. Biocapacity, on the supply side, refers to the biologically productive land and sea area of a specific region (city, state, or nation). This encompasses forest lands, grazing lands, cropland, fishing grounds, and even built-up land. Conversely, the Ecological Footprint, representing the demand side, quantifies a population's consumption of plant-based food and fiber products, livestock and fish products, timber and other forest products, space for urban infrastructure development, and the forest area required to sequester its carbon dioxide emissions from fossil fuel consumption. This year we hit that date on August 1st 2023. Which means for the rest of the year we were in deficit, that is we will need approximately 70% more of earth to balance the demand. The graph from Footprint (2023) Earth Overshoot Day clearly shows that.




Source: National Footprint and Biocapacity Accounts 2023 Edition

*Figure 30:*
*Earth Overshoot Day*

All these points towards increased consumption from the human population.

### 4.17.1 What drives consumption?

Brian Roach et al (2019) Before the eighteenth century, families and communities did not consume more than required. Religious value systems generally taught material restraint. Patterns of dress and household display were dictated by tradition, depending on the class to which one belonged, with little change over time. Past emphasis was more often placed on community spending, such as for a new church, as opposed to private spending. Then came the Industrial revolution which gave birth to consumer society. This revolution transformed production and in turn revolutionized the way the goods were sold giving rise to consumerism. The mass exodus from rural agricultural communities to urban centers in pursuit of employment triggered significant societal disruptions. Displaced from traditional sources of meaning derived from community and established practices, individuals sought new avenues for self-definition. This often manifested in the consumption of goods, which became a means of personal identity construction. To capitalize on this shift, shopkeepers adopted novel marketing strategies, such as the creation of window displays and the utilization of newspaper advertising, to entice potential customers. Additionally, the erosion of rigid class structures fostered a newfound freedom of expression for the common people. This extended to the display of wealth, a practice that would have been previously discouraged or even outlawed.

Then came the concept that workers in the industries are consumers. They preferred to work longer hours to earn more and spend more. Leisure was not seen as necessity, but spending power was seen as key social parameter. This gave rise to consumer society.

Fueling this was department store – selling the lifestyle, cross selling products, increasing aspirations of people and attracting them to spend more. To add to this credit was introduced, allowing consumers to borrow and spend more. Marketing became very important part of selling – selling the "good life" image which was otherwise not focused much. By start of 21st century all consumerisms became global phenomenon. Economy started getting driven by consumption. More the consumption more the economy growth giving rise to multiple jobs and increasing standard of life.

Everybody including government started promoting high consumption. This gave rise to incessant consumption. When consumption is driving better economy how is this impacting sustainability?

### 4.17.2 Is consumption the real problem?

Dolan Paddy (2002) in his journal on Sustainable consumption raised this question. He says viewing Dolan Paddy (2002) consumption as simply the problem follows a somewhat etic and positivistic perspective – an aerial view of sustainable development. Etic perspective involves objective analysis of a culture or social phenomenon whereas Positivistic perspective involves the philosophical approach of positivism, which emphasizes the application of scientific methods to social phenomena.

Dolan Paddy (2002) says it is vital to understand consumerism as a cultural process from within as well as without. It is only in this way that the external view that sees the ecological and long-term effects of increasing consumption can be translated through the meaning complexes of consumers, individually and collectively. Dolan Paddy (2022) goes on to elucidate the challenges in the field of sustainability. He says regardless of its social or ecological framing, operationalization of the concept is the main challenge. While we can achieve a conceptual understanding of sustainable development, the translation into empirically verifiable metrics remains elusive. Determining the precise level of development that ensures indefinite resource availability (e.g., petroleum, coal, gas) or environmental stability (e.g., ozone layer, rainforests, biodiversity) presents a significant hurdle. Although objective measures, such as scientific geo-indicators, can highlight unsustainable practices, pinpointing the ideal level or trajectory of development for long-term viability continues to be a complex question. This is no doubt a difficult question to answer. Then what can we do? Should we just go on with mindless consumption artificially driving the wellbeing but looking good in terms of economy.

This is where balancing between need and greed comes into picture. Mahatma Gandhi – world renowned leader very famously said "The Earth has enough resources to meet the needs of all but not enough to satisfy the greed of even one person". That is where the line needs to be drawn.

William.T.Cavanaugh (2008) writes in Being Consumed "In consumer culture, dissatisfaction and satisfaction cease to be opposites, for pleasure is not so much in the possession of things as in their pursuit. There is pleasure in the pursuit of novelty, and the pleasure resides not so much in having as in wanting. Once we have obtained an item, it brings desire to a temporary halt, and the item loses some of its appeal. Possession kills desire, familiarity breeds contempt. That is why shopping, not buying itself, is the heart of consumerism. The consumerist spirit is a restless spirit, typified by detachment, because desire must be constantly kept on the move."

This sums it up very beautifully on consumerism spirit.

Having said this, there are also other causes of increased consumerism. Kilari Chandra Sekhar et al (2022) in their paper "Evaluation of Consumerism on Sustainability" call price rise, adulteration, product duplication and increasing artificial demands as major cause of consumerism beyond influential factors like age, income, occupation and lifestyle. Product quality is a key factor influencing consumer behavior and consumption patterns. Kilari Chandra Sekhar et al (2022) Unethical commercial practices involving the sale of substandard or counterfeit goods at exorbitant prices can exacerbate unsustainable consumption patterns. The inherent lack of durability and functionality in these products often necessitates frequent replacements, thereby inflating overall consumption rates. Furthermore, deceptive advertising strategies employed by certain brands can significantly distort consumer decision-making processes. By disseminating unrealistic portrayals of product benefits or obfuscating negative attributes, such advertisements can manipulate consumer preferences and lead to impulsive purchases exceeding actual needs.

### 4.17.3 Summary

Consumerism plays a critical role in ensuring sustainability and impacts Energy Markets. Consumerism is directly linked to human behavior and is driven by the societal ways of perceiving wealth and success. Also, it highlights the thin line between need and greed. It is strongly believed that if the social norms altered, human consciousness raised then we will experience change in the consumption pattern of humans and will exert less pressure on Earth and will accordingly control the ever-rising demand for energy and other resources. This factor plays a key role in Energy Markets.

## 4.18 Circularity

Circularity is not a new concept. This concept had started making waves in late 1960's. Infact Spilhaus A (1966) had written: "Ideally, the system would be completely closed. All water would be purified and reused; all solid wastes would be sent back as resources for making more things."

### 4.18.1 What does Circularity mean?

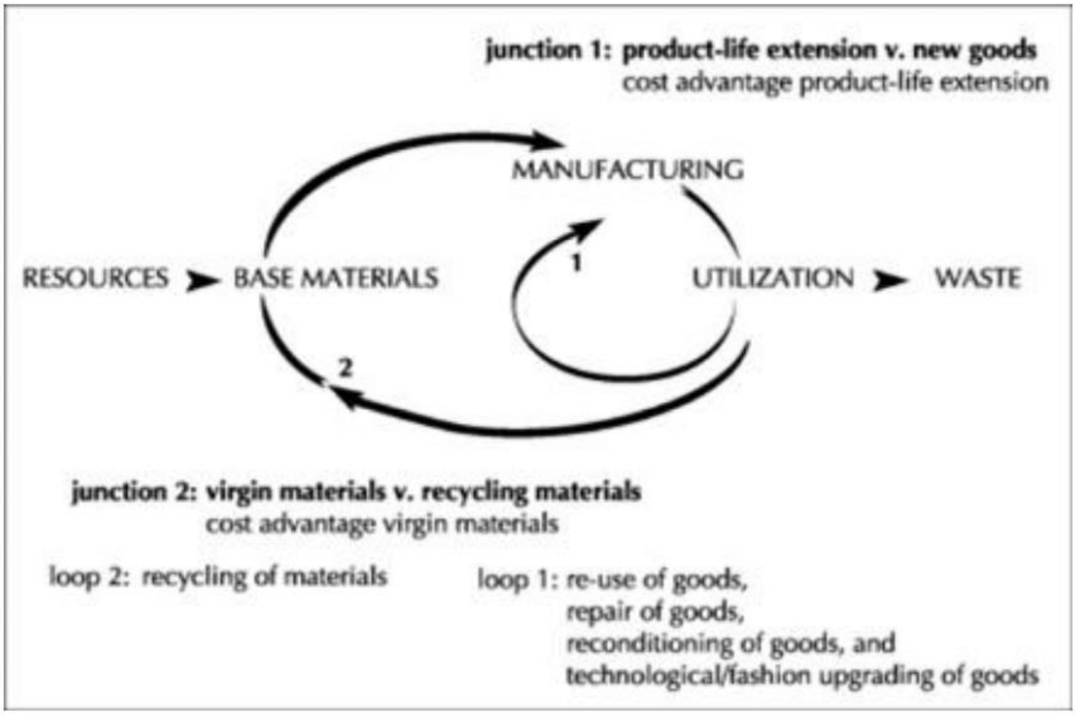
Generally, the manufacturing process is linear in the sense it follows four main steps:

- Produce
- Sell
- Use
- Waste (landfills/incinerate)

In simple words circularity aims to convert this linear process into a circle process where in the waste and other materials used can be restored or regenerated.

This concept of circularity is now driving Circular Economy. According to the World Economic Forum (2022), a circular economy is a system that encourages minimal usage of world's resources, reduce waste and reduce carbon emission. In other words a system that is restorative or regenerative by intention and design.

In a perfect circular system Frosch et al (1989) the consumption of energy and materials is optimized; waste generation is minimized and the effluents of one process serve as the raw material for another process. The industrial ecosystem ideally should function like that of a biological system.




Source: Based on Stahel and Ready, 1981:70 (figure supplied by Stahel, personal communication, May 2019)

*Figure 31:*
*Circularity in materials*

Extending circularity into economics becomes circular economy.

### 4.18.2 Circularity Economy:

Circularity Economy has two strands Paul Ekins et al (2011)

- First relating to flow of materials through an economy
- Secondly economic conditions that bring the flow of materials

The idea of the circular economy has two long strands, the first relating to the flow of materials through an economy, and the second concerned with thinking about the economic conditions that might bring about such a flow.

Circular defines circular flow of materials. Basic idea is waste of one process is feedstock for next product or process. Goods when they reach end of life, they need to undergo the "R" transformation.

- Reuse: Put it to different use, or extend the life
- Repair: Get back to conservative days, where there was no use and throw concept. Every product could be repaired, and the life of the product could be extended.
- Recycle: Deconstruct the product and try and recycle as many parts as possible which can be recycled back into the process.

PWC summarizes this action into 3 main principles.

- Prioritize renewable inputs,
- Maximize product use,
- Recover by-products and waste.

Within each of these categories PwC recommends ten initiatives which will create the economic conditions to bring the flow of materials

**Prioritize renewable inputs:**

- **Enable Circular sourcing** – attempt to use renewables, bio-based or recycled materials as much as possible. 3D printing as a technology can be one of the solutions to avoid carbon emissions caused by transportation of goods and will enable easy recovery of the materials used. 3D printing usually uses thermoplastic materials which is easily recovered and can be converted to other products. Similarly, products produced by 3D printing are lighter and stronger due to usage of recycled filaments.
- **Provide sustainable design** – Design should be such that the product can be easily de-constructed, repaired, reused, repurposed and up-cycled. For example Adidas Futurecraft.loop manufactures a product which is made from single source without

glue. This helps in recovering the material and can be recycled to produce next pair of shoes.

- **Ensure Resource efficiency** – least wastage in the production process. Integrate downstream process to ensure waste from one can become feedstock of another process.

**Maximize product use:**

- **Shift to as a service model –** instead of focusing on just selling products, provide service. For example, an article published by Deloitte Daniel Grosvenor et al (2022) instead of providing power as commodity, Utilities companies are partnering with renewable energy generation companies, telecom providers, battery providers to provide energy as a service.
- **Creating shared services** – like Uber services where the road transportation is shared instead of owning cars. This is being taken at non-conventional industries like LNG carriers as well. For example Frieda et al (2022) reports in Petronas Report that they have created a platform to optimize logistics spend, reduce carbon footprint and enhance operations efficiency.
- **Efficient maintenance** of assets to avoid breakdowns and proactively increasing life of the assets. Some of the examples to boost EV adoption several companies are now providing "Battery as a service". Cerebrumix (2023) – battery as a service ensures that customer newer runs out of battery. She is not worried about the maintenance of battery as she is always assured of fully charged battery as per needs. This addresses the rang anxiety problem of commuters and enables increase sales of Electric Vehicles. Renault, adopts this model. They sell cars without batteries and batteries have to be leased. Similarly other example can be "miles as a service". This is another

subscription model where vehicles are rented on miles basis. User subscribes for monthly miles and pays only for that. The entire vehicle maintenance is on the service provider. Now that maintenance is centralized, lot more efficiencies can be baked in.

- **Re-distribution** – Enable secondhand goods market. There are already secondhand vehicles which have clearly made it's mark. There is evidence of more and more second hand markets for example In India Furlenco – provides furniture, home appliances – including used ones for rent. In China on Alibaba – formal/ethnic/designer clothes are provided for rent. This brings down the landfills due to excess clothing and also keeps it light on the pocket of the user at the same time fulfilling the desire to wear those aspirational designer clothes.

**Recover by-products and waste.**

- Industrial Symbiosis is emerging as one of the areas which helps in circularity. Oughton (2022) in his paper has defined Industrial symbiosis as an organization which engages diverse organizations in a network to foster eco-innovation and long-term culture change by creating mutually profitable transactions for novel sourcing of required inputs, value-added destinations for non-product outputs, and improved business and technical processes. For example, Kalundorg city is known for its symbiosis it has created. Since 1972 this symbiosis ensures the residue from one company becomes the feedstock of another company benefiting both business and environment. For example the output from Denmark's largest oil refinery, run by Equinor is input to the pharmaceutical company Novo Nordisk which produces the enzyme Novozymes and Ørsted provides renewable power to these companies – sharing the same ecosystem.

- Another symbiosis which is coming off late is generating bio-energy by leveraging municipal waste. These plants are being setup close to the municipal yards which collects loads of waste, which is feed as feedstock to bio-fuel refinery to generate energy.
- Many countries are coming up with old vehicle scrapping policy which helps in recovering some of the metals like zinc, iron, steel, plastic, which can then be recycled or repurposed.
- Gunter Pauli (2011) calls out many innovations as part of his Blue Economy principles which believes in regeneration and in that process creates jobs and thriving economy. Example he gives leveraging coffee waste, they grow edible mushrooms, which helps in solving some of the hunger problem and generating money. He believes this economy is innovative, competitive and generates jobs. Green economy is expensive, blue economy is real, inspired by nature and helps people. The coffee is known for absorbing odor. The same concept is used to put fine coffee waste into poly ethylene which is then used to make jogging clothes. This controls the odor and the coffee waste is put to good use.

The next question which comes to mind is what are the indicators which measures circularity in the economy.

#### 4.18.3 Indicators for measuring circularity:

The organization for economic cooperation and development OECD (2019) collects 474 circular-economy indicators. They belong to 29 circular economy studies of which 8 are at national level, 8 at regional level and 11 at local level. Within this the indicators are split across 5 categories

- Environment

- Governance
- Economic and business
- Infrastructure and technology
- Jobs

#### 4.18.4 Summary

Circularity is one of the key pillars which can help avoid usage of virgin elements and thereby reducing the burden on mother earth. Meanwhile by controlling consumption as a society we can reduce Energy demand. Other strategy which effects consumption is by ensuring high energy efficiency and energy conservation. Let us discuss into these two aspects.

## 4.19 Energy Efficiency

### 4.19.1 What is Energy Efficiency

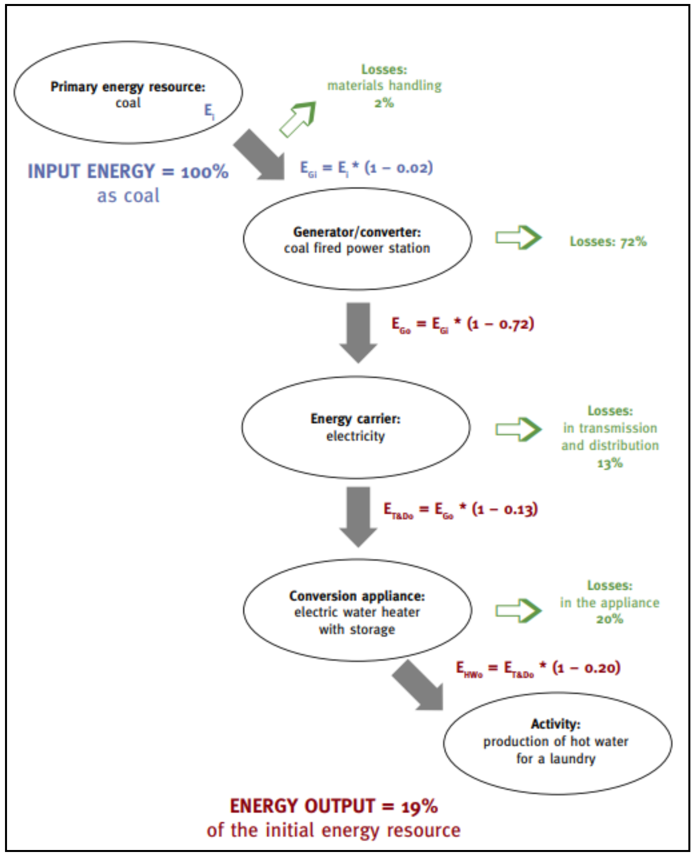
Patterson, Murray et al (1996) refers to using less energy to produce the same amount of services or useful output.

For example, in the industrial sector, energy efficiency can be measured by the amount of energy required to produce a tonne of product. Hence, energy efficiency is often broadly defined by the simple ratio: 2 Useful output of a process over Energy input into a process. There are number of indicators to measure and monitor the energy efficiency. Below are the four main types:

- **Thermodynamics**: These indicators are derived from the science of thermodynamics. Some of these indicators are simple ratios and some are more sophisticated measures that relate actual energy usage to an 'ideal' process.

- **Physical thermodynamics:** These indicators is combination of thermodynamics and physics. The physical unit measures the service delivery of the process. For example, tonnes delivered, Km covered etcetera.
- **Economic-thermodynamic:** these are also hybrid indicators where the service delivery (output) of the process is measured in terms of market prices. The energy input, as with the thermodynamic and physical-thermodynamic indicators, is measured in terms of conventional thermodynamic units.
- **Economic**: these indicators measure changes in energy efficiency purely in terms of market values ($). That is, both the energy input and service delivery (output) are enumerated in monetary terms.

Let us look at an example from a manual published Sustainable Energy Regulation And Policy-Making Training Manual. Here the author clearly explains the energy lost in hot water production from the source to the consumption point.




Source: SUSTAINABLE ENERGY REGULATION AND POLICY-MAKING TRAINING MANUAL

*Figure 32:*
*Example of Energy Losses in hot water*

- Coal handling results un 2% loss. This is lost to area around the plant, lost in loading/unloading from trucks etcetera.
- Power station operates at 28% overall efficiency. This is because of the loss of hot combustion gases from the stack, warm/cool water discharge, mechanical inefficiencies in turbines, generators etcetera.
- Transmission of electricity to actual location of hot water production is around 87%. The rest is lost during the transmission in lines/transformers etcetera.

- The efficiency of the water heater at the laundry is 80 per cent (heat losses are experienced from the boiler, storage tanks and pipe work).

  Therefore, the cumulative losses over the four stages thus amount to over 80 per cent of the original coal energy content.

  In terms of efficiency, the overall efficiency is**:** 0.98 x 0.28 x 0.87 x 0.80 = 0.191 (or 19.1%)

This gives a very good example of energy is lost; therefore, it is of utmost importance to increase the energy efficiency to effectively use the energy produced. Thereby reducing the need for higher energy and in turn controlling carbon emissions.

### 4.19.2 Why is Energy Efficiency important?

Energy efficiency brings down the energy consumption, bringing down the carbon emissions and the energy budget. We researched into some of the energy dependent nations budget. Sanjeev Choudhary (2023) India's oil and gas import bill stands at around $35Billion. France Energy bills skyrocketed to 100Billion Euros in the year 2022. This has direct impact on the economy of the countries and debt levels. It is therefore need of the hour to bring down the energy bills and creating energy efficiency is one such method. Keeping this in minds governments are investing heavily. IEA (2022) in their Energy Efficiency report says that Since 2020, governments around the world have been leading the charge on energy efficiency by investing a whopping $1 trillion. This translates to roughly $250 billion annually poured into projects like building upgrades, improved public transportation, and electric vehicle initiatives. That's a significant chunk of change, representing two-thirds of all the money spent on clean energy recovery in recent years.

IEA (2022) also says the massive increase in clean energy investment in the Net Zero Scenario will create 14 million jobs in clean energy supply by 2030, more than offsetting the loss of around 5 million jobs in fossil fuel supply as demand declines. A further 16 million jobs are created thanks to additional spending on more efficient appliances, electric and fuel cell vehicles, building retrofits and energy efficient construction.

### 4.19.3 Where do we find Energy inefficiencies?

There are many sectors where energy inefficiencies can be found.

- Buildings: According to the report 2022 Global Status Report for Buildings and Construction released in COP27 in Egypt this sector is accounted for over 34 per cent of energy demand and around 37 per cent of energy and process-related CO2 emissions in 2021. A major portion of this energy is wasted due to poor insulation, inefficient heating and colling systems, leakages through windows and doors, poor design of the building, inefficient lighting system, outdated appliances etcetera
- Industry: Industrial processes is also a major source of energy inefficiency, accounting for about 35% of global energy consumption. Inefficient machinery and equipment, outdated manufacturing processes, poor maintenance, lack of skilled workers, poor waste management all contribute to energy waste in industry.

### 4.19.4 How do we ensure energy efficiencies?

For our research we looked at key sectors.

They say it all starts from home. Here are some of the simple things that can be easily done at home to improve energy efficiencies. SaveOnEnergy (2022) lists these details:

- Ensure our furnace are regularly serviced to increase its efficiency.
- Wrapping the water heater to insulate the water heater and reduce heat loss.
- Ensuring the ductwork is properly sealed, the windows and doors are properly sealing the place.

- Using ceiling fans when you need to cool down only specific areas of the work and not the entire house. In reverse option it pushes hot air down, keeping your room warm during winters.
- Use air dry option for drying utensils, use cloth liners to dry clothes.
- Automate your usage – for example sensor-based lighting, smart thermostats for ensuring optimum heating and cooling, scheduling appliances as per the weather conditions etcetera.
- Simple habits of unplugging/switching of chargers/power supply when not in use.

Many of the Utilities companies are providing several services which encourages household/building efficiencies. In a blog published by EnergySage (2023) they clearly call out some of the energy efficiencies program offered by different utilities. For example

- Southern California Edison: SCE offers a variety of rebates on energy-efficient appliances, lighting, HVAC equipment, and renewable energy systems. For example, SCE offers a rebate of up to $200 for the purchase of a new, energy-efficient central air conditioner.
- Pacific Gas & Electric: PG&E offers a variety of rebates on energy-efficient appliances, lighting, HVAC equipment, and renewable energy systems. For example, PG&E offers a rebate of up to $100 for the purchase of a new, energy-efficient refrigerator.
- National Grid: National Grid offers a variety of rebates on energy-efficient appliances, lighting, HVAC equipment, and renewable energy systems. For example, National Grid offers a rebate of up to $750 for the purchase of a new, energy-efficient air source heat pump.

- BSES Rajdhani Power Limited (BRPL): A power discom in India has partnered with EESL for a 'energy efficient appliance program' to help their residential and industrial costumers easily procure energy efficient appliances.

In addition to Utility companies several governments are also running several initiatives to encourage adaptation of energy efficiencies appliances. For example

- China offers a rebate of up to 50% on the purchase of energy-efficient appliances, such as refrigerators, washing machines, and air conditioners.
- India offers a rebate of up to 25% on the purchase of energy-efficient lighting, such as LED bulbs and CFLs.
- Japan offers a rebate of up to 30% on the installation of energy-efficient HVAC equipment, such as heat pumps and furnaces.

**Manufacturing sector**: Manufacturing companies are looking at improving energy efficiencies by adopting the following.

- Using more energy efficient equipment such as motors, compressors, pumps. This has potential to bring reduce energy consumption by 50%. For example, GE is using additive manufacturing to produce lighter and more efficient aircraft engines.
- Improving process efficiency by using waste heat from one process to power another process. They are also using sensors and controls to automate their processes and improve efficiency. For example, Toyota is using robots to automate its welding processes, which has reduced energy consumption by up to 50%. Siemens is using digital twins to optimize its manufacturing processes and reduce energy waste.

**Transportation:** Governments are establishing strict fuel efficiency standards for vehicles. For example, the California Air Resources Board (CARB) runs the Low emission vehicle program that requires new vehicles to be sold in California be more fuel efficient and producing lesser emissions. Indian government from 2014, has imposed passenger vehicle fuel-efficiency standards. Once implemented in 2015, these standards mandated efficiency targets for new cars at the equivalent of 130 gCO2/km in 2017 and 113 gCO2/km in 2022. Fuel efficiency labelling for new vehicles has been mandatory since 2011.

### 4.19.5 How is Digitalization helping in this process?

IEA (2019) in their article on energy efficiency and digitalization have said that Digitalization can improve energy efficiency through technologies that gather and analyze data to effect real-world changes to energy use. Digitalization offers the potential to increase energy efficiency through technologies that gather and analyze data before using it to make changes to the physical environment (either automatically, or through human intervention). These sensors gather data and other conditions effecting the energy use like climate, temperature, previous usage patterns, number of people in the room et cetera and process this data through artificial intelligence algorithm. This processed information is then sent to physical devices to optimize. For example, a smartphone app can suggest an energy efficient route to work, but the commuter must act on that advice. Other devices can optimize energy efficiency more autonomously: For example, switches in a building's cooling system or robots in a production line.

Digitalization enables “smart” buildings, vehicles, and industrial facilities to provide new sources of flexible load to the energy system, which can help to reduce renewables curtailment on the supply side and support communities to consume energy produced themselves, "behind the meter".

IEA (2019) says that the power of digital technologies to both improve end-use efficiency and system efficiency ultimately benefits the overall energy system through avoided investments in energy infrastructure (such as peaking plant), improved integration of renewables, and enhanced energy security, amongst other impacts.

## 4.20 Energy Conservation

While energy efficiency is all about using less energy for the same amount of work, energy conservation focusses on reducing the amount of work. For example, reducing the consumption of energy for lighting by switching off the lights when not in use, unplugging appliance when not required, walking within 2-4 km distance instead of using powered vehicles, shutting off air conditioners when not in use etcetera.

Choong Weng Wai et al (2013) Energy conservation hinges on two main aspects a) technology fixed b) Human behavior.

The following section will discuss these aspects in detail.

### 4.20.1 Technology Fixed

Technology interventions, often referred to as "technology-fixed" solutions, encompass the application of instruments and necessitate substantial upfront investments. These encompass the introduction of efficient processes, upgrades to automation systems, or the installation of large-scale energy-saving devices like heat recovery systems, innovative building designs, inverters, pre-heaters, motion sensors, building envelope improvements, and similar technologies.

A critical consideration for technology-fixed solutions is payback period, the time it takes for cost savings to offset the initial investment. While demonstrably effective in achieving significant and rapid energy conservation, the high initial cost can be prohibitive for organizations with limited budgets. Furthermore, technology-fixed solutions may present limitations in terms of long-term adaptability. They may not readily accommodate future changes in operational needs or technological advancements. While technology-fixed solutions offer the advantage of not requiring immediate behavioral modifications from users, this characteristic can be a double-edged sword. This unaltered user habits can perpetuate energy-wasting practices, potentially undermining the long-term sustainability of these interventions. Therefore, technology-fixed solutions should be strategically coupled with initiatives that cultivate enduring transformations in user attitudes and behaviors towards energy consumption. This combined approach holds greater promise for achieving lasting energy conservation benefits.

### 4.20.2 Human Behavior

Human behavior changes require changes in human attitude which can be achieved by introducing raising awareness, motivation and skill development. Choong Weng Wai et al (2013) The efficacy of energy conservation programs hinges on the implementation of targeted interventions tailored to specific community needs. A crucial preliminary step involves a thorough needs assessment to identify the most appropriate stimuli. During the initial awareness-building phase, two primary approaches can be leveraged: energy-saving tips and problem-solving exercises centered on energy consumption.

Energy-saving tips play a pivotal role in demonstrating to building occupants the ease with which they can contribute to energy conservation efforts. By disseminating practical recommendations, such as switching off lights in unoccupied rooms or placing computers in sleep mode when idle, these interventions aim to elevate occupants' knowledge base regarding energy use and its significance. This, in turn, fosters a sense of empowerment and equips occupants with readily implementable strategies to integrate energy-conscious practices into their daily routines. The second type of awareness can hinge on educating on the energy problems which will help people better understand the impact of energy consumption on the environment, financial burden on the country and society at large in due course of time. This awareness in turn should lead to changes in consumers behavior.

I Khan et al (2016) in their study in Bangladesh found that there are three major broad categories of programs that can be implemented for residential consumers' behavior change- real time feedback generating in home devices and displays, customized-regular feedback delivered to consumers and dynamic pricing and rate design programs. One of the ways to enable this is installing smart meters across the consumers (both retail and industrial).

I Khan et al (2016) Smart meters provide real-time consumption data, enabling household appliance-level disaggregation for immediate energy use awareness. Conversely, traditional meter readings deliver customized, albeit delayed, feedback through monthly electricity bills. Dynamic pricing, often implemented through time-of-use (TOU) tariffs, establishes differential electricity costs based on peak and off-peak demand periods. This empowers consumers to strategically schedule appliance usage, potentially reducing both energy consumption and electricity expenditure.

Michael Baechler et al (2011) Another intervention which will influence the behavioral change is Energy audit. Energy audits consists of a mechanism to identify operational and equipment optimizations that demonstrably translate to energy conservation, cost reduction, and enhanced performance. These audits can be undertaken as independent initiatives or integrated into a more comprehensive analysis encompassing a portfolio of facilities or an entire building stock. Through a meticulous evaluation process, energy audits illuminate the following aspects:

- Operational and maintenance adjustments that necessitate no upfront investment yet yield quantifiable energy savings.
- Recommendations for short-term, low-cost retrofits that enhance energy efficiency.

- Action plans that strategically guide capital investments targeted at energy-saving measures.
- Immediate opportunities to rectify comfort and code-compliance issues.
- Avenues for improved adherence to established lighting and thermal comfort standards.

### 4.20.3 What are some of the Energy companies doing in this space?

Many energy companies are now helping their customers in energy conservation space. It might be counter intuitive to their business, but keeping the environmental goals in mind and the impact it creates on the ecology and long term well being of people, these companies are helping the customers to conserve. Here are some of the examples.

- Origin Energy offers range of services to help consumers reduce their bills which includes Home Energy audit, centralized energy services like cooling, heating for building, energy efficient appliances upgrade, personalized case management, incentive payments, and tailored payment plans. They regularly educate their customers on energy savings tips.
- National Grid runs similar programs like that of Origin Energy. In addition to this National Gird also run a behavioral demand response program in Clifton Park, NY, where customers receive points and rewards in exchange for reducing energy use on critical peak days.
- Tata Power in India runs an energy and resource conservation club that works with schools and children to raise awareness about energy conservation. They also provide entire home automation services which helps in managing multiple appliances and can help in identifying hot spots to reduce consumption.
- Duke Energy has a “Neighborhood Energy Saver Program: that educates participants on energy conservation through walk-through assessments. The program also connects

households with community organizations and weatherization agencies to help them make further improvements.

- EDF runs Home Efficiency Hub program which provides personalized plan for homeowners to conserve energy. They also offer unique services managed solar park or wind farm services through which they seek one-time payment to fund the project construction and the customers will in turn be offered a share in the farm. This farm will be fully insured against damage and any type of malfunction. The customer can be assured of consistent renewable power from this source.

### 4.20.4 Summary

Energy conservation and Energy efficiency goes hand in hand. Ultimate goal is reducing the energy consumption and delink this with growth of the economy. While energy efficiency focuses on designing and developing energy efficient appliances and devices, energy conservation focuses more on human behavior and social norms. Energy producers especially the distributors play a critical role in this space by providing incentives to customers to adapt energy efficient appliances and energy conservation behavior and culture.

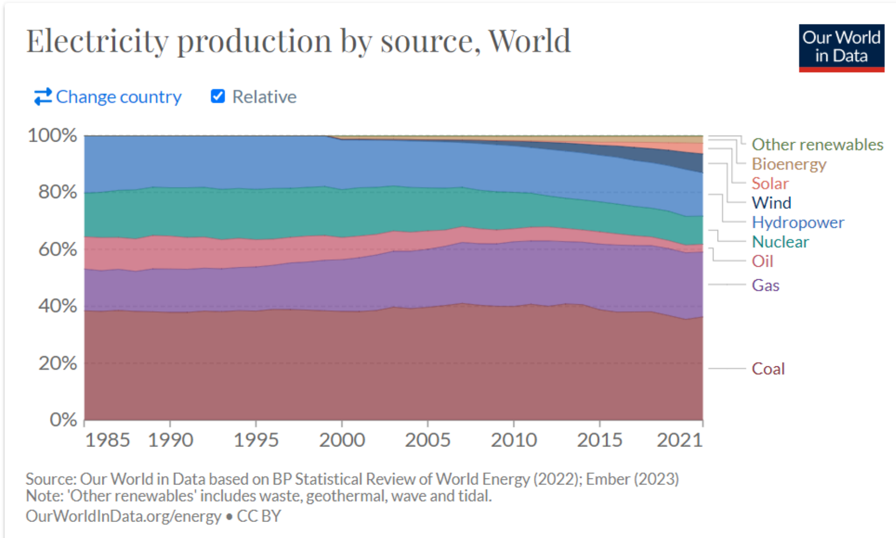
# CHAPTER 5:

# DISCUSSIONS, OBSERVATIONS, IMPLICATIONS AND CONCLUSION

The research showed growing population and increased middle class population is going to bring in more demand for Energy. Countries with higher Human Development Index (HDI) tend to consume more energy compared to nations with lower HDI. Which means developed nations tend to have more carbon emission than developing or underdeveloped nations. Be it Green Economy or Kate's Doughnut economics one message is very clear; we must shift to cleaner technologies to ensure we remain within the planetary boundaries. It is only when we move to cleaner technologies, we can decouple GDP growth with emissions and ensure more holistic society respecting planetary boundaries. Also spending in green technologies will ensure growth of economy, creating more green jobs and improving quality of life.

## 5.1 Discussions

We discussed how the Energy market is transformed to include greener/cleaner/abatement technologies. We did a deep dive on each of the cleaner technology and discussed how different energy companies are investing in this market and how IT is helping in the process of adoption. Having said these cleaner technologies has got a long way to go. Renewables constitute around 35-38% of the energy mix. Hydropower is providing more renewable energy compared to other renewables.




Source: Our World in Data based on BP Statistical Review of World Energy(2022)

*Figure 33:*
*Electricity Production by source*

Despite the popular belief electricity generated by solar still constitutes around 2% of the overall mix of energy. Coal continues to dominate the power generation. We still have a long way to ensure renewables constitute at least 50% of the energy mix.

While these technologies ensure less carbon is emitted, what happens to the carbon which is already produced and is in atmosphere. Or what happens to the carbon which is emitted in atmosphere due to various operations or manufacturing process or consumption process. This is where carbon capture technologies come into picture. Also, in hard to abate industry like cement, chemicals, steel there will be carbon emissions which needs to be tackled. Which means the emissions will happen, can that be reduced perhaps not efficiently. Can it be prevented from entering atmosphere?

IEA (2020) in their paper on "Why Carbon Capture technologies are important" articulate that to meet climate goals, policy makers need to address emissions from existing coal-fired power plants and those being built today. Yet, under current policies stated by governments, while CO2 emissions from the existing coal-fired fleet would decline by approximately 40%, annual emissions would still amount to 6 $GtCO_2$ per year in 2040. Significant additions to coal-fired capacity were still under construction at the start of 2020, highlighting the challenge ahead.

Perhaps this is where the capture technologies play a major role. Research showed there are several such technologies like Carbon Capture Utilization & Storage, Biological Sequestration & Storage are playing role in capturing the carbon and helping some of the hard to abate industry like cement, steel, chemicals manufacturing etcetera. Infact, for these industries capture technologies may be the only option available to manage their emissions. For example, in cement production, where two-thirds of emissions are from chemical reactions related to heating limestone (rather than burning fossil fuels), CCUS is currently the only scalable solution for reducing emissions.

Having said these capturing technologies are very expensive. It may cost 100-120$ to capture one ton of $CO_2$. But in certain case this may be cheaper option to deploy, for example in many of the old coal power plant which is very essential to meet the power needs of the area, can be retrofitted with CCUS technology to continue its operations and yet limit the emissions. In cases where switching to renewable source is difficult capture technology can provide that band aid which can help in the journey of net-zero.

While this is true, there are other changes that Energy market has to adopt to reduce emissions and meet the new reality – especially where electricity needs are going to jump many folds as world electrifies. For example, with the growing adoption of Electric Vehicles, refineries who produce petrol/diesel from crude oil will have to cut down the production. Similarly, aviation fuel is pivoting towards Sustainable Aviation Fuel (SAF) made from Biofuel, something which will bring down the demand for traditional aviation fuel. Given this future how should refiners now gear themselves to cater to future needs. Refiners are now moving to produce petrochemicals directly from the crude. The other major impact due to increase demand of electrification is on Utilities industry – especially on the Transmission and Distribution(T&D) segment. It is projected that electricity generated worldwide will increase by nearly 50 percent in the coming three decades, to reach some 42 thousand terawatt-hours by 2050. If this must happen in addition to producing more energy (which is covered in earlier chapter), provisions have to be made to transmit and distribute this electricity to consumers. Which means T&D segment of Utilities have to undergo major upgrade or modernization. Also, Utilities companies will have to relook at the way they are managing customers now. They not only have to provide un-interrupted energy, but also help them reduce their bills through various energy audits, energy conservation tips and overall energy management. This is also giving rise to new opportunities to Utilities companies to provide different types of services like setting up of solar panels on rooftop, running managed solar or wind farms which has retail customer's stakes, energy efficient appliances on buy or rent basis, personalized energy savings plans and many others.

## 5.2 Observations

Below were the observations:

a) It is true that for development energy is required, but the research showed that the amount of energy can be reduced by adopting more energy efficient technologies. Energy conservation is another big area which has potential to impact energy requirement. These two elements bring down the energy consumption. While this ensures lower energy but does not determine lower emissions. To reduce the emissions energy has to come from greener sources of energy. The next set of research focused on to understand different green technologies and how energy companies are adopting.

b) The research showed that if energy comes from cleaner sources, then emissions will decrease. Therefore, Energy markets must transform to provide Energy coming from cleaner technologies like Solar, Wind, Hydropower, Nuclear, biofuels and geothermal. This will change the way the energy is produced. But this brings in challenges of intermittency which means these sources of energy (leaving Nuclear) does not assure of continuous supply of energy unlike thermal plant.

c) Research showed that to solve the intermittency problem battery technologies needs to be adopted to store the excess power in batteries and then consume when the need arises i.e. when the sun does not shine, or wind does not blow. This also gives rise to new generation of consumers who can also produce their own power (for example by roof installed solar panels). Which means the flow of electricity will now be bi-directional, consumers will consume power from grid only when they run out of their power. Also if they have excess power they can sell it off to the grid.

d) As we move more towards electrification to reduce emissions the Transmission and Distribution network needs to be modernized and expanded to meet the demands. The electric utility is driven by the five global factors of decarbonization, decentralization, deregulation, democratization and digitalization, a diverse set of devices involving various disruptive resources are now connected to the electricity grid – devices that are generally owned and operated by electricity customers and deployed "behind the meter". All these five factors are intertwined. Most of the energy companies are making efforts to embrace decarbonization in their own operations and by providing greener power. Companies are also investing heavily in mordernizing the grid to be ready to serve the increase demand of power over next couple of decades. DERs, Microgrids provide the extra cushion in managing the demand and supply. Also, many independent players are trying to establish their own electric sources either through solar panel installations, setting up of wind turbine or small hydropower projects. Newer business models are evolving in this process. Having said this efficiency of the grid remains a concern even today. Both in terms of transmission and distribution efficiency. This needs science and technology coming together to solve this problem.

e) While these technologies can bring down the emissions, not all industries can switch to green technologies due to the high energy intensity requirement. For example Steel, cement industry need extremely high furnace temperature which is difficult to achieve through electricity. In such cases the solution is to capture the emissions happening due to burning of fossil fuels. Carbon Capture technologies help address this problem.

f) While energy demand may continue and renewables coupled with Carbon capture technologies help in absorbing the carbon, the needs for petrochemicals will continue to rise. Given the trend many Energy companies are now shifting the gears to Crude Oil To Chemicals (COTC) instead of setting up traditional refineries. This COTS strategy will be able to produce materials of tomorrow like Lubes, solvents, plastic etcetera. COTC will ensure maximum yield and minimum emissions. Have backward and forward integration across the value chain really helps keep the emissions in control and leverage the existing investment in refineries. This will also ensure the local economy is not disturbed as the labor can now be easily extended in petrochemical industries. Customer intimacy will increase- since now we are producing products for direct consumer consumptions and will have more opportunity for branding and creating unique differentiations, unlike when producing fuels for vehicles.

The key commodity driving the above change is carbon. It is all about managing carbon physically and in books to meet the ESG goals of a company. This has given rise to newer markets where in carbon can be traded. All the carbon emissions ultimately go into atmosphere and from there it spreads. It cannot be limited to an area, city or country. It is this premise which is fundamental to carbon market. Following this logic countries, people, companies came together to limit their emissions to certain amount which is known as carbon budget. The idea is as a group the emissions have to be reduced and not necessarily target at an individual level. This is the first principle. The second principle is to reduce the carbon wherever it is possible, easier and less expensive.

With this as fundamentals, the carbon market was born. Which naturally gravitates towards trading.

g) Carbon Markets provides a platform to manage emissions holistically across different stakeholders across the globe. This not only enable management of emissions but also provides a means to attract investment in green projects which is the need of the hour. Carbon allowance and credits provides accountability on individual institutions to manage their emissions, also enables them to treat the entire globe as their playground where emissions can be reduced or abated. Having said this Carbon Markets are yet to evolve in terms of having uniform framework, unified data model, unified API's and clear traceability to avoid greenwashing. With the help of digital technologies some of these challenges can be tackled at scale, fueling our net zero transition.

h) Carbon trading provide others opportunity to invest and trade in abatement technologies which will help balance the carbon. This provides excellent opportunity to help de-link emissions with growth. It also encourages green investments. The challenge however can be verification of the physical commodity ie carbon associated with this trade. How do you ensure actually carbon has be captured in some far remote place. While IT can help to some extent the actual physical verifiability is still a challenge.

### 5.3 Implications

Implications I would like to discuss under three categories.

a) **Implications of the Energy companies:** While there are green technologies available which energy companies have started adopting, world cannot do away with fossil fuels as it is still required to produce polymers which forms the fundamentals of our modern society. One cannot imagine life without polymers from the bed we sleep to machines we use, to the cars we drive to the phones we use to the buildings we stay to the food we consume (in terms of fertilizers). All needs polymers. And this demand will continue in future irrespective of energy demand and this cannot be met by green technologies. To cater to this Energy refiners are shifting their focus to produce polymers directly from crude by adopting crude to chemical process. This will skip the cycle of refining crude and using the feedstock from this process to produce chemicals. Also, research showed increase focus on upgrading refineries to produce more bio-fuels as this is easier for refiners to retrofit their knowledge, supply chains and logistics. Similarly, when it comes to upstream players in energy sector they are more inclined in exploring geo-thermal energy sources as this plays in to their sub-surface and geo-physics knowledge and expertise they have built over decades. Having said this there is enough evidence to show that most of the Energy companies are focusing on building green sources of renewable energy. But not many of the Oil and Gas players are focusing on nuclear energy. Instead, Utilities companies like EDF, Engie, Exelon, Dominion and others are focusing on this energy source.

b) **Implications on the industry:** Energy industry is stands for trading and taking positions on crude stocks and power contracts. But given the Energy transformation new commodity has been added into the mix which is carbon. Carbon markets are evolving and is increasingly becoming a very valuable trading commodity. In the carbon market, carbon is given an economic value, allowing people, companies, or nations to trade it. When a company buys carbon, it is buying the right to burn it. When a company sells carbon, it gives up its rights to burn it. This is giving rise to new business lines and bringing changes in the dynamics of different companies. For example Oxy is betting big on carbon capture technologies which will help it to absorb carbon and issue carbon credits to other companies giving rise to new business or revenue lines. Also, this ensures overall as one world, one earth we are having opportunities to effectively manage and reduce the carbon emissions without hurting the growth and meeting energy demands of people. This is very crucial in 21st century and will play pivotal role in ensuring sustainability.

c) **Consumers play a key role in ensuring sustainability**. There are several strategies/approaches to try and help meet this spirit yet be kind to our mother earth. Some of them are by inculcating ethical and sustainable behaviors. By demanding products which are sustainably sourced, produced and distributed. By willing to pay bit of extra premium to encourage the producers to focus more on green products. At the same pushing the producer to reduce waste, reduce their scope 1, 2 and 3 emissions, by reusing/recycling, by having reverse logistics to get the products at the end of their use and recycle it, by reducing usage of virgin materials etcetera.

Enabling these implications is information technology which play crucial role in connecting stakeholders across ecosystem, brining insights into operations and recommend actions. We discussed most of the digital technologies but for GenAI. It is evolving field, and more research needs to be done in how GenAI will play a role in this space.

This paper lists different technologies both energy and information technologies that needs to be adopted to ensure sustainability.

## 5.4 Conclusion

The purpose of this study is to understand what transformations energy markets have to undergo at the intersection of economics, the energy demands of the growing population and digital technologies. Through this study I have articulated different technologies to be adopted and their limitations.

So, in a nutshell if I want to summarize in diagram the Energy market transformation refer to the diagram below

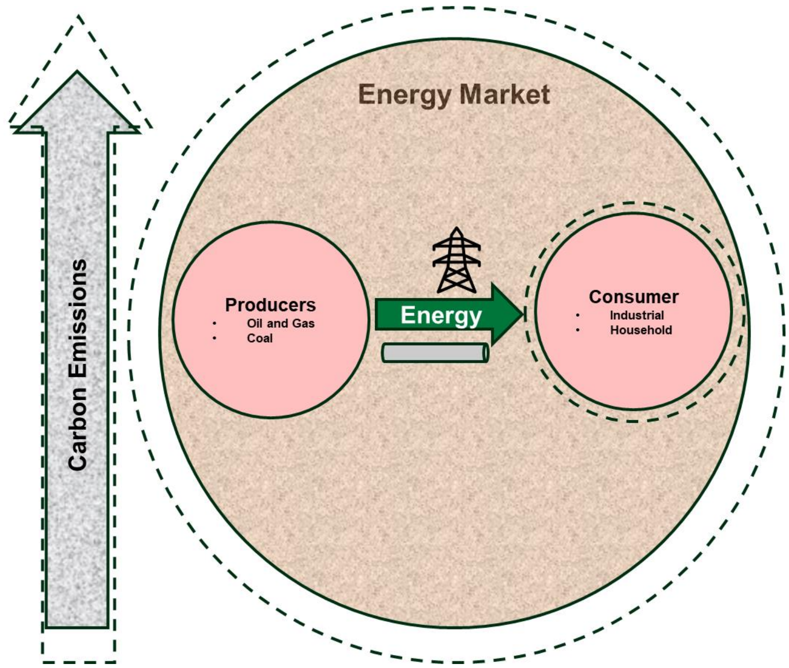



*Figure 34:*
*Current Energy Market*

The brown portion signifies the Energy Market which has producers (Oil and gas, Coal producers) who produce energy and consumers (both retail and industrial) consume this energy. Energy is transmitted through pipelines and transmission &

distribution grids. It is in one direction. Next to the energy market is the rising carbon emission associated with Energy production and consumption. The broken outline signifies growth in the consumption when population and quality of life increases. Leading to the increase in Energy Market size (shown in broken outline) and associated carbon emissions (shown in broken outline arrow). The commodity being traded here is Energy (both in terms of liquid, gas and power).

This market must transform to below depicted in the diagram below.

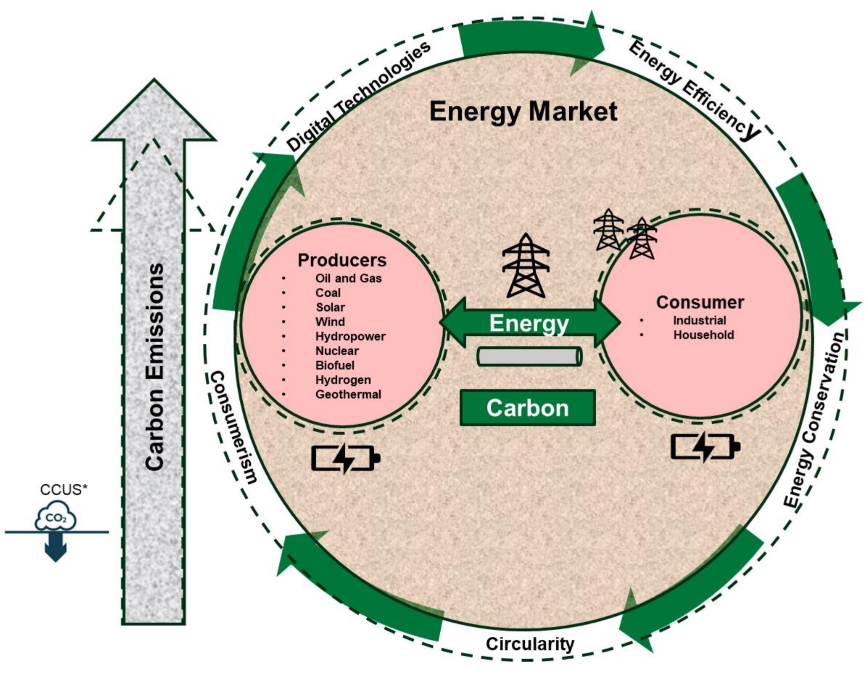



*Figure 35:*
*Transformed Energy Market*

Transformed Energy Market brings in different sources of energy like Biofuels, Hydrogen, Solar, Wind, Hydropower, Nuclear, Geothermal in addition to traditional fuels like Oil, Gas and Coal. Consumers will now be able to produce therefore becoming prosumers. Supporting this, micro grids will emerge and to support this transmission and distribution grids have to be transformed. The energy requirement should not directly grow with the increase in population. There will be elements like energy efficiency, energy conservation, circularity, consumerism, and digital technologies which will help in reducing energy demands. Battery technologies will help tackle intermittency issue associated with renewable energies. Technologies like CCUs will help reduce the emissions from hard to abate industries. This market will have new commodity playing a crucial role in the way energy is procured, stored, managed, and consumed.

In addition to this I have addressed the sub objectives of this research. The conclusion of which is summarized below.

- How to ensure equitable and sustainable quality of life while transforming the Energy markets?

  Providing Energy at the right place and right cost is of great importance to ensure equitable growth. Having said this to ensure sustainable quality of life energy source becomes very critical. Coupled this with living habits, lifestyles and societal human consciousness will play a very pivotal role.

- How do we decouple Energy demand and society progress?

  Responsible consumerism balancing greed, needs and aspirations will have a much larger role to play. Having said this the way Gross Domestic Product (GDP) of the country is measured must be changed. Quality of life, which is measured across different parameters like life expectancy, education, environmental impact, happiness index etcetera should be included in the GDP measurement. Also, the %age of GDP should be measured on how much money is being spent/generated through green jobs and green energy composition of the energy mix of a nation. Once we do this the society progress is automatically linked to true society progress and lower energy demand supplied by greener sources.

- What are some of the best practices adopted across the world which helps in maintaining the balance between economics growth and environment?

  Our research showed that Energy Efficiency, Energy Conservation and Circularity play a major role in ensuring the balance between economics of growth and environment. While Energy efficiency ensures less energy consumption for the same amount of work, energy conservation is deep routed with the behavior of customer to very consciously use less energy as possible. Simple habits in day-to-day life can make a huge difference in energy consumption. Circularity on the other hand encourages reuse, recycle, repair as much as possible and avoid usage of virgin materials. This brings about a complete change in the communities and the entire ecosystem of producers and consumers into play in a very coherent manner.
- What transformations are required at the consumer end to achieve these goals?

  Our research showed that the biggest change required at consumer end to achieve the sustainability goals is to have change in mindset. Accumulating materials does not define happiness. Need to move out of me-mine mindset and think of society as a holistic entity. Become conscious of every consumption in day-to-day life and understand the bigger implication. Instill the environmental consciousness in the next generation and learn or rather re-learn to live with environment. Consciously demand environmentally sustainable goods and services. Embrace sustainability and make circularity as mantras of conscious living.
- What transformations are required in business (industries) to drive sustainability?

  Energy companies have to consciously shift their focus to produce more green energy from different sources like Solar, Wind, Nuclear, Geothermal, hydrogen, Hydropower and Biofuels. Having said this the ecosystem also has to shake up like changes in the transportation – moving from internal combustion engine to electric vehicle or hydrogen powered vehicles, transformation in grids to cater to the bi-directional flow of energy and intermittency of renewable energy, transformations in battery technology to store huge amounts of energy and at the same time ensure the battery footprint is as carbon neutral as possible. Additionally, adoption of Carbon capture technology in cases where adoption of renewable energy is not feasible.

- How can technology be a big enabler in this space?

  This research proved that Digital technologies can play a major role in ensuring sustainability, from production to consumption and recycling. Digital technologies help solve some of the critical challenges like where to set up the renewables energy generation with minimum carbon footprint and maximum margins, what is the demand, how to link that with the variability in renewable generation, how to bring in elements of energy efficiency and encourage energy conservation. Digital technologies like block chain, artificial intelligence, IoT play a crucial role in ensuring circularity and bring in change in consumer behavior. Also, digital technologies play a crucial role in helping customer embrace electrification of transportation and shared services.

However, this study does not cover the following.

- A critical consideration in the evaluation of green energy sources is a comprehensive understanding of their life cycle carbon footprint. While the operational phase of certain renewable energy technologies, such as wind energy, may not directly generate carbon emissions, a holistic assessment is necessary. Experts emphasize that the entire life cycle, encompassing all stages from material extraction and manufacturing to construction and operation, must be taken into account. For instance, wind turbines necessitate the mining of various materials, including steel, concrete, fiber, glass, copper, and rare earth elements like neodymium and dysprosium for the permanent magnets. The production of each of these materials contributes to the overall carbon footprint of wind energy.  Therefore, a life cycle analysis is essential for each green technology to accurately assess its environmental impact.

- More research needs to be done in understanding the financial implications adopting these technologies and how this will be funded.
- This study has also not delved deeper into the different areas of consumption like retail, transportation, manufacturing, agriculture, heating, and cooling needs. Each of this sector has its own challenges and opportunities which can influence energy markets. Also, each of these industries need to undergo transformation like
  - Transportation – Need to roll out more affordable and reliable electric vehicles, build Hydrogen powered engines for heavy vehicles like trucks, ships etcetera.
  - Manufacturing sector needs to transform to enable electric furnace instead of traditional gas fired furnace. There are several challenges in this area which needs to be addressed.
  - Agriculture sector needs to transform to consume less fertilizer, better management of yield. More research is required on how to adopt some of the solutions like precision farming, better crop rotation management, biological weeding etcetera on a wide scale and yet meet the food demands.
- Study has also not looked deeper into consumer habits like meat consumption – which is known to be one of the industries causing heavy methane emissions. Since this is not directly related to Energy companies, it has not been covered in this research. However, when it comes to sustainability, this topic is considered to be playing a major role, which cannot be ignored.
- While Digital technologies are very promising in terms of solving the optimization and connecting different value pockets in the entire Energy value chain, it's own carbon footprint is high. More the complexity of technologies used, more compute power

consumed leading to huge servers which needs tons of power to keep it cool. Unless this is powered by renewable energy digital technologies itself pose a huge challenge in terms of being energy guzzlers. This area needs more research to understand how and where the power requirements both at the server and client end can be optimized to have net zero carbon footprint.

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