Is Green technology Really the Answer to Sustainability or Just Shifting the Problem?

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DECLARATION

I hereby attest that I am the sole author of this thesis and that its contents are only the result of the readings and research I have conducted.

Camille Louhichi

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This dissertation further serves as a personal affirmation of the enduring adage, 'where there is a will, there is a way.' It is my hope that this work stands as a testament to the principle that with genuine desire, dedicated effort, and necessary sacrifices, the attainment of personal goals is always within reach, and the resulting feeling of accomplishment justifies the efforts undertaken.

Finally, I dedicate this doctoral research to my mother. She has always encouraged me, supported me, and pushed me to reach my goals, no matter what. Her own achievements have been a constant inspiration to me, fueling my desire to not just follow in her footsteps, but maybe even leave a slightly bigger footprint of my own.

ABSTRACT

This doctoral thesis critically examines the efficacy of green technologies as a comprehensive solution to global sustainability challenges, questioning whether they represent genuine progress or merely a displacement of environmental burdens. Entitled ‘Is Green Technology Really the Answer to Sustainability or Just Shifting the Problem?’, In this study the multidimensional notion of sustainability is presented, its definition, three legs, definition challenges, metrics, practical uses as well as its future direction are proceeded. Secondly, it investigates the environmental crisis and its (parent) solutions to climate change, biodiversity loss, resource depletion and the human costs of environmental degradation before studying the role of green technologies as a beacon of hope and the penetration of government regulations. This thesis stands by the employment of a secondary research methodology to analyse the potential as well as limitations of two important green technologies; electric vehicles (EVs) and artificial intelligence (AI) through SWOT analysis to establish their strengths, weaknesses, and opportunities. In this research, the discussion and analysis shows that green technologies are highly important in the tool box of mitigation of some environmental impacts, but do not represent an eco-friendly holistic solution. This study shows that the technologies often bring new environmental ones and ethical dilemmas, but in reality, they do not resolve the real problems. The findings underscore the enduring relevance of the ‘Limits to Growth’ paradigm and emphasise the necessity for a paradigm shift towards a holistic, systemic approach to sustainability that integrates technological innovation with fundamental changes in societal values, economic models, and consumption patterns. Ultimately, this research argues that true sustainability requires a global consciousness and behavioural transformation, advocating for international regulations and a recognition that green technologies are akin to symptom-relieving medicines, not curative solutions, highlighting the ongoing need for critical evaluation and ethical considerations in the pursuit of a sustainable future.

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ACRONYMS AND ABREVIATIONS

ADEM- Agence de l'Environnement et de la Maitrise de l'Energie

AI- Artificial Intelligence

ARCEP- Autorité de le Règlementation des Communications Electroniques, des postes et de la distribution de la Presse.

ARPA-E- Advanced Research Projects Agency-Energy

BRICS- an intergovernmental organisation consisting of ten *countries (ex: China, India.)*

CBD- Convention on Biological Diversity

CCS- Carbon Capture and Storage

CH4- Methane

CO2- Carbon dioxide

DAC- Direct Air Capture

DRC- Democratic Republic of Congo

EGD- European Green Deal

EPR- Extended Producer Responsibility

ESD- Education for Sustainable Development

EOL- End-Of-Life

EMS- Energy Management Systems

ETS- Emission Trading Scheme

EU- European Union's

EV- Electric Vehicle

GCF- Green Climate Fund

GDP- Gross Domestic Product

GGGI- Global Green Growth Institute

GHG- Greenhouse Gas

GIS- Geographic Information Systems

GIoT- Green Internet of Things

GPI- Genuine Progress Indicator

GPS- Global Positioning System

GPUs- Graphics Processing Units

GRI- Global Reporting Initiative

HDI- Human Development Index

HVAC- Heating, Ventilation, and Air Conditioning

IAMs- Integrated Assessment Models

ICCT- International Council on Clean Transportation

ICE- Internal Combustion Engine

IEA- International Energy Agency

IIED- International Institute for Environment and Development

IPCC- Intergovernmental Panel on Climate Change

IRENA- International Renewable Energy Agency

ITC- Investment Tax Credit

IoT- Internet of Things

kWh- kilowatt-hour

MaaS- Mobility-As-A-Service platform

MOOCs- Massive Open Online Courses

NDCs- National Determined Contributions

NGOs- Non-governmental organisations

N2O- Nitrous oxide

NOx- nitrogen oxides

NSE- Net Zero Emission

OECD- Organisation for Economic Co-operation and Development (38 countries)

PM- Particulate Matter

PTC- Production Tax Credit

R&D- Recherche and Development

REEs- Rare Earth Elements

SASB- Sustainability Accounting Standards Board

SDGs- Sustainable Development Goals

SO2- Sulphur dioxide

SWOT- Strengths, Weaknesses, Opportunities, Threats

TPUs- Tensor Processing Units

TWh- terawatt-hours

UAE- United Arab Emirates

UK- United Kingdom

UN- United Nations

UNCED- United Nations Conference on Environment and Development

UNDP- United Nations Development Programme

UNEP- United Nations Environment Programme

UNESCO- United Nations Educational, Scientific and Cultural Organisation

UNFCCC- United Nations Framework Convention on Climate Change

V2G- Vehicle-to-Grid technology

WRI- World Resources Institute

1. Introduction and Aim of Study

The ‘Meadows Report’ of the 1960s warned us of the planet’s resource limits and human activity’s effect. 1972 also saw the publication of a report the Meadows Report (also known as The Limits to Growth) authored by Donella and Dennis Meadows, and commissioned by the Club of Rome investigating the long-term impacts of exponential growths in human population and consumption of resources. That report concluded that if the trends of the day continued, humanity would have severe environmental and societal problems of resource depletion, pollution, and climate change.

At the time the report’s findings were met with scepticism but as the world is today grappling with the very same things the report warned of, they have gained renewed attention. Today, the Meadows Report is a seminal work referred to as a pioneer within the science of sustainability and its conclusions are still powerful dialogue to help us comprehend the scope of those challenges and potential to live in a sustainable world tomorrow.

Here are some of the key findings of the Meadows Report:

- The world's population is growing exponentially, and this growth is putting a strain on natural resources.
- Human activities are causing widespread pollution, which is damaging ecosystems and human health.
- Economic growth is not sustainable in the long term, as it is reliant on the finite resources of the planet.

The Meadows Report did not offer a specific solution to these problems, but it did call for a fundamental change in our thinking about how we interact with the environment.

According to the report, to escape from this current model of economic growth and development that relies on natural resource exploitation, the study must seek a more sustainable path of growth that respects the limits of the planet.

The findings of the Meadows Report had and at least some of its implications continue to be relevant today. The more urgent place for this call for fundamental change in how to think about being in relationship with the environment is as it confront, climate change, resource depletion and environmental degradation.

It was not until 1988 that a group of experts emerged: the Intergovernmental Panel on Climate Change (IPCC). This organisation was established to assess the scientific, technical, and socioeconomic information relevant to understanding climate change, its potential effects, and possible response options. The IPCC's work has been instrumental in raising global awareness of the climate crisis and informing international policy decisions.

James Watt's invention of the steam engine in 1769 marked a turning point in human history. This ground-breaking technology fuelled the mass exploitation of coal, ushering in the Industrial Revolution. The Industrial Revolution transformed traditional artisanal manufacturing into mechanised production, setting the stage for a succession of technological advancements. Factories equipped with steam engines enabled a dramatic increase in production capacity.

1.1 Link between Industrialisation and Environmental Impact

Progressive increase in pollution and the rearing of the polar cap have been directly attributed to rise of the Industrial Revolution and the associated escalation in coal consumption. Fossil fuels are burned, which burns up greenhouse gases released which trap heat causing the planet to be warmer. This greenhouse effect phenomenon has a simple but grave consequence that includes eventually rising sea levels, extreme weather events, and the disruption of ecosystems.

The Industrial Revolution can be divided into several distinct periods, each characterised by significant technological and societal advancements:

- **First Industrial Revolution (1760-1840):** The era of steam power, marked by the invention of the steam engine and the rise of mechanised manufacturing.
- **Second Industrial Revolution (1870-1914):** The age of mass production, driven by advancements in electricity, internal combustion engines, and assembly lines.
- **Third Industrial Revolution (1950-1970):** The rise of automation and electronics, characterised by the development of computers, transistors, and integrated circuits.

- **Fourth Industrial Revolution (1980s-present):** The digital age, marked by the convergence of digital, physical, and biological technologies, including artificial intelligence, robotics, and the Internet of Things.
- **The Fifth Industrial Revolution: A New Era of Virtualisation and Humanoid Robotics**

The year 2020 marked a turning point in the Industrial Revolution, ushering in the Fifth Industrial Revolution. This new phase is characterised by a significant increase in digital communication and the emergence of humanoid robotics, further blurring the lines between the physical and virtual worlds.

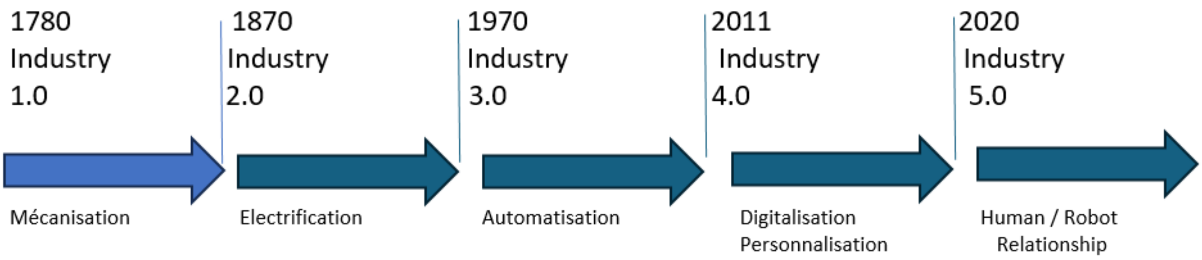


Figure 1 Evolution of Industrial Eras (Proaction International Jean-Philippe Raiche, 2022)

We can correlate the progressive increase in pollution and global warming with the Third Industrial Revolution. 'Since 1970, the global average temperature has been rising at a rate of 1.7°C per century, compared to a long-term decline over the past 7,000 years at a baseline rate of 0.01°C per century.'(NOAA, 2016; Marcott et al., 2013)

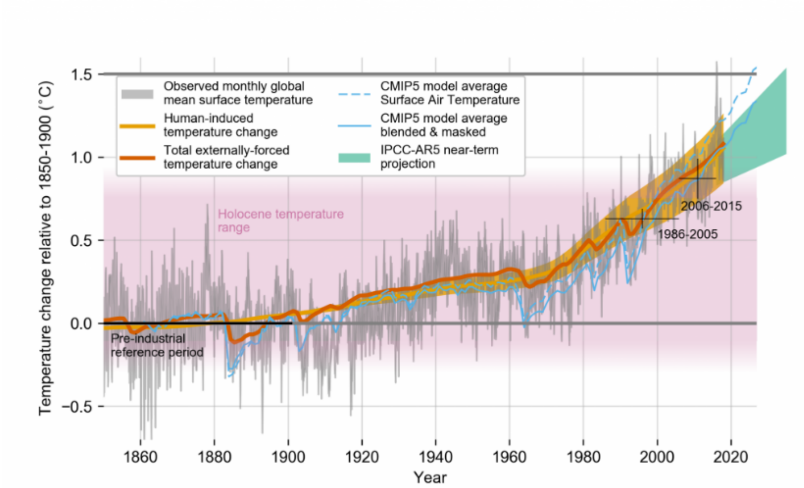


Figure 2 Temperature Change(IPCC, 2021)

Throughout the various phases of the Industrial Revolution, human activity has profoundly reshaped international trade relations. Technological advancements have revolutionised transportation, communication, and manufacturing processes, enabling the movement of goods and services across borders at an unprecedented scale. This interconnected global economy has fostered economic growth, cultural exchange, and the interdependence of nations. However, human actions during these technological revolutions have not been without significant risks. The rapid industrialisation and economic expansion have come at a considerable cost to the environment. Pollution, resource depletion, and habitat destruction are just a few of the environmental consequences that have emerged alongside technological progress.

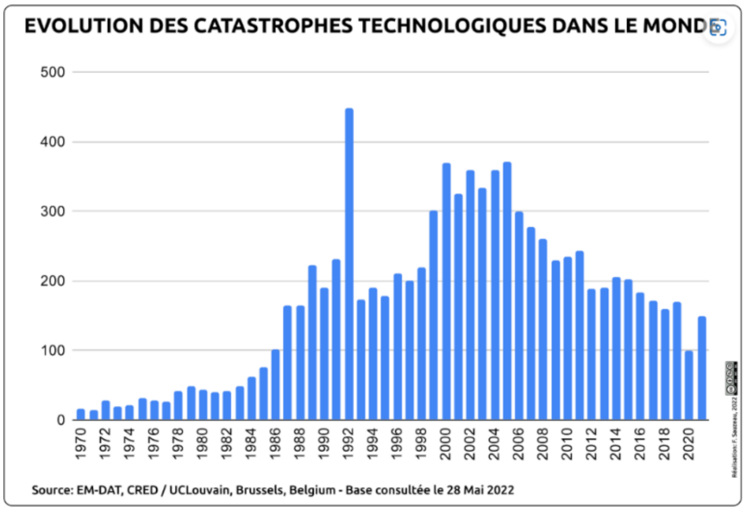


Figure 3 Evolution of technological disasters in the world (HG Sempai, 2022)

We have had different types of oil pollution with various shipwrecks (2010) oil spills in the Gulf of Mexico or 2002 off the Spanish coast, or toxic products emanating from factories like in July 1976, a cloud of dioxin Escapes from a chemical factory in Séveso, Italy. We draw the reader's attention to nuclear accidents. Such as that of Chernobyl on April 26, 1986, where a reactor exploded or that of Fukushima-Dalichi following a magnitude 9 earthquake off the coast of Japan on March 11, 2011. We are seeing natural disasters on the rise, perfectly parallel to the technological revolution and the increase in consumption across the world.

Given the correlation between technological development, the different phases of industrialisation and overconsumption, how can we affirm that the technology we describe as green is a sustainable response to global warming, pollution, resource scarcity, and equity between humans and other species?

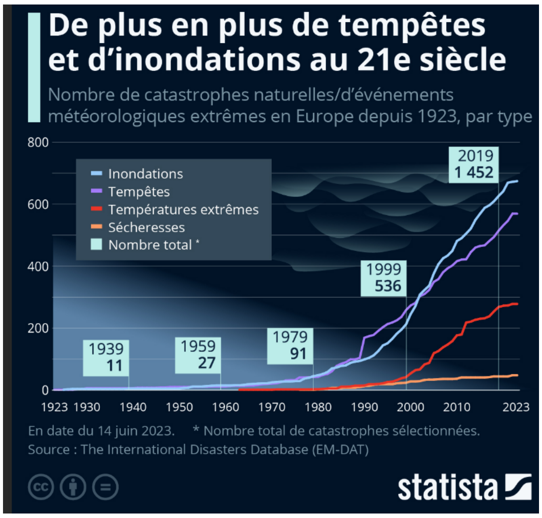


Figure 4 Evolution of natural disasters in Europe since 1923(Anna Fleck, Statista, 2023)

How can we be sure that Artificial intelligence and robotisation will not bring other difficulties that we have not yet considered? Replacing one technology with another cannot be done without a risk study. Did we do it? Is sustainable development really sustainable?

1.2 Is Green Technology Really the Answer to Sustainability or Just Shifting the Problem?

It is these questions that I will attempt to answer in this bibliographic research paper.

While technological advancements propelled societal progress, the benefits were not equally distributed. This era witnessed the rise of unequal wealth distribution, global exploitation of resources, and the gradual increase in greenhouse gases documented earlier. As the world population approached 1 billion in 1804, Thomas Malthus' infamous 1798 prediction of population growth outstripping food supply added fuel to earlier, less prominent sustainability concerns.

The 19th century saw a surge in discussions regarding the environmental and social consequences of industrialisation. Citizen groups like the Sierra Club, established in 1892, focused on wildlife conservation (Cohen, 1988). Publications like George Perkins Marsh's 1864 work, which predicted human extinction due to environmental interventions, showcased early discussions about sustainability (then not yet termed as such).

A 1912 newspaper article referencing the impact of our actions on future generations demonstrating that sustainability anxieties are not a recent phenomenon (Dhanani, 2022).

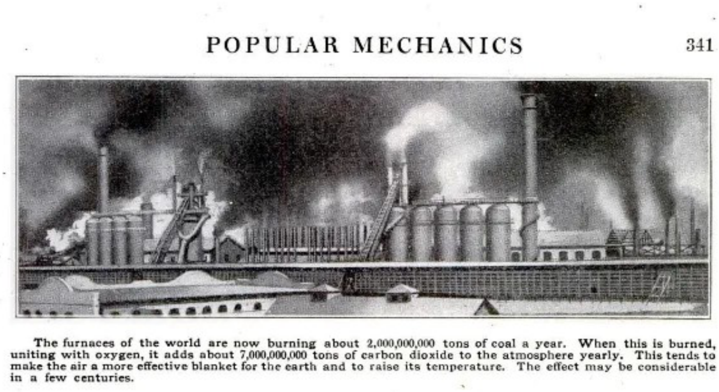


Figure 5 Image and caption from Popular Mechanics magazine (March, 1912)

Recent discoveries from January 2024 revealed that the fossil fuel industry was aware of climate change threats as early as 1954. Interestingly, the groundwork for this research, conducted by Charles David Keeling and forming the basis of our current understanding of human-induced climate change, was partially funded by oil and automobile companies themselves.

The 21st century finds humanity at a crossroads. The spectre of environmental degradation hangs heavy, with climate change, biodiversity loss, and resource depletion posing existential threats. In response, green technologies have emerged as potential saviours, promising a path towards a sustainable future.

These technologies foreshadow a world unshackled from fossil next fuel dependence and environmental destruction from renewable energy sources like solar and wind power, to electric and cars and innovative agricultural practises. But neither is the storey behind green technologies. While their potentials are clear cut, it would be futile to ignore the fact that every solution is coming with trade-offs and limitations. The first part of this essay research looks at exploring green technologies as a means for solving environmental issues, with recognition also of the trade-offs and limitations, which should be considered.

For this we need to start by establishing a foundational understanding of sustainability before we get to explore the green technologies. Just as important for a truly sustainable future is to develop solutions that embrace all three aspects of sustainability in an equal measure.

Under threat are ecosystem services that are essential for human well-being, urgently demanding the repetition of action at an alarming pace, as species after species vanishes. This is further complicated by resource depletion, that is, freshwater scarcity and soil erosion. Not only is the environmental crisis a threat to the health of the planet but also it will impact food security, livelihoods, and human health.

Technology has been the constant tool used by man to solve problems and advance civilisation. Until recently, however, it had been a little easier than this; we relied heavily on technology while not having much of an impact on our environment. Economic growth for the last centuries has been powered by fossil fuel-based technologies, but they also came at a price for the planet. To appreciate the potential of green technologies to provide a way out of this current historical context of growth and crisis, one must first understand the historical context.

A compelling vision of a future independent from fossil fuel dependence, green technologies provide. Solar and wind power are renewable energy sources and, while they also produce clean electricity, they do so without harmful emissions from the environment. We can integrate solar panels and wind turbines into our landscapes and create power without giving up too much environmental impact. Electric vehicles replace fossil fuel drivers and elimi-nate tailpipe emissions, two of the main causes of air pollution and climate change. Sustainable agriculture practises also look at healthy soil, conservation of water, and reliance on chemical inputs, which are things that are outside purely of energy production. However, these practices are to maximise agricultural productivity with the least possible environmental impacts.

Green technologies derive advantages that are not only environmental. Additionally, they can also facilitate energy independence and security. Many nations have come to rely on fossil fuels, and this reliance generally ties nations to volatile geopolitical situations and price fluctuations. Domestically located renewable energy sources can provide a path to energy security and independence from foreign oil and gas. Green technologies also can generate new jobs and increase economic growth. The development of, installation and maintenance of these technologies create new job markets in renewable energy sectors and require skilled labour.

There will be more ambitious dives into particular green technologies, looking at what promise they hold and then what obstacles. Chapters on Electric vehicles and AI for sustainability are to be discussed. In addition, the essay will also look into the contribution of government policies and regulations in fostering further development and use of green technologies. It also examines the importance of individual choices and the need for cooperation in attaining a sustainable future on a global scale. In the long run, this research could allow businesses, policymakers and consumers to understand the actual impact of green technology initiatives in real life and figure out which initiatives are truly effective and which may be generating the opposite results.

A future based on recognising the challenges of green technology is not a future of all the perfect solutions, but of evermore improved solutions. It is a future that employs technological innovation for its power and its responsible and ecologically sustainable utilisation to the benefit of the present and future generations.

2. Literature Review

2.1 Defining Sustainability

Sustainability has reached critical mass, with urgency, and has made its mark across all aspects of society – from government policy, legislation, corporate strategy and community projects. In this part, sustainability is defined, history and evolution of the concept is traced, the multifold dimensions of sustainability are analysed and the challenges and metrics for assessing sustainability are explored. An integral part of this study is that sustainability is a concern that goes beyond an ecological consideration and centres on a cell entwine between environmental integrity, economic viability and social equity. To have a sustainable future, which are often referred to as the three pillars of sustainability, these elements must be balanced. This part attempts to make sense of the term 'sustainability' by going through a thorough reading of scholarly sources and empirical evidence through which it clarifies what it means and how it can be measured and possibly implemented effectively in diverse environments of application.

The first provides a historical background to the seediness of the sustainability concept, first uncovering the nascent stages from the historical sources. The early discourse of sustainability was heavily influenced by foundational texts such as the Brundtland Report, formally known as ‘ Our Common Future’ by the World Commission on Environment and Development (1987). Sustainable development, defined by the report’s definition as ‘development that meets the needs of the present without compromising the ability of future generations to meet their own needs’, has remained a broadly defined, a model, that remained in the contemporary understanding of the term. Analysis of this period shows that sustainability is an outgrowth of a reaction based on the recognition of ecological limits and the requirement for accommodation between environmental care and economic growth.

The concept is further investigated, with a keen interest in tracing how this concept has sprung from the application of the global movements as well as influencers in this line of thought. This section takes a look at what organisations like the United Nations have done, through the Sustainable Development Goals (SDGs) and works by some important faculty like from the National Research Council and IPCC reports on climate change. The contents of these sources present a succinct perspective of how sustainability has widened its scope to encompass dimensions of social questions unlike mere ecological matters. At the same time, criticisms of the three pillars model and calls for an integrated approach were explored provoking ongoing debates and the delineation of how a cohesive sustainability framework is possible.

Finally, given the measurement and operationalisation of sustainability, this portion also looks at different sustainability measures and indicators put forward and used. For this section, studies analysed are The Earth Institute's efforts (The Earth Institute, 2021). In developing sustainability policies and metrics, which emphasise the importance of coherent and universally accepted measures for sustainability assessment. Additionally, green accounting practices, green chemistry, and engineering principles were investigated as practical implementations of sustainability. These methods reflect the evolving practice of embedding sustainability into organisational frameworks, emphasising accountability, and innovation in reducing environmental footprints.

We address several critical questions, including: How has the definition of sustainability evolved over time? What challenges arise in defining and measuring sustainability? How are the environmental, economic, and social pillars interconnected, and what case studies illustrate this balance? An analysis of these questions yields profound insights into the practical obstacles and innovations driving progress toward sustainability. Specific attention is given to real-world applications of sustainability principles in various sectors, from government policies to community-based initiatives.

Ultimately, the objective of this first part is not merely to define sustainability but to offer a roadmap for its practical realisation. By synthesising historical context, key theoretical contributions, and empirical data, it aims to contribute to the ongoing dialogue on sustainability, offering recommendations for future policies and practices that can foster a balanced and enduring human-environment relationship. Defining sustainability clearly and measuring it effectively are critical steps in ensuring that global development respects planetary limits.

2.1.1 Defining Sustainability in Context of Literature

What is commonly referred to as sustainability, as a concept, has taken an evolution over time that can trace its roots to the early human civilisations with land stewardship and resource conservation practised long before the formal coining of the term. The fact that sustainability has its historical foundations in the world of indigenous practises of maintaining a harmonious balance in relation with nature is evidenced by the fact that traditional ecological knowledge wherever found is sustainability embedded. These societies discovered the flowing nature of systems, living by instinct and without ignorance understanding of the value of natural resources to allow them to sustain themselves for generations following. (Senedd Research, 2016)

However, the modern narrative of sustainability has its roots in the mid-20th century, when people started to realise the planet has finite resources and industrial growth has to be regulated. Often used as a moment signifying the starting of the environmental movement, 1962 is the year Rachel Carson's 'Silent Spring' was published documenting the damaging effects that pesticides have on wildlife and ecosystems. It was a tide towards environmental awareness that would soon sweep the world over, resulting in policy shifts and environmental protection agencies (IOPscience, 2023).

The term 'sustainable development' made an entry in the limelight with the publication of the Brundtland Report by the World Commission on Environment and Development in 1987. It delivered a now famous definition of what sustainability was; 'development that meets the needs of today without compromising the ability of future generations to meet their own needs' — which was important to figures such as Gro Harlem Brundtland, the Chair of World Commission on Environment and Development, and Lester Brown, the founder of the Worldwatch Institute.. The Worldwatch Institute was a globally focused environmental research organisation, though it ceased operations in 2017 (Oxford Reference, 2024). Their contributions significantly shaped the discourse around environmental sustainability and the urgent need for a shift in development paradigms. The historical context provided by these early definitions and key proponents illustrates a foundational understanding that has been continually refined and expanded.

As the global community began to increasingly without compromising 'the ability of future generations to meet their own needs' (Asian Development Bank, 2012). This seminal work laid the groundwork for subsequent environmental policy and legislative frameworks and underscored the necessity for an integrated approach addressing environmental, economic, and social dimensions.

2.1.2 Early proponents of sustainability

The idea of sustainability, once recognised, went through considerable evolution in regards to its understanding of the interconnectedness of ecological systems and human activities. In 1992, the Rio de Janeiro held the United Nations Conference on Environment and Development (the Earth Summit), further emphasising the need for green practises with the production of landmark documents such as Agenda 21 and the Rio Declaration. The bilateral agreements signified the international framework in which countries need to think in developing sustainable development and integrate such principles in their national policies (KPMG, 2022).

However, the modern understanding of sustainability has evolved into what can be understood as a complicated task with diverse social, economic and environmental pillars. Current definitions include not only the conservation of resources, but also the fair distribution of wealth and opportunity, including social inclusiveness and justice. Since then, this concept has been applied by experts to a sustainable cities, clean energy, climate adaptation, and corporate governance. These expansive views of sustainability have received considerable contributions from academic institutions such as McGill University who have offered multidimensional definitions that include these views of sustainability (McGill University, 2013).

Global movements had an outstanding influence on development and advancement of sustainability. Support and policy reforms have been mobilised and carried out successfully by non governmental organisations (NGOs) and to some extent other international bodies including the United Nations and the Intergovernmental Panel on Climate Change (IPCC). When adopted in 2015, the Sustainable Development Goals (SDGs) represented a major breakthrough, as they represented an overarching framework for global sustainability work aimed at eradicating poverty and at the same time protecting the planet and ensuring prosperity for all (KPMG, 2022).

There is a place for policy and legislation in operationalising sustainability. Sustainability has integrated into corporate governance and industrial processes reflected by the rise of the green accounting practises, green chemistry and green engineering. For example, the European Union's Green Deal and the United States' Clean Air Act are examples of how governments are moving towards incorporating the sustainability into law as way to reduce environmental degradation and encourage sustainable development (Columbia University, 2021). Moreover, programmes such as Circular Economy which proposes the renewal of materials as stated by the idea of reuse and recycling materials, boost the transition towards more sustainable economic models.

In support of the ongoing development and refinement of sustainability concepts, interdisciplinary research and collaborative international frameworks are fuelled. Liberal arts, research, and technical universities have played a crucial role in developing comprehensive assessments and modelling capabilities that draw from such ecological, economic, and social variables (Little et al., 2016). Taken together, they support an emergent framework for guidance—within policy circles, for businesses and in communities—to support sustainable practises.

In conclusion, sustainable has been on a path of continuous learning and adaptation, which has so far led to where we are today. Sustainability has thus evolved from its historical roots in traditional ecological practises to even more complex global problems with its modern iterations. Early definitions, modern interpretations and policy frameworks show the complex fine line that has to be walked to actually effect true sustainability. In advancing, the integrated and interdisciplinary approaches brought to bear on recent breakthroughs will be critical to moving down the path towards a sustainable future.

2.1.3 The Three Pillars of Sustainability

Sustainability strategies that are effective combine environmental stewardship with economic growth and social responsibility. Each of these pillars is a defining domain of human activity and wellbeing with its own set of challenges and objectives. For the development of holistic and effective sustainability strategies which will support long term sustainability of human society as well as natural world, it is important to understand the interplay of these pillars.

The focus of sustainability discourse is environmental sustainability and the prevention and protection of natural ecosystem. The fact that natural resources must be managed responsibly and people should think about what they take from the earth and how they will take care of it for future generations because it will be gone is very, very important. In the arena of efforts in this, there are policies and practises that seek to reduce greenhouse gas emissions, promote renewable energy sources, and protect the biodiversity. For instance, green accounting techniques for this incorporate ecological thought into finance reports and help organisations to measure and manage their ecological effect. Green Chemistry and Green Engineering are also initiatives to avoid the use hazardous materials and to design eco friendly products and processes (Little et al., 2016).

The second pillar is economic sustainability which aims to build a resilient economy that is able to sustain economic activities on the long run without depleting natural resources or destructive features towards the environment. In this context, this implies the shift from traditional economic index such as Gross Domestic Product (GDP) to broader social and environmental externalities. Alternative indicators such as the Genuine Progress Indicator and the Human Development Index. Genuine Progress Indicator (GPI) or Human Development Index (HDI) is both a metric to measure a nation’s well-being in a more holistic way rather than the measures such as Gross Domestic Product (GDP) (Human Development Reports, 2022). By taking account of natural capital, health and social equity, IT enhance the language of assessing economic well-being, offering a more complex evaluation. The purpose of economic sustainability lie with the alignment of economic development with the social and environmental protection in such a way as to promote economic growth that's both balanced and equitable to all members of society.

Social sustainability, the third pillar, emphasises the importance of social equity, inclusiveness, and justice in the pursuit of sustainable development. Issues under their focus include poverty, inequality, access to education, and healthcare, to establish a society where individuals have no space to thrive without having the opportunity. Social sustainability asks for going beyond equity, it requires leaving the building more resilient to climate, economic, or other systemic shocks. Through programmes and policies focusing on social infrastructure improvements, community involvement boosting, and equal access to resources, social sustainability, or aptly, social sustainability (McGill University, 2013) is a critical component of this.

One of the crucial aspects of the overall framework is interconnectivity of the three pillars. Even profound economic and social ramifications of environmental degradation, and vice versa, can be observed. For example, the dreadful exploitation of natural resources can drive economic decline and give rise to social unrest, whereas attempts to stimulate economic growth out of disregard to environmental and social conditions may ultimately do substantial harm to the ecological habitat and deepen inequality in society. Thus, obtaining sustainability relies on an integrative approach balancing between synergies and trade offs in all environmental, economic and social dimensions.

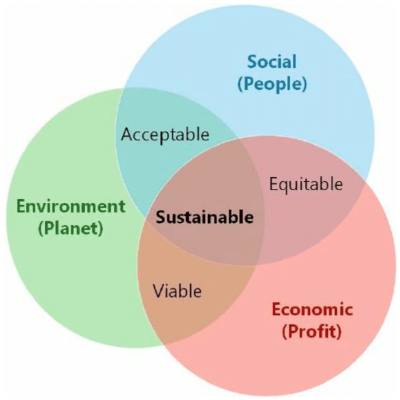


Figure 6 ESG veem diagram (Purvis, Mao and Robinson 2018)

Case studies serve as a rich avenue for study on how various sectors and communities countenance the intricacies of balancing these three poles. For example, the adoption of the Sustainable Development Goals (SDGs) by different countries and organisations signifies an attempt to deal with the diversity of environmental sustainability. The SDGs aims to target in the area of environmental conservation, economic development and social wellbeing in a comprehensive manner (Asian Development Bank, 2012). Corporate sustainability practises is another notable case study where businesses integrates sustainability principles in its operations to improve long term profitability and environmental impact. B Corporation, or B Corp, is a certification that verifies companies meet very high standards of verified performance, accountability, and transparency on issues beyond profit. These factors encompass social and environmental responsibility. Initiatives such as the B Corporation certification program. Make it more possible for companies to meet high standards of social and environmental performance, accountability, and transparency.

To achieve the balancing of these three pillars of sustainability, it has to come from all stakeholders, governments, businesses, communities and individuals. Regulations that will promote sustainable practises while meeting the needs of vulnerable populations ought to be developed and implemented by policymakers. Sustainability needs to be something businesses adopt, and it needs to be adopted in a way that is in line with the businesses' core operations and long term goals. Both at individual and community levels, people need to widely adopt sustainable behaviours and strongly advocate for enabling policies. Sustainability cannot be solved in isolation—collaborative efforts and interdisciplinary approaches are necessary at our scale and in terms of scale.

To conclude, if all of the three pillars of the sustainability viz. environmental, economic and social pillars are put together, it would lead to the concept of a comprehensive sustainability framework. In order to create viable and sustainable development for the future, it is important to understand these interconnected pillars and create and/or respond to strategies that enable a more long term living and safety. Working towards a sustainable future that is good for both people and the planet means we need to use integrated policies, innovative practises and collaborative efforts.

2.1.4 Challenges in Defining Sustainability

Sustainability is difficult to define, for it engages with multiple dimensions that display continual change. Its definitions are inherently ambiguous and central to the debate. Throughout time, interpretations have cumulated with different agendas and views. The early definition, which was taken from the Brundtland Report offered an initial set of foundational definitions and have subsequently led to a range or understanding based on the limits of this definition. The definition the report uses for 'development that meets the present needs without compromising the ability of future generations to meet their own needs' is often critiqued for its lack of specificity and lack of applicability in different contexts (Asian Development Bank, 2012).

Defining sustainability is complicated and broad, and it is one of the principle problems. Sustainability must also be concerned with environmental preservation, economic stability and social equity which are often in opposition with each other. This tri-dimensional nature implies that economics will be sustainable but may need not be the case environmentally, and vice versa. Sustainability is so broad in its scope that only a 'single, unified definition' would apply to it universally. In addition, sustainability is dynamic and depends on new scientific ideas, social change, and the economy, which makes the difficulty grow even more (McGill University).

Defining sustainability complicates the measurement problem. However, the need for such reliable and complete metrics is apparent, but this is also difficult to achieve. However, traditional economic indicators such as GDP can not tell us the environmental and social costs of economic activities, which lead to developing other indicators with e.g. the Genuine Progress Indicator or the Human Development Index (McGill University, 2013). Unfortunately, these indicators are also limited in that they are too complex or subjective. Additionally, there is lack of standardised measurement tools that leads to inconsistencies thus it is not easy to compare sustainability efforts of different organisations or regions (Columbia University, 2021)

Sustainability also introduces cultural variations in terms of identifying what is challenging. There are varying interpretation of what sustainability means and how it should be achieved from one cultural context to the other. Take the indigenous communities who may prioritise the conservation of their local ecosystems and native ways of life while urban populations might try to reduce carbon footprints and to have better energy efficiency. Some of these divergent perspectives can cause conflicts in goals and practises of sustainability which can make it harder to develop a single strategy. In order to develop effective and inclusive sustainability policies, however, one must understand and incorporate these cultural differences (Little et al., 2016).

The definition and implementation of sustainability is greatly determined by political influences. In other words, governments, and political ideologies can matter in how sustainability is prioritised and is addressed. For example, countries with a market orientation might encourage private sector solutions and technological innovation to meet the sustainability challenge, while state led countries might prioritise regulatory measures and public investments. Thus, the distinction between the political approaches elaborated here can affect the sustainability policies' effectiveness and the level of public support they receive. Changes in politics, leadership and political cycles may also result in shifts in policy focus, a lack of long term sustainability and uncertainty (KPMG, 2022).

However, another major challenge to defining and achieving sustainability is technological constraints. Technological advancement can enable sustainability through use of renewable energy sources, efficient waste management systems and sustainable agriculture practises, however, its implementation faces economic, social and infrastructural barriers only. Limited adoption of sustainable technologies is also limited by high costs, the lack of technological infrastructure and a lack of technical knowledge, especially in developing regions. Further, some technologies may have adverse environmental or social effects unintended (Little et al., 2016).

Discourse on sustainability is a discourse on ethical considerations. However, intergenerational equity is based on a principle that future generations be able to meet their needs, which does not alleviate the ethics involved in the distribution of resources, the pattern of consumption, and environmental justice. This has prompted concerns about inequalities in both investment in and outcomes of sustainability efforts at a national and community level between wealthier nations and communities. There are also ethical dilemmas in resolving between the needs of existing populations and future generations particularly when the demands of the economy and society in the short term come into conflict with long term environmental goal (McGill University, 2013).

To conclude, sustainability is a multidimensional, ambiguous, measurement issue, relative to cultural variations, political dynamics, technology limitations and ethical considerations. These challenges highlight the importance of a synthetic and integrated approach to sustainability by being adaptable and context specific. Future that has combined environmental, economic and social successes has to be achieved through the sustained evolution of sustainability definitions and the production of standardised, reliable metrics.

2.1.5 Metrics and Indicators of Sustainability

Accurate and comprehensive metrics to measure sustainability practises are central to how you will implement sustainability. Metrics and indicators are quantitative and qualitative and draw a broad line under which there is no intention to focus too narrowly on just one dimension. Based on these metrics and indicators, a clear picture of progress to sustainability goals is envisioned. Only when these initiatives completely consider and include both ecological and financial factors together with social factors in a comprehensive sustainability framework are they successful. Measures of sustainability of various types of metrics and indicators are explored, their applications, and worldwide developed standards and frameworks for their use in this chapter.

Tangible aspects of sustainability have to be measured by quantitative metrics. This includes fixed, quantifiable data points of carbon emissions, energy consumption, water, and generation of waste. As an example, the carbon footprint is a well known, quantitative metric that provides a measure of total greenhouse gases emitted from an organisation or nation's direct and indirect activities and processes (Columbia University, 2021). On the other hand energy consumption metrics help to track how energy efficient the use of the energy is, including reductions by renewables and better use of energy saving practises (Little et al., 2016). Sustainability of the water resource is assessed mainly in the regions with scarcity of the water resource, and water usage indicators are important in this regard. They are consumption, sourcing and practises like water recycling and water conservation impacts.

Quantitative metrics are complemented by qualitative indicators like aspects of governance quality, community engagement and cultural strength, which are not easily measurable. For example, indicators related to the social sustainability might measure the degree to which the policy making process is inclusive, or the degree to which social services are accessible (McGill University, 2013). They indicate whether the qualitative aspects of the policy or evoked changes to processes could help to make sustainability outcomes better. Metrics of governance, although less amenable to quantification, provide insight into transparency, accountability of organisational and government practises, on which long term sustainability goals depend.

There are global standards and frameworks that have been developed to help us measure sustainability in an uniform and standard way. Two prominent examples for guidelines and standards of sustainability reporting and disclosure are the Global Reporting Initiative (GRI), the Sustainability Accounting Standards Board (SASB), and (KPMG, 2022). These frameworks assist the organisations in interpreting the sustainability nuances with specific clear indicators and measurement protocols that can be utilised easily by organisations across various industries and sectors. Moreover, common sustainability metrics similar to globally accepted accounting principles sought to be developed by The Earth Institute in its efforts toward the development of standardisation and comparability of sustainability practises (Little et al., 2016).

Environmental sustainability indicators seek to save ecosystems and limit environmental footprint associated to human activities. Some of the metrics that can be included are biodiversity indices which measure the health of ecosystems, and diverse of species within them, and air and water quality indicators, such as those that indicate levels of pollutants, and their impacts on human health and the environment (Little et al., 2016). It is also shown that renewable energy adoption rates and efficiency improvements are indicative of the de-carbonation of energy markets and the general greenness of energy systems.

Economic sustainability metrics extends beyond traditional economic measures such as GDP, Gross Domestic Product. This is a monetary measure of the market value of all the finished goods and services produced within the country's borders during some given time interval. Measures to be included are those which will account for environmental and social externalities. The Genuine Progress Indicator serves as an example of a type of alternative metric used to asses socio-economic progress by taking into consideration factors such as natural capital, the health, the level of education, as well as social equity (McGill University, 2013). These indicators emphasise the interdependence of the economic activities and sustainable practise, and seeks policies or practise that promotes long term sustainability rather than the short term economic gain.

Issues such as equity, inclusiveness and quality of life are the social sustainability indicators. In this area the key metrics are measures related to the reduction in poverty, access to education and healthcare, and community resilience. Social equity indicators provide possible answers to the disadvantages that could prevent some populations from reaching sustainable livelihoods (KPMG, 2022). For sustainability initiatives to be successful and accepted at large by society at large, it must be clear that all members of society are benefiting from sustainability endeavours.

Thus, in summary, metrics and indicators for sustainability development need to be developed and applied for assessments and the guidance of progress on sustainable development goals. Data on environmental, social and economic factors can be quantified, but data on governance, community engagement and cultural values which support sustainability are qualitative in nature. By the adherence of global standards and frameworks, sustainability reporting becomes consistent and comparable across organisations thus facilitating a common understanding of what sustainable practises are. Integration of these metrics into policies and practises helps organisations and governments to adopt informed decisions to bring forward sustainability goals and fosters long term viability.

2.1.6 Sustainability in Practice

It is more meaningful to use the works of theoretical constructs of sustainability in practise rather than only in theory. The principles of sustainability have been attempted to be translated into real actions by a number of entities, ranging from global organisations to local communities. Section 3 looks at how sustainability has been operationalised from the perspective of the Sustainable Development Goals, corporate sustainability, community based initiatives, government policies and the role of non-governmental organisations (NGOs). It also provides lessons from case studies of successful implementations that can be used as guidelines for future attempts.

One of the cornerstones of the global sustainability efforts is the United Nations' Sustainable Development Goals, which constitute a detailed framework of 17 goals aimed at addressing many challenges, such as poverty, hunger, education, gender equality, environment etc. An all-inclusive pattern blueprint for the realisation of sustainability on a national and global scale, these goals form a comprehensive comprehension of what sustainability means at the national and global extent. They have also galvenized nations to formulate and implement policies and strategy that concur with these ambitions, thus creating a spirit of fulfilling the affairs of sustainable development (Asian Development Bank, 2012).

Increasingly, the business strategies of leading companies include corporate sustainability practises. Organisations know that ethical reasons alone do not give sufficient reasons for adopting sustainable practises; that they are also important to long term profitability and competitive advantage. That the regulation requires that corporations comply with sustainability reporting standards like those as issued by the Global Reporting Initiative (GRI) and the Sustainability Accounting Standards Board (SASB) reflects the value of transparency and accountability within business operations. In industries from manufacturing to technology, companies have been focusing on minimising their carbon footprint, improving their resource efficiency and conducting a responsible sourcing. Corporate practises that align with the Earth Institute’s efforts to develop common sustainability metrics contribute to the further efforts of the Earth Institute to develop common sustainability metrics, giving a standardised basis for measuring and comparing the sustainability performance (Columbia University, 2021).

Community based sustainability initiatives are important to building a community based sustainable development. These initiatives tend to rely on the utilisation and nature of traditional ecological knowledge, local knowledge, and community engagement to tackle particular environmental and social challenges. Local conservation projects preserving biodiversity, urban gardening programmes promoting food security and community resiliency, as well as renewable energy cooperatives building energy independent and sustainable services are examples (Little et al., 2016).

The involvement of communities in these grassroots efforts shows how much power they have in making the sustainable practise changes that also create models for other contexts.

Policies of the government are indispensable to the progress of sustainability goals at the national and regional levels. Regulatory frameworks set up such as policies are effective in regulating the practises of many sectors in sustainable way. In the recent years, governments throughout the world have started to adopt a variety of policies focused on increasing renewable energy generation, increasing energy efficiency, reducing greenhouse gas emissions and preserving natural resources. Key policies as carbon pricing, subsidies for clean energy technologies, regulations on waste management and pollution control play a role in steering societies to sustainable behaviours. The collaborative nature of the international agreement, such as the Paris Agreement further confirms how critical government action is to attaining global sustainability objectives.

Non-governmental organisations play huge role in the sustainability landscape, working as spheres of environmental protection, social justice, and economic equity. At different levels of work, NGOs use to raise awareness, influence policy and implement projects in line with its objectives on sustainability. At the same time, they serve to empower communities and mobilise resources, all of which can be done in the areas of conservation, renewable energy and sustainable agriculture. By supplementing these efforts from governments and corporations, NGOs add the third and one of the most diverse stakeholder to the approach of sustainability.

Practicalities of sustainability are learned from case studies of implementations. For example, Sweden’s transition to a sustainable energy system based on large energy efficiency and renewable energy investment could provide a model to follow in other countries. In the same line, outdoor apparel company Patagonia is a good promoter of corporate sustainability because it has ecological responsibility ingrained in its top business focus and projects like using recycled materials and promoting environmental causes. Examples here show the importance of leadership, innovation and x collaboration for attainment of sustainable outcomes.

For sustainability principles to be applied in practise, it requires holistic and integrative approach that takes into account interdependency of all environmental, economic, and social factors. If effort is aligned across these dimensions and the work of governments, corporations, communities and NGOs is coalesced, then this is how the path to a sustainable future can be realised. Our take aways from successful roll outs stress the necessity of resilence, adaptabilty, and the strong concept of a more sustainable world.

2.1.7 Future Directions for Sustainability

It is of the utmost importance that as the world body grapples with the mammoth task of dealing with the issues of climate change, resource scarcity and social inequities, there are innovations to the concept of sustainability. The future trajectory of sustainable development hinges on the integration of advanced technologies, progressive policies, and comprehensive educational initiatives. This chapter takes a look at the emerging innovations, the role of technology, efforts in sustainability education and outreach, policy recommendations, global collaborative efforts; and a vision for a sustainable future.

It is about the innovations in sustainability that can change the way we deal with the environmental, social, and the economic challenges. The advancement in technology, including blockchain for transparent supply chain, artificial intelligence for resource allocation and nanotechnology for waste management are facilitating more efficient and effective sustainability practises. Green chemistry and green engineering have been evolving, and they are progressing to new ways to minimise the environmental foot prints. The areas of these disciplines are to design products and processes with as little hazardous substances as possible in the more sustainable industrial ecosystem.

Technology serves multiple purposes in pushing for sustainability efforts. It includes the development and deployment of renewable energy technologies like solar, wind, biomass, that are important in cutting greenhouse gas emissions. It helps in the integration of the renewable energy sources in better way, along with increasing efficiency and reliability of electricity distribution. Also, those in energy storage solutions, which include lithium ion batteries and developing hydrogen storage solutions, hold promise for balance supply and demand in renewable energy systems.

Furthermore, technology facilitates the monitoring and assessment of sustainability metrics. Remote sensing and geography information systems (GIS) hold up valuable data for following functional changes while big data analytics utilises intricate information sets to detect patterns and guide choice making. Development of integrated assessment models (IAMs) that combine economic, environmental and social variables helps policy makers evaluate impacts of different sustainability scenarios and develop informed strategies.

For increasing general public awareness and understanding of sustainability concepts, great efforts are made for educational and outreach activities. Sustainability education is made to be imparted in the educational curricula at all levels, the primary, secondary and the tertiary, so that the future generation is able to have the knowledge as well as the skills required to fight the challenges posed by sustainability. McGill University and other universities and research institutions are essential in advancing sustainability science and training the next generation of sustainability leaders.

Sustainability education is based on participatory approaches and community engagement. Activities that involve the local populations take part in conservation projects, sustainable farming programmes, and renewable energy installations not only add to the success of such projects but also promotes a feeling of interest and guardianship in progress. Other dissemination vehicles include public awareness campaigns, workshops, and seminars which afford individuals the means committed to adopting more sustainable lifestyles.

To achieve sustainability, policy recommendations must rest upon data based on scientific evidence that is robust and takes diverse perspectives into account. Comprehensive climate policies, including the introduction of carbon pricing mechanisms, subsidies for renewables, and stringent emissions standards, should be automatically given first priority by governments. Circular economy policies that inhibit waste generation through recycling, reusing materials and designing environmentally friendly products, are indispensable in minimising resource depletion and environmental degradation.

International agreements and frameworks along with national policies are also necessary for global cooperation in terms of sustainability. Collective action, as shown by the Paris Agreement, which aims to limit temperature rise to below 2 degrees Celsius, can certainly help remedy climate change. For global progress, it is crucial to strengthen such international partnership and to ensure that all nations, especially the ones the most vulnerable to climate impacts, have the resources andsupport to back the efforts taken towards sustainability.

Knowledge and capacity building efforts are also carried out on a global collaborative basis. The exchange of best practises, financial resources, and technical expertise between countries is facilitated by the Global Green Growth Institute (GGGI) and the Green Climate Fund (GCF). These partnerships allow developing nations to skip the environmentally destructive technologies and practises and jump straight to sustainable technologies and practises, assuring equal spread of sustainability returns throughout the world.

To achieve an envisioned sustainable future, it would be imperative that environmental conservation, social equity, and economic viability be tackled in a holistic and inclusive way. Cities provide clean energy, Zero waste societies, and resilient communities that are able to adapt to environmental changes included in this vision. This also includes businesses which promote sustainability in their operational processes, governments that implement and enforce progressive policies, and individuals who choose to cut down on their ecological footprints.

This sustainable future however is not easy to get to, but is a challenge full of opportunity. Through innovation, the use of technology, generated education, and stimulation of global partnership, we can guide the world towards a more sustainable and resilient pathway. Transforming the vision of sustainability to reality through thriving planet for the next generation, all stakeholders will contribute towards it.

The historical origins are first introduced, and the development of the central concepts examined as the relationships of the environmental, the economic and the social begin to unravel in an intricate weave. The enduring theme across foundational insights of the Brundtland Report, to contemporary interpretations of sustainability, is the requirement for a balanced approach that is in the well being of present as well as future generation. Through synthesis, we summarised the key findings of the study and advanced on the process of navigating the perpetual path towards a sustainable future.

The history of sustainability unveils that it features the practise of ecological stability and conservation of resources by the ancient civilizations. However, it has only been sensed that environmental degradation and the borders of unlimited industrial growth are being formalised over time. The introduction of sustainable development as a process to meet the needs of current generations without compromising the ability of future generations to meet their own needs has shaped the global policies and attitude. This vision has therefore been based on the fact that preservation of the environment and the socioeconomic development must go hand in hand.

There have been many advancements to early definitions and the proponents of sustainability and an evolution in what sustainability means. There are many dimensions of sustainability that were integrated which now includes social justice, economic viability, and environmental health. The United Nations Sustainable Development Goals (SDGs) have given a blueprint to how all these dimensions have to be achieved in concrete and measurable terms, encompassing them in a comprehensive framework of sustainable development. There is wide spread commitment to these goals through the engagement of diverse stakeholders from governments and corporations as well as communities and NGOs.

We cannot underestimate complexities and challenges related to the definition of sustainability. There are many problems in definitions, measurement, cultural, political, technological constraints, and ethical issues. The challenges in addressing these issues call for a nuanced and context sensitive approach that takes into consideration the differing perspectives and mobility needs of different communities and sectors. Organisations cultivate accountability and effectiveness in helping them reach their sustainability goals by standardising and transparent measuring of sustainability such as what is developed in the Earth Institute.

We must consider all the three pillars of sustainability—environmental, economic and social—with the united theory. Environmental sustainability touts the preservation of ecosystems and the rational use of natural resources while economic sustainability curbs for equitable growth and overall sustainability that is not restricted to established standard such as GDP. The third pillar of social sustainability revolves around equity, inclusiveness, and life quality. The case studies show synergies and trade-offs of these pillars and highlight the fact that sustainable strategies are needed that integrate the different aspects of sustainability (Little et al., 2016).

The practical application of sustainability principles is evident through various initiatives and policies. Corporate sustainability practices exemplify the integration of sustainability into business operations, enhancing long-term profitability and reducing environmental impacts. Community-based sustainability initiatives harness local knowledge and engagement to address specific challenges. Government policies provide regulatory frameworks that promote sustainable practices across sectors. Non-governmental organisations advocate for environmental protection and social justice, complementing governmental and corporate efforts (KMPG, 2022). Success stories from around the world demonstrate the transformative potential of collaborative and innovative approaches to sustainability.

2.2 The Environnemental Crisis and its Impact

Today, environmental degradation is a pressing issue in the contemporary world addressing a range of aspects of society and its natural environment. This chapter delves into the multifaceted impacts of the environmental crisis, with a primary focus on four key areas: climate change, biodiversity loss, resource depletion, and the human cost of environmental degradation. It synthesises different scholarly sources with the purpose to offer a holistic vision of the crisis, its causes and any possible solutions that would mitigate the crisis' negative effects. In the next part, the paper discusses climate change, including its causes, consequences and evidences of scientific. However, the importance of the study of climate change cannot be overemphasised because it is responsible for the severe consequences on the global weather pattern, sea level rise, and increase in natural disasters. Sources covered by this paper include empirical research of greenhouse gas (GHG) emissions, climate models, and historical climate data from ice cores and other geological records. Taken together, these sources illustrate that modern climate change is anthropogenic, and specifically illustrates the stalemate between fossil fuel combustion, deforestation and industrial activity as key contributors. However, the research on mitigation strategy shows the importance of renewing energy sources and improving the efficiency of the energy usage, as well as the policies should be introduced for reduction of greenhouse gas emissions. The chapter continues by exploring biodiversity loss after the previous study of the issue of climate change. The maintenance of ecosystem stability, food security to mankind, along with countless other ecosystem services that humans depend on, all depend on biodiversity. Next, the reviewed literature, consisting of case studies of endangered species, conservation efforts and the economic and social costs of biodiversity loss are discussed.

They show that species are dying fast, especially driven away by destruction of habitat, pollution and overexploitation. Still, the analysis of conservation strategies, including (protected areas, wildlife corridors and biodiversity friendly agriculture) provides clues to what can potentially be done to safeguard the planet’s biological richness. The next chapter of the paper deals with resource depletion: specifically, in the case of water, minerals, and fossil fuels. The review of literature outlines the unsustainable practise of resource depletion which include intensive agriculture, mining, and fossil fuel extraction. Not only do these practises deplete natural resources, but they also do severe environmental degradation, such as soil erosion, water pollution, and habitat destruction. Resource depletion carries long realised far reaching consequences for food security, economic stability and social conditions. The research also investigates sustainable management solutions, preferably water conservation techniques, sustainable mining practises and a switch from the use of conventional energy sources to renewable ones and the other measures aimed at curbing resource depletion. The last part of the chapter discusses the cost of environmental degradation for people, the effects on people's health, livelihoods and social equity. Studies of the air and water pollution, the social impact of environmental injustice and the climate risk to health are among the sources reviewed. Environmental degradation disproportionately impacts poor and marginalised communities and leads to increased vulnerability of diseases, displacement, and economic hardship. It is on this idea of environmental justice that this inequities are conceptualised as a critical framework to address them, advocating for fair treatment and meaningful involvement of all communities in environmental decision making. It also analyses how policy responses and solutions like climate resilience planning, pollution control measures and social protection programmes can reduce, but not eliminate, the cost of the human toll from environmental degradation. During this research several question are asked: How have human activity impacted the environmental crisis? What are the main threats to biodiversity and what are some effective conservation efforts possible to address these threats? What are the effects of resource depletion on the entire global community and what are some sustainable practises that can be employed to address this issue? Last, how is environmental degradation related to human health and social equity, and what is a policy measure that can mitigate against the least vulnerable populations? This research paper in essence gives a full environmental crisis analysis through research of scientific data, case study, and the policy evaluation to have a complex but clear cut understanding on how the human activities relate with the environmental health. This is not just to bring out the gravity of the crisis but also to underscore the requirement for collective world action to secure the environment for future generations.

2.2.1 Climate Change

Climate change is a major concern for the global population, covering numerous environmental, socioeconomic and social aspects (Lee, 2023). The discussion of climate change within this research paper encompasses its causes, consequences, scientific evidence, and potential mitigation strategies. This section relies on what has been investigated across the various scholarly sources and seeks to explain and make explicit the fact that climate change is multifaceted and needs urgent action against the same. Ultimately the causes of climate change lie in very basic facts that arise from the burning of fossil fuels, deforestation, and many more industrial processes. A large part of these activities has resulted in concentrations of greenhouse gases in the atmosphere, especially carbon dioxide ($CO2$), methane ($CH4$) and nitrous oxide ($N2O$), being markedly higher. It is estimated that 57% of total emissions are from combustion of coal, oil and natural gas for energy and transportation (Martines 2023).

However, the problem is further made worse by deforestation for agricultural expansion that reduces the planet's carbon sinks as forests are such significant carbon sinks. Additionally, industrial processes and agricultural practices contribute to the release of methane and nitrous oxide, potent greenhouse gases with a much higher warming potential than $CO2$ on a per molecule basis (Martines, 2023). The consequences of climate change are far-reaching and multifaceted, impacting weather patterns, sea levels, ecosystems, and human societies. Rising global temperatures have led to the alteration of precipitation patterns, resulting in more frequent and severe droughts, floods, and storms.

These changes in weather patterns adversely affect agricultural productivity, water resources, and food security (Brown, 2023). Sea level rise, driven by the thermal expansion of seawater and the melting of polar ice caps, threatens coastal communities with increased flooding, saltwater intrusion, and erosion. The resulting displacement of populations and loss of infrastructure have significant socio-economic repercussions (Doe, 2023). Additionally, climate change disrupts ecosystems and biodiversity by altering habitats and species distributions. The interconnectedness of these impacts creates a cascading effect, wherein changes in one aspect of the environment trigger further changes in others, compounding the overall challenge (Johnson, 2023).

Robust and extensive is the scientific evidence in existence and the anthropogenic origin of climate change. This historical data collected from ice cores indicates that current concentrations of atmospheric CO2 have never been higher in at least the past 650,000 years and are totally human caused (Williams, 2023). Climate models that simulate the climate system of Earth with physical principles and empirical data always predict even more warming as the greenhouse gas emissions continue. Historical climate data are used to validate these models which are found to be reliable in forecasting future climate scenarios (Williams, 2023). As to the second question, the rising global temperatures, the declining ice cover, and shifting weather patterns are corroborating the scientific consensus about the fact that predominantly human activities drive contemporary climate change (Johnson, 2023).

The involvement of mitigation strategies can enable environmental sustainability by curtailing climate change while implementing across multiple sectors of economy and diversified scales. Transitioning to renewable energy sources, such as solar, wind, and hydropower, is a critical component of reducing greenhouse gas emissions. Enhancing energy efficiency in buildings, transportation, and industrial processes also plays a significant role in reducing overall energy demand and associated emissions (Doe, 2023). Reforestation and afforestation efforts can augment carbon sequestration, while sustainable agricultural practices can reduce methane and nitrous oxide emissions.

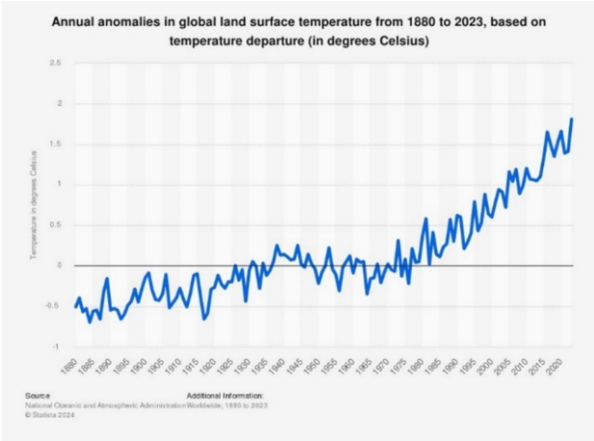


Figure 7 Annual anomalies in global land surface (Ritchie and Rose, 2020)

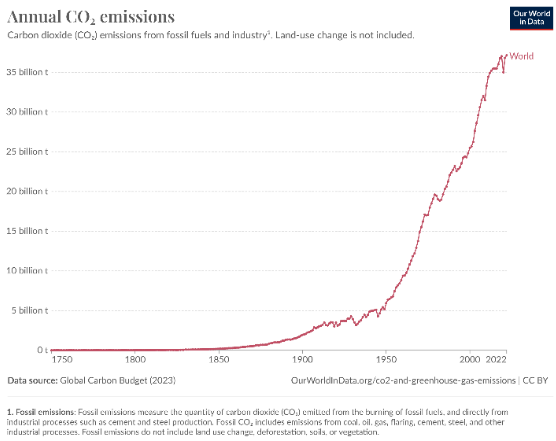


Figure 8 evolution of Carbon Dioxide emissions 1750-2022 (Ritchie, 2021)

The light drop in 2021 could be due to the limited human activity due to Covid 19. Furthermore, policies that promote carbon pricing, subsidies for clean energy technologies, and regulations on emissions are essential for driving systemic changes towards a low-carbon economy (Martines, 2023). Therefore, it is determined that climate change is driven by human activities through increment in greenhouse gas emission and concentration along with severe consequences associated with weather patterns, ecosystems, sea levels, and human societies. Robust scientific evidence underscores the need for urgent and coordinated action to mitigate its impacts. By implementing comprehensive mitigation strategies across various sectors, it is possible to curb greenhouse gas emissions and foster a more sustainable and resilient future for all.

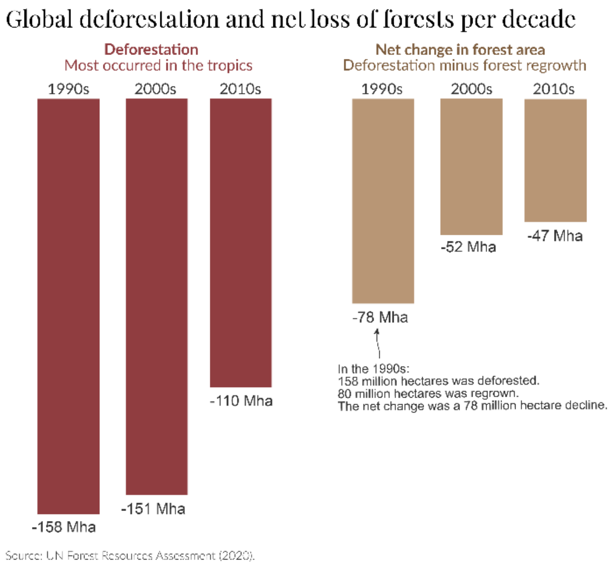


Figure 9 Global Deforestation and Net Loss of Forest (Ritchie, 2021)

2.2.2 Biodiversity Loss

Biodiversity binds Earth's life together; moreover, it is also defined as the variety of life on Earth. But among the many other services it provides, it plays an essential role in providing food security, water purification, disease regulation, climate stabilisation, and so on for human life. Thus, loss of biodiversity is of great importance not only in terms of the natural world, but in terms of human society as well. The importance of biodiversity, the sort which it is facing, the efforts that are being made to conserve it, and the case studies on work that is currently in progress is explored in this chapter. Biodiversity has to be important. Resilient and able to resist environmental stressor such as climate change, pollution and habitat destruction, there are more diverse ecosystems. Biodiversity helps the productivity of ecosystems serve their purposes, which include pollinating crops, development of soil fertility, and purification of water. Without it, such services are fundamental to human survival and well-being. For example, various plant species are necessary to farmers for agricultural production, as they provide the soil health, pest control and nutrient cycling. Also, species genetic diversity is important to resilience to environmental change, so that species can persist in the long term (Thomas, 2021).

Nevertheless, biodiversity is facing serious threat from various human activities including that is identified as habitat destruction which is caused by agricultural expansion, urbanisation and infrastructure development. Deforestation for agriculture destroys vast tracts of tropical forests, home to many of the world's species. For example, the Amazon rainforest, often referred to as the 'lungs of the Earth,' has witnessed substantial deforestation to make way for cattle ranching and soybean cultivation (Thomas, 2021). Pollution, including chemical runoff from agriculture, industrial waste, and plastic pollution, further degrades ecosystems and harms wildlife. The introduction of invasive species disrupts local ecosystems, often outcompeting native species and leading to their decline or extinction. Climate change exacerbates these threats by altering habitats and forcing species to migrate to new areas, often beyond their adaptive capacity. Coral reefs, which are highly sensitive to temperature changes, are experiencing widespread bleaching events due to rising sea temperatures. The Arctic region is also undergoing rapid changes, with melting ice affecting species such as polar bears, which rely on sea ice for hunting (Doe, 2023). Furthermore, it is depicted that overexploitation of resources through hunting, fishing and agricultural land expansion has readily increased change in climate. Furthermore, pet trades and hunting practices has led to adaptability of the wildlife towards migration which disturbs the availability of biodiversity in a region. The loss of biodiversity can be prevented through the inclusion of ecological integrity enabled by all the stakeholders and governance. The former strategies include establishing protected areas, such as the national parks and wildlife reserves, that are sanctuaries for the endangered species. They are important areas in conserving habitats, and giving safe spaces for different species to live. Migration of species to a stable environment can allow the resilience of biodiversity while providing effectiveness of the species and habitats that maintains the level of biodiversity and also enhance through genetic exchanges. Conservation projects based in the community have also demonstrated some promise in creating sustainable practices and better outcomes for biodiversity (Thomas, 2021).

There is another important approach in restoration ecology towards restoring degraded ecosystems to have its ecosystems working well again. Important parts include reforestation and afforestation projects which aid in carbon sequestration, promoting healthy soils and also give a home for wildlife. Sustainable agricultural practice and afforestation along with controlled usage of inorganic material in farming can readily allow the biodiversity to maintain itself in the region. The captive breeding and species reintroduction programs seek to support endangered species' populations and reintroduce them into the wild. Furthermore, it is proven through several cases that sustainable practices and change management within the region in accordance to sustainable practices can readily allow biodiversity to maintain efficiently. The reintroduction of grey wolf population to Yellowstone National Park is an example of positive effect of restoring keystone species. The ecosystem benefits of being away from the wolves include reduction of prey populations and restoration of riparian habitats. It is also evident in the decline of the monarch butterfly in North America for the conservation of migratory species. Pesticide use and, coupled with habitat loss along the line of their migratory route have drastically decreased their population, prompting conservationists to restore milkweed habitats and control exposure to pesticides (Thomas, 2021).

In conclusion, biodiversity loss poses a significant threat to the stability and functionality of ecosystems and the services they provide. The importance of biodiversity is evident in its contributions to ecosystem resilience, productivity, and human well-being. However, numerous threats, including habitat destruction, pollution, climate change, and overexploitation, continue to endanger various species. Conservation efforts, including protected areas, restoration ecology, and sustainable practices, are essential for preserving the planet's biodiversity. Case studies demonstrate both the successes and challenges in this field, underscoring the need for continued and enhanced conservation initiatives to ensure the survival of the world’s diverse species.

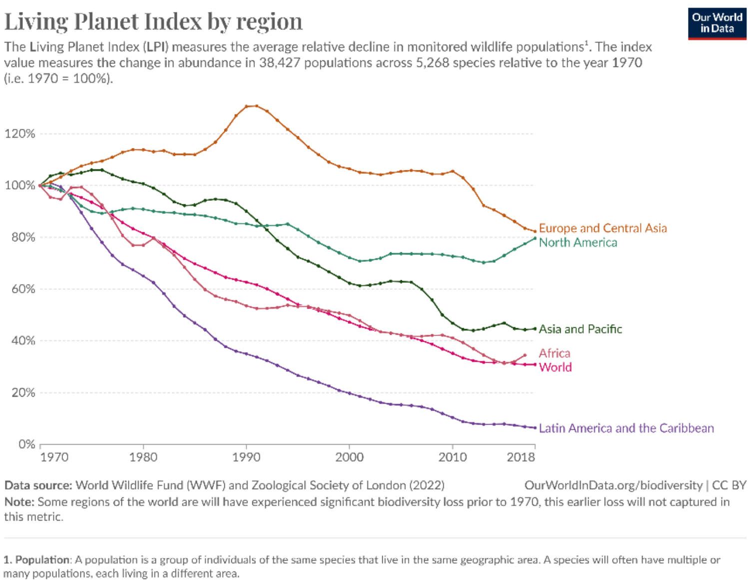


Figure 10 The average relative in monitored wildlife population (Ritchie et al., 2021)

2.2.3 Resource Depletion

Resource depletion is found to be a prevalent challenge for persistent economic growth which occurs due to extra dependence on finite resources and non-renewable sources of energy. Therefore, this chapter focused on the involvement of finite resources such as water, minerals, and fossil fuels, while examining the possible alternatives and impact of the usage of such resources that has readily instigated economic threshold to deplete. Water, minerals, and fossil fuels, as finite resources have increased dependency for sustainability of human lives. Due to essential nature of water in sustainable living, it is an increased concern among humanity to conserve and save water efficiently. Furthermore, the overuse of resources further challenges the sustainability of human lives through climatic change as well that disrupts hydrological cycles and alters precipitation patterns. Thus, it contributes to water scarcity in several regions of the world where access to clean water is found to be a priviledge (Johnson, 2021).

The mining of minerals necessary for modern technology, including rare earth elements, also leads to habitat destruction and soil erosion. The overexploitation of these mineral resources raises concerns about their long-term availability and the environmental impacts associated with their extraction. Fossil fuels, which have powered industrialisation and economic growth, are another crucial finite resource facing depletion. The relentless pursuit of oil, coal, and natural gas has led to significant ecological disturbances, including greenhouse gas emissions that drive climate change. Fossil fuel extraction often involves environmentally destructive practices such as mountaintop removal, deep-sea drilling, and fracking, which further degrade land and water resources (Martines, 2023). The interconnected nature of these resource challenges necessitates a comprehensive understanding of their status, trends, and impacts. Contemporary economic and social systems are simultaneously supportive of the unsustainable approaches and overexploitation that is leading to resource depletion. High-yield, cheap in price crops that requires intensive agricultural practices also contribute highly in water and soil depletion. The practice of monoculture farming, intensive irrigation and use of chemical inputs degrades soil health and the water resource, making them unsustainable in the long term (Johnson, 2021). Industrial operations, especially in mining and energetic processes, address short terms gains at the expense of the environment. The unregulated exploitation is exacerbated, while resources are begun to be exploited without any economic incentives to conservation. Resource depletion can have far reaching consequences of variety from the cause of ecosystems to economies and even social structures. The water scarcity therefore affects agricultural productivity, which in turn renders the people food insecure and economically unstable.

Industrial development and the economy's conversion to renewable energy sources depend on the process of depletion of minerals necessary for their technology and for infrastructure. Under the pressure of fossil fuel depletion, countries have to search for alternative energy sources, sometimes at a large environmental expense. Moreover, extraction of resources is an environmental bad that results in biodiversity loss, soil erosion, water pollution, and so forth, thus complicating the problems of ecological sustainability (Doe, 2023). Effective sustainable management solutions are required to ensure that no resource is depleted and to prevent eco system imbalance in the longer term. Strategies towards water conservation, like utilizing techniques of rainwater harvesting, efficient irrigation systems, and wastewater recycling, can mitigate water resource stress. Such practices must be combined with policies that control water use and encourage the use of water efficient technology. In the mining sector, it is important to promote sustainability in mining such as reducing land disturbance, mitigating pollution and mining site rehabilitation to mitigate environmental impacts (Johnson, 2023). With the transition to renewable energy such as solar, wind and hydropower, it is necessary to cut back on reliance of fossil fuel and avoid its negative environmental impact. The investment in renewable energy can readily ensure sustainability of desired level in diversified economies that leads to inclusion of sustainability for biodiversity by reducing the requirement of mining for energy conversions. Furthermore, adoption of circular economy principles that includes environmental cost of business can also ensure that the non-renewable resources usage is comprehensively marginalised (Thomas, 2021).

The inclusion of techniques including agroforestry, organic farming, and regenerative agriculture are designated techniques for preservation of biodiversity and soil health as well. They offer a sustainable method for agriculture that are readily ignored in the modernised agricultural practices. Furthermore, education awareness programs of such agriculture based regions readily enables the stakeholders to realise the importance of sustainable farming techniques for longevity of their respective lands and maintaining organic practices as well (Johnson, 2023). Therefore, resource depletion is readily considered as a concern in sustainable farming practices while ensuring that overexploitation of resources is constructively mitigated while ensuring that the finite resources as water, minerals, and fossil fuels are effectively conserved to marginalise the environmental cost of business. The consequences expand across environmental, economic, and social dimensions, that enables the requirement of rapid action in agricultural industry, like any other industry.

Fossil fuels, primarily coal, oil, and natural gas, have enabled desired level of economic productivity while enhancing trade as well. However, the environmental cost is significantly high which undermines their contribution towards sustainability of the products.

- **Depletion:** The reserve of fossil fuel and other forms of non-renewable energy are finite including gas, crude oil etc. According to BP's Statistical Review of World Energy, the current oil reserves of the world are depicted to last only five decades with the existing consumption level across commercial and industrial markets (BP, 2022). Meanwhile, the report also explored that coal and natural gas also have finite reserves; however, the estimates vary in accordance to the available data for reserves.

- **Environmental Impact:** Fossil fuels are consumed using combustion practices that enables the release of greenhouse gases which are vital in environmental degradation and air pollution to contribute towards climate change. Furthermore, this includes carbon dioxide (Erwin, 2008; NOAA, 2023; Pörtner et al., 2022).

2.2.3.1 The Looming Water Crisis: A Precious Resource Under Pressure

Despite the essential need for water, population growth, climate change and unsustainable water management practices are at the point of overwhelming this vital resource. As per the World Economic Forum (2023), the global water demand is likely to be up to 40% higher than supply by 2030. A major factor in this rising demand is the fact that urbanisation and industrial activity are increasing. The water scarcity is caused by changes in precipitation patterns, rising temperatures and spectacular increases in the melting of glaciers. Water availability for agriculture, for human consumption, is becoming more frequent and more severe. Freshwater sources are contaminated by industrial waste, agricultural runoff, and improper wastewater disposal and are hence unfit for consumption or irrigation.

2.2.3.2 Essential Minerals: The Invisible Backbone of Modern Life

A number of minerals are vital components of modern life and include copper, lithium, cobalt and rare earth elements. The electronic market is significantly dependent on infrastructure and provision of renewable resources for desired level of sustainability. Yet, obtaining and harnessing them remains questionable as far as sustainability of extraction and processing go. Lithium and rare earth elements, too, can only exist in certain, limited geographic locations (Serpell et al., 2021). Their intensive use, coupled with a lack of readily available substitutes, can lead to potential shortages and geopolitical tensions over resource control. Mining for minerals can have a significant environmental impact, including deforestation, soil erosion, and water pollution. Improper disposal of mining waste further exacerbates the problem (Ritchie and Rosado, 2022).

2.2.3.3 Consequences of Resource Scarcity: A Cascade of Challenges

The loss of fossil fuels, water, and essential minerals will have far-reaching consequences across various sectors:

- **Energy Security:** Over-reliance on depleting fossil fuels creates energy insecurity, potentially leading to price volatility and disruptions in essential services.

- **Economic Disruption:** Water scarcity can disrupt agricultural production, food security, and industrial processes. Additionally, a lack of critical minerals can hinder technological advancements and economic growth.
- **Social Conflict:** Competition for scarce resources can lead to political instability, social unrest, and migration as communities grapple with water shortages and economic hardship.

2.2.3.4 Navigating the Challenge: Strategies for a Sustainable Future

The potential loss of these critical resources necessitates a paradigm shift towards responsible resource management and development of alternative solutions. Here are some key strategies:

- **Energy Transition:** Developing renewable energy sources like solar, wind, geothermal, and hydropower is crucial to reduce dependence on fossil fuels and mitigate climate change impacts.
- **Water Conservation:** Promoting water conservation practices in agriculture, industry, and households can significantly reduce demand. Additionally, investing in efficient water treatment and distribution systems can minimise waste.
- **Circular Economy:** Adopting a circular economy approach that prioritises recycling and resource recovery can minimise the need for virgin resource extraction and reduce environmental impact.
- **Technological Advancements:** Investing in research and development of new technologies for resource extraction, substitution, and reuse can help address future scarcity challenges.
- **International Cooperation:** Global cooperation is essential for effective resource management. Sharing knowledge, developing international regulations, and promoting fair trade practices for critical minerals are crucial to addressing these shared challenges.

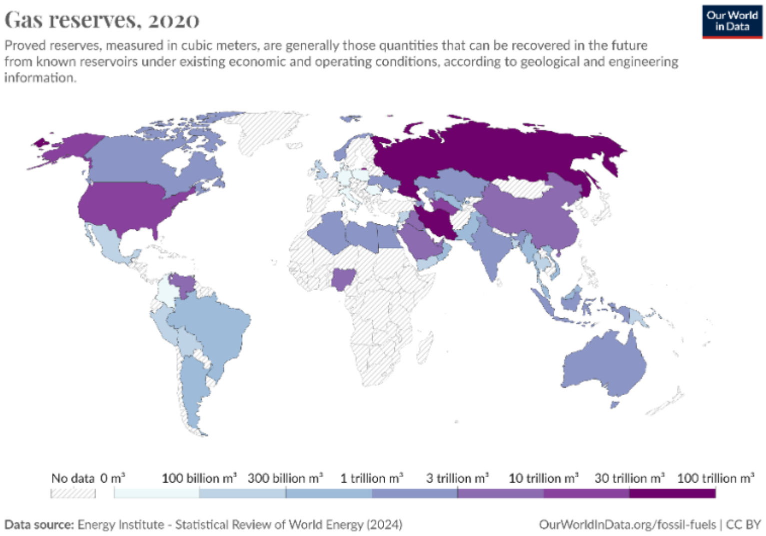


Figure 11 Gas reserves in the world in 2020 (Ritche and Roser, 2024)

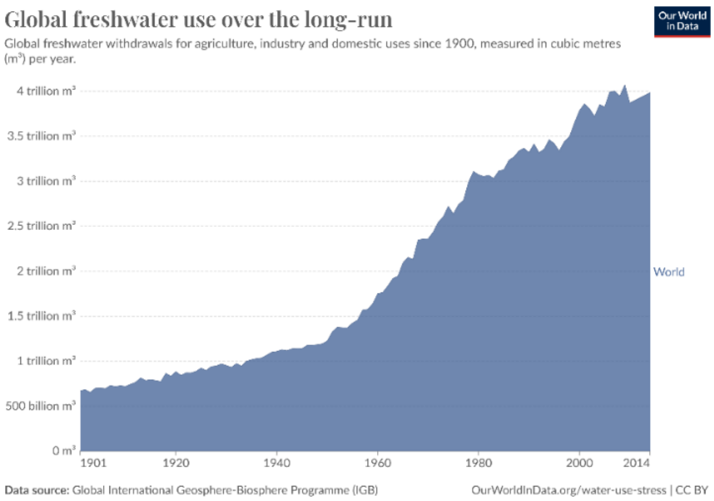


Figure 12 Global freshwater use (Ritche and Roser, 2024)

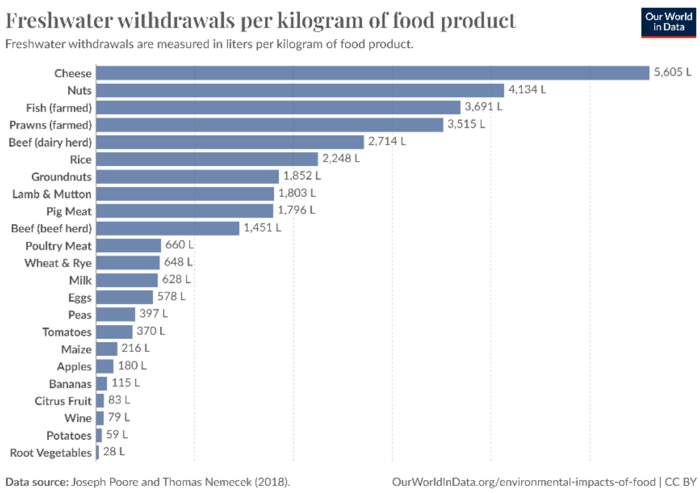


Figure 13 Freshwater withdrawals per kilogram of food product (Ritchie and Roser, 2024)

While the study observes rising global drinking water consumption, agriculture is actually the biggest culprit when it comes to freshwater use. Around 70% of all freshwater withdrawals are for agriculture, primarily irrigation. This high consumption is even more concerning as the planet warms. With climate change, we'll likely see more erratic weather patterns, including droughts, which could stress freshwater resources.

2.2.4 The human cost of environmental degradation

The human cost of environmental degradation extends far beyond ecological impacts, influencing health, livelihoods, and social equity. This chapter examines the multifaceted health impacts, considers the effects on livelihoods, discusses issues of social equity, and evaluates policy responses and solutions to mitigate these adverse consequences. Environmental degradation exerts significant health impacts on populations worldwide. Air pollution, resulting from fossil fuel combustion, industrial emissions, and vehicular exhaust, contributes to a rise in respiratory and cardiovascular diseases. Chronic exposure to pollutants such as particulate matter (PM2.5), nitrogen dioxide (NO2), and Sulphur dioxide (SO2) is linked to increased morbidity and mortality rates (Miller, 2006). Climate change exacerbates these health risks by inducing extreme weather events such as heatwaves, which elevate the incidence of heat-related illnesses and deaths (Vodonos and Schwartz, 2021).

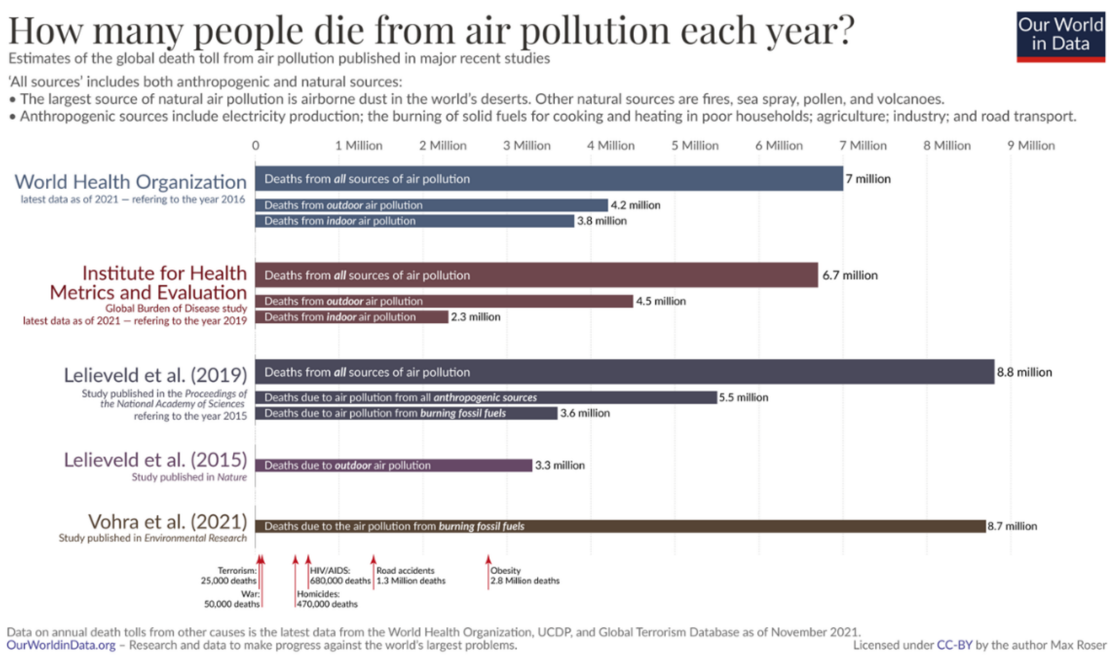


Figure 14 How many people die from air pollution each year (Roser, 2021)

Additionally, changes in temperature and precipitation patterns influence the spread of vector-borne diseases, such as malaria and dengue fever, by altering the habitats of disease carriers like mosquitoes (Brown, 2023). Water pollution, another manifestation of environmental degradation, leads to widespread waterborne diseases and disrupts access to clean drinking water. Industrial discharge, agricultural runoff, and improper waste disposal contaminate water sources with harmful chemicals and pathogens. Populations dependent on these water bodies for drinking, bathing, and irrigation face heightened health risks, including gastrointestinal infections and skin diseases. Moreover, the scarcity of potable water, driven by overextraction and climate-induced droughts, compromises public health, particularly in low-income areas with limited infrastructure (Johnson, 2023). Environmental degradation also impacts livelihoods, particularly for communities that rely on natural resources for their sustenance. Subsistence farmers, pastoralists, and fishers are among those most vulnerable to the degradation of ecosystems. Soil degradation and desertification, often resulting from unsustainable agricultural practices, reduce land productivity and crop yields, threatening food security and livelihoods (Doe, 2023). Coastal and freshwater ecosystems suffering from pollution and overfishing negatively affect the fishing communities, leading to diminished fish stocks and loss of income. Indigenous communities, whose cultural practices and diets are intricately linked to specific ecosystems, experience severe disruptions when their natural environments are degraded (Thomas, 2021). Not only do these livelihood challenges increase due to climate change that changes growing seasons, increases the frequency of extreme weather events and causes sea level rise, but it also makes sea level rise and inundates coastal agricultural lands as well as impacts availability of arable land. All in all, it is so cumulative that it drives migration, it increases the level of poverty, it exacerbates economic instability. Environmental degradation is a context in which social equity issues pose prominently on account of the fact that vulnerable and marginalised groups bear the worst of it. Among other groups, low income communities that live near industrial areas are highly exposed to environmental pollution and more likely to incur health related complications. Most of these populations have the financial means, political clout, and access to healthcare not available for the mitigation and adaptation to environmental risks. Thus, social inequalities will be exacerbated by environmental degradation, further entrenching inequality, and environmental injustice (Williams, 2023). These impacts are most concerning to the children and elderly populations. Given their developing respiratory and immune systems, children are more susceptible to pollutants, while the elderly are at risk from extreme weather events and worsening air and water quality due to pre-existing health condition and reduced adaptive capacity (Brown, 2023). Direct exposure to environmental hazards occurs in outdoor workers, for example in agriculture and construction, and raises the occupational health risks as well as productivity reduction. Expanding environmental degradation and poor human cost require policy responses and solutions to improve the social equity.

Environmental regulations and standards that can withstand public scrutiny, however, can be a mechanism to cut pollution at least as much as any other regulatory mechanisms. In order to tackle the greenhouse emission, industrial emissions reducing is top priority of the policymaking authorities, which should also support the clean energy alternatives and improve air and water quality monitoring systems (Johnson, 2023). Additionally, climate resilience planning, including the development of infrastructure to withstand extreme weather events and community-based disaster risk reduction programs, can enhance the adaptive capacity of vulnerable populations. Environmental justice frameworks are pivotal in ensuring equitable policy responses. These frameworks advocate for the fair treatment and meaningful involvement of all people, regardless of race, ethnicity, or income, in environmental governance. Programs focused on environmental health literacy, community engagement, and participatory decision-making can empower marginalised communities to advocate for their rights and partake in shaping policies that directly affect them (Williams, 2023). Investments in public health infrastructure, such as climate-resilient healthcare facilities and early warning systems for climate-sensitive diseases, are crucial for protecting health in the face of climate change. Ecosystem-based approaches to adaptation, such as restoring wetlands and mangroves, can provide natural buffers against environmental hazards while supporting livelihoods and biodiversity conservation. In conclusion, the human cost of environmental degradation is extensive, impacting health, livelihoods, and social equity.

The importance of environmental justice framework is in ensuring the proper policy responses. The latter frameworks promote equity in active participation of all persons (irrespective of their race, ethnicity or income) in environmental governance. Program that seeks to improve environmental health literacy, community engagement and participatory decision making can strengthen the capacity of marginalized communities to engage with policies that impact them directly (Williams, 2023). For protecting health in the face of climate change, it is important to invest public health infrastructure including for climate resilient healthcare facilities, early warning systems against climate sensitive diseases. Restoring wetlands and mangroves are also ecosystem based approaches to adaptation that will also provide natural buffers against environmental hazards which supports livelihoods and other biodiversity conservation. Ironically, in conclusion, the human cost of environmental degradation is also immense, antecedent in terms of the health, livelihoods, and social equity.

The analysis of climate change highlights the critical role of anthropogenic activities, such as fossil fuel combustion and deforestation, in driving global warming. The consequences of climate change are profound, affecting weather patterns, sea levels, ecosystems, and human health. Empirical evidence, supported by climate models and historical data, underscores the need for immediate mitigation strategies to reduce greenhouse gas emissions and transition to renewable energy sources (Williams, 2023; Martines, 2023). The adoption of sustainable practices and policies is essential to curb the adverse impacts of climate change and promote resilience in both natural and human systems (Doe, 2023). Biodiversity loss, driven by habitat destruction, pollution, and climate change, poses a significant threat to the stability and functionality of ecosystems. Biodiverse ecosystems are vital for providing essential services, such as food security, water purification, and climate regulation, that underpin human well-being. Conservation efforts, including protected areas, wildlife corridors, and sustainable agricultural practices, are crucial for preserving biodiversity and ensuring the survival of various species (Thomas, 2021).

Success of such efforts is shown with case studies but such efforts are still far from complete conservation of biodiversity. Resource depletion, particularly of water, minerals, and fossil fuels, results from overexploitation and unsustainable practices. Resource depletion has environmental, economic, and social effects that all have consequences across environmental, food security, economic stability and ecosystem health (Johnson, 2023). Water conservation, sustainable mining practices, renewable energy transition are some of the solutions that can help in management of the dwindling resources and nurture a sustainable ecological balance. Furthermore, it is determined that environmental degradation is determined as human cost for public health, livelihood and social equity. However, it is essential that the decision making of the stakeholders is identified effectively in pursuit to understand the variation of environmental harm through practices that contributes to controlled biodiversity and resistance in sustainability. Industrial and agricultural activities increase air and water pollution driven by these risks to health including climate change (Miller, 2006). Equity is essential to mitigating these impacts and must be Lesson guided by environmental justice principles, in responding to them. A good strategy to fill the gap in reducing the immaterial loss due to environmental degradation is investments in public health infrastructure, robust environmental regulations, as well as the community engagement (Brown, 2023). Finally, there is a need for immediate and coordinated response to address the multiplicity or dimensions of environmental crisis.

Therefore, an understanding of the complex interplay between human activities and environmental health can be beneficial for the sustainability of environment that improves dimensions for decision making.

2.3 The Rise of Green Technology

2.3.1 Reliance on Technology

The relentless march of technological progress has carved an indelible mark on the trajectory of human civilisation. From the dawn of the Industrial Revolution to the digital renaissance of the modern era, each epoch has witnessed ground-breaking innovations that have reshaped the fabric of society, redefining our relationship with the world around us. As we stand at the precipice of the Fourth Industrial Revolution, commonly known as Industry 5.0, it is imperative to explore the profound impact technology has had on human development, resource consumption, and our quest for environmental sustainability (Schwab, 2024).

This chapter delves into the historical advancements and exponential growth of technology, scrutinising its multifaceted influence on various aspects of human life. Drawing from a comprehensive array of scholarly sources, encompassing seminal works on sustainable supply chain management, green technologies, and the intersection of technology with environmental stewardship, this study aims to provide a holistic understanding of our reliance on technology across multiple dimensions.

Through an in-depth exploration of key technological milestones, from the early innovations of the late 19th and early 21st centuries to the advent of modern computing and the internet, this paper unravels the intricate tapestry of technological evolution and its profound impact on human development and quality of life. The inclusion of transformative power of technologies including AI, robotics, and internet of things (IoT) enables sectors of economies to optimise including healthcare, education and other workplace dynamics while influencing the social interaction of employees effectively as well.

The chapter further explored the link between technological advancements and resource consumption that enables optimisation of operations while linking towards environmental impact to increase the dependence on technology. It examines the challenges posed by e-waste and the pressing need for effective recycling strategies, while also exploring the potential of technological solutions to mitigate environmental degradation and pave the way for sustainable development.

Drawing upon a diverse array of scholarly sources, this chapter navigates the intricate landscape of policies and ethical considerations that must guide responsible technological development. It emphasises the urgent need for a harmonious balance between progress and environmental stewardship, underscoring the imperative of adopting a holistic approach that integrates technological innovation with ecological consciousness.
Ultimately, it aims to provide a comprehensive understanding of our reliance on technology, illuminating its multifaceted impacts while offering insights into the path forward – a future where human ingenuity and environmental preservation coalesce, forging a sustainable and prosperous trajectory for generations to come.

2.3.2 Historical Advancements in Technology

Human civilisation has taken a series of technological breakthroughs that have forever altered the course of humanity. This chapter delves into the historical advancements that paved the way for our modern, technology-driven world, illuminating the pivotal innovations that catalysed unprecedented progress and altered the course of human development.
Human History was witnessing the dawn of the Industrial Revolution in the late 18th century. Societies have been propelled into new era of mass manufacturing and economic growth by advent of mechanisation and harnessing of steam power (Srivathsa et al., 2023). The development of urban centers is not all it brought, this revolution signaled a split with progress, redefining it, not to mention heralding a new human condition.
With the passage of time, the 19th century brought about a flock of technological revolutions that appeared on the transportation and communication scene. Its development of the electric light was only one of the many ways in which electricity pushed out the bounds of the workday and reshaped human activity patterns. At the same time, the telephone reduced geographic barriers to pull communication from distant places into immediate contact (Peel et al., 2017). The automobile was a real leap in individual mobility, for it created entirely new patterns of personal autonomy and entirely new patterns of labor and industry by changing the face of urban planning and infrastructure.
Crucially, these technological leaps brought human history to the point where the pace of human society advanced greatly, leading to a world that experienced globalisation, economic growth and mass cultural exchange in this world, where this effect still continues today. It was the early modern society that time and space were compressed and goods, people and ideas moved across borders; transportation and communication were the sine qua non of early

modern society (Fisher et al., 2024). It was at the beginning of the 20th century that the digital age began when personal computers, the internet and mobile devices were introduced. Human behaviour and our interactions would never be the same as we embarked into this era of seismic shift of boundaries and ushering in a new era of access and information exchange. The arrival of this high of this transformative era is marked by the onset of Industry 5.0 technologies wherein computers are incorporated in autonomous decision making processes to optimize logistics and deliver high levels of operational efficiency.

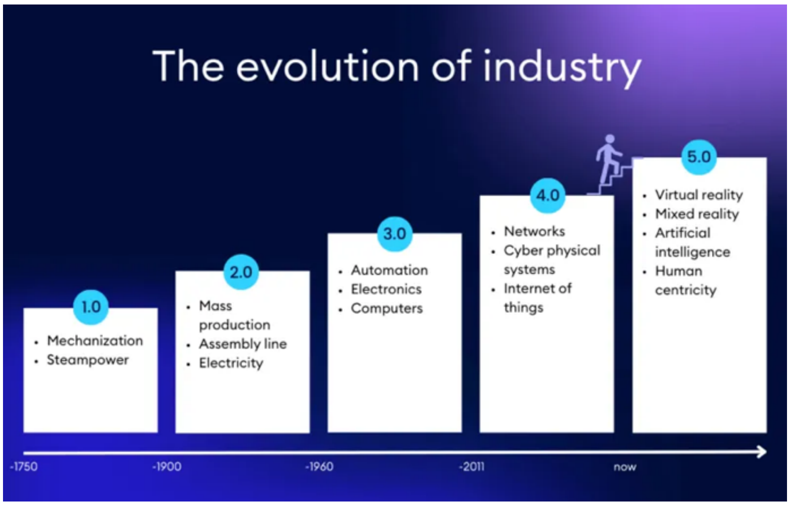


Figure 15 The Evolution of Industry (SER Solutions, 2020)

The 21st century has witnessed an unprecedented acceleration of technological progress, reshaping societies, economies, and cultures globally.

This digital revolution is characterised by exponential growth in computing power, connectivity, and data generation, leading to breakthroughs in various fields (Brynjolfsson and McAfee, 2014). One of the most visible impacts has been in communication. The advent of smartphones, coupled with the proliferation of high-speed internet, has transformed how people connect. Social media platforms, such as Facebook, Instagram, and Twitter, have facilitated unprecedented levels of social interaction and information sharing. The rise of messaging apps like WhatsApp and WeChat has redefined personal communication, while video conferencing tools like Soom and Teams have revolutionised remote work and collaboration (Davenport and Patil, 2013).

The internet itself has evolved from a static web of information to a dynamic platform for commerce, entertainment, and education. Online shopping has become mainstream, with e-commerce giants like Amazon dominating the retail landscape. Streaming services like Netflix and Spotify have disrupted traditional media industries, offering on-demand content to a global audience. Massive Open Online Courses (MOOCs) have democratised access to higher education, enabling millions to learn from top universities worldwide (Schmarso, 2016).

While these revolutionary innovations introduced unparalleled advancements, they simultaneously laid the groundwork for the complex environmental challenges that we confront today. The reliance on fossil fuels, industrial waste, and large-scale production methodologies created enduring ecological disturbances, prompting initiatives to reconcile industrial growth with environmental preservation (Srivathsa et al., 2023). As we stand on the precipice of a new epoch, the imperative to harmonise sustainability and advancement has never been more pressing, shaping the trajectory of technological development for generations to come.

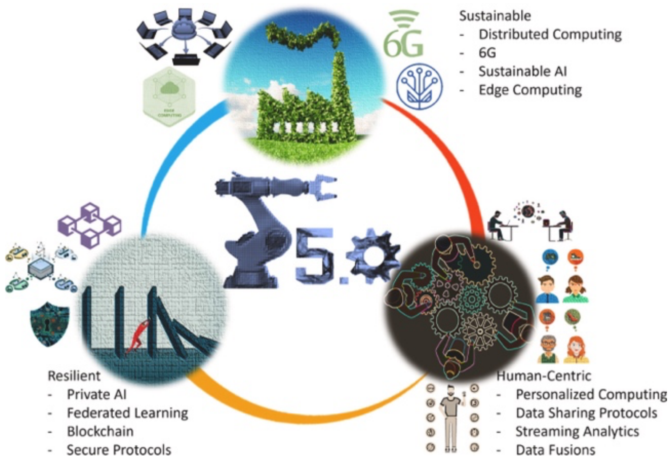


Figure 16 Axe et domaine de la 5.0 (Zeb et al., 2023)

2.3.2.1 Exponential Growth of Technology

The pace of technological progress has been nothing short of exponential, propelling us into an era of unprecedented innovation and transformation. This chapter delves into the driving forces behind this rapid growth, unveiling the profound implications it holds for our society, economy, and the very fabric of human existence.

2.3.2.2 Moore's Law and the Pace of Technological Change

One of the most influential predictions shaping the trajectory of modern technology is Moore's Law, named after Intel co-founder Gordon Moore (Moore and Malone, 2015). This law posits that the number of transistors on a microchip doubles approximately every two years, while the cost of computers is halved. This self-fulfilling prophecy has driven the relentless pursuit of miniaturisation and enhanced performance in electronic components, catalysing a cycle of innovation that has reshaped virtually every aspect of our lives (Fisher et al., 2023).

In response to this constant evolution in the technology landscape in part thanks to Moore's Law the product life cycles have become ever shorter and consumer demand ever more voracious for the latest and greatest devices. It is also an unerring symptom of an upgrade cycle that is literally relentless and painful to the environment, by adding to the proliferation of electronic waste and resource depletion. Following the COVID 19 pandemic recovery efforts, governments and industries have responded by advocating green stimulus packages and accelerating capacity in green production especially (Srivathsa et al., 2023).

2.3.2.3 Emergence of Artificial Intelligence and Robotics

Advancement in AI and robotics instigated a positive trend in innovation, reshaping industries, automating processes, and augmenting human capabilities. The adoption of these technologies and their integration with the world of Industry 4.0 has been instrumental in agitating both the resource efficiency and environmental damage brought about by the human hand. AI and robotics become essential tools in environmental sustainability as it enhances natural resources utilization, reduces waste production and prolongs the equipment lifespan (Peel et al., 2017).

2.3.2.4 The Internet of Things (IoT) and Connectivity

Internet of Things (IoT) has been a game changer in mass connectivity of the systems, devices and networks seamlessly around the world. This interconnectedness has contributed to excessive levels of efficiency and data exchange, thereby revolutionising the operation of industrial apparatus, facilitating correct and efficient supply chain direction and the observation of the environment. The expansion of the IoT has induced the transformation of an economy to a green economy and a responsible, resource resource management; the initiatives of Green Internet of Things (GIoT) surround the energy efficient services and the embracing renewable energies (Fisher et al., 2023).

2.3.2.5 Impacts and Implications of Rapid Technological Growth

The exponential growth of technology has great impacts, which transpire far beyond the scope of technology and economic prosperity. For certain, it has changed the way humans behave, disrupted of communication patterns, and passed so drastically that the fabric of social interaction has undergone a dramatic shift. Things like job replacement, skill gaps, and the dissolution of human connections (Srivathsa et al., 2023) are things that come with the new technology. Furthermore, the fast changing technology obliges us to constantly rethink a method of our environmental impact and resource management. The IoT or AI may be the answer for sustainability, but their scalability and diffusion carry the big hurdle to be overcome through an intense stakeholder involvement of different sectors. The time is now to allow participation in this new era of exponential growth while conserving, and in some cases protecting, the wellbeing of our planet by fostering collaboration to reduce investment risks and equitable distribution of green technologies (Peel et al., 2017).

2.3.3 Impact of Technology on Human Development and Quality of Life

Every single aspect of human life has been profoundly influenced by technological advancements, which have changed the way we live completely beyond our imagination. This chapter examines the general impact of technology on human development and quality of life and how the power of technology is felt through innovation in so many fields of activity.

2.3.3.1 Healthcare and Biotechnology Innovations

Technological breakthroughs have revolutionized the realm of healthcare and transformed this field in ways that grant this industry a new kind of medical innovation and better patient outcomes. The implementation of the biotechnology advances like the genetic engineering and the advent of the biopharmaceutical creates a revolution in disease diagnosis, treatment, and prevention. Or, modern medical imaging and surgical procedures are performed with minimal need for surgery (Srivathsa et al., 2023). Additionally, the use of technology in healthcare supply chain management has helped to sustain the practices, and ensure the efficient delivery of life saving hospitals and tool with reduced environmental impact. Technological innovations have strengthened the health of the One Health, that is the interconnectedness of human, animal and environmental health (Fisher et al., 2017).

2.3.3.2 Workplace Transformations and Remote Work

Technology has so changed the way we do work, the way it is done and how our workday spent turns out to be because of time spent at work doing the new technology. The pandemic created another consequence, and that is that remote work is accelerating and we are witnessing the rise of the remote paradigm, redifining the office, which means that the employees actually have more flexility and more autonomy in managing their work AND their personal life. By doing so, this shift not only shrinks work and home commute time, it sparks resource consumption pattern and environmental impact redescription (Fisher et al., 2017).

The marginalisation of energy consumption, organisations have readily aligned themselves with a policy to control carbon emission that enables the principles of circular economy. Furthermore, the involvement of changing work dynamics including work from home marginalises the power and energy requirements of a business that assists them in marginalisation of carbon emission as well (Peel et al., 2017). Meanwhile, Covid-19 forcefully integrated the strategies associated with social interaction occurring online and reducing the requirement of conventional working dynamics that required significant carbon emission including carbon from the transport sector to energy consumption in office as well that required significant assistance from non-renewable resources. Furthermore, due to lockdowns and physical distancing forces, individuals were able to integrate alternative measures such as digital platforms for communication, rather than physical interaction that saves and conserves the environmental cost of businesses.

Prior to the pandemic, there were clear trends towards remote work, online shopping, and digital socialisation. However, these trends were accelerated exponentially as people were compelled to adapt to a world confined largely to their homes. This abrupt shift resulted in a heightened reliance on technology for fulfilling essential needs and maintaining social connections.

Consequently, the pandemic has contributed to a more isolated existence for many. While digital platforms offer unprecedented connectivity, they also foster a sense of detachment from physical reality.

2.3.3.3 Education and Information Accessibility

Technology has made education and information democratised, bridging gap and divides of geography and socioeconomic. MOOC and digital library have opened up a lot of educational resources that people of different backgrounds could not reach before and nowhere are these better represented than online platforms like YouTube. The Fourth Industrial Revolution has brought forward other remote learning opportunities that further widen educational horizons and make knowledge acquisition and skill development (Peel et al., 2017). However, the digital divide continues to exist due to economic disparities that enhances inequality with the educational environment while trying to adapt to equality in the framework. In less ambiguous terms, the divide between policymakers and practitioners should be closed with technological progress and socioeconomic barriers to inclusive growth for all demographics and geography (Srivathsa et al., 2023).

2.3.3.4 Social Interactions and Communication

The introduction of digital and mobile communication technologies, simultaneously facilitating better connectivity but also means that social interactions will change, and critical social skills will atrophy all with the traditional relationship losing its strength. The spatial and temporal barriers, so to speak, of digital platforms have dissolved, allowing people to stay connected across miles and time, yet paradoxically, there has been a sense of isolation for some who now invest into lives in digital worlds, especially when the dynamism of person to person interactions get lost in translation from the digital world (Srivathsa et al., 2023). At the same time, the integration of the Internet of Things (IoT) in personal and professional lives has completed a drafting of new communication patterns, with remote control and monitoring a common thing. As society comes to grips with how remote digital interactions are beneficial, but fundamental human need for tangible social connections (Fisher et al., 2023), the need to balance the remarkable benefaction of remote digital interactions from the necessity of socially real interactions takes center stage.

2.3.3.5 Technology, Resource Consumption, and Environmental Impact

With each passing year, the march of technology continues forward; furthermore, it is being increasingly understood that the interaction with technology facilitates an inherent relationship to resource consumption and environmental sustainability. Therefore, the chapter also delves into the intricate interplay between technological advancements, energy consumption, waste management, and the pursuit of a sustainable future.

2.3.3.6 Energy Consumption and Renewable Alternatives

Simultaneous with exponential growth of technology has been the accelerating need for energy, which has put enormous pressure on the exploitation of limited natural resources and advancement of greenhouse gas emissions. This rising energy consumption (Srivathsa et al., 2023) has arisen due to an increase in data centres, an increase in the prevalence of energy intensive computing processes, and an ever growing appetite for electronic devices. Renewable energy has found its way through technological innovations. Solar panels development, wind turbines and hydroelectric systems development offer clean sources of alternative energy, thus reducing the environmental impact of energy production. Additionally, the viability and scalability of renewable energy sources (including battery systems, hydrogen fuel cells) has been improved by advancement in energy storage technologies. (Fisher et al., 2023).

2.3.3.7 E-Waste and Recycling Challenges

The crisis of electronic waste (e-waste) has arisen from rapid pace of technological obsolescence and an insatiable demand from society for the latest devices. Electronic goods with hazardous materials like lead, mercury and cadmium are only next to human health and the environment. As a global problem of effective e waste management and recycling, several efforts are needed including governments, industries, and consumers (Peel et al., 2017). With these facts in mind, potential strategies include extended producer responsibility frameworks, which require manufacturers to proceed a manufacturer responsibility for the end of life phase of the materials they produce. Moreover, technological advancement in recycling process is found to be crucial in management of e-waste in the context of utilisation of obsolete technologies that can readily undermine the inclusion of e-waste in the economy while sufficiently adhering to the principles of circular economy (Srivathsa et al., 2023).

2.3.3.8 Technological Solutions for Environmental Sustainability

Despite the fact that technology is exacerbating environmental challenges, it could also play a key role to create technology enabled solutions to promote sustainability. Real time monitoring and optimisation for resource consumption made possible by the advent of the Internet of Things (IoT) and smart devices has been helpful in performing more efficient energy management and lessening the waste (Fisher et al., 2023). In addition, advances are also made in areas such as precision agriculture, sustainable manufacturing, and green building technology to reduce further development of ecological footprint and meet the needs of the world's population continuing to grow. Besides, the technology of carbon capture and storage (CCS) and direct air capture (DAC) provide attractive approaches to counteract the effects of climate change by removing greenhouse gases from the environment. With these innovations combined with their attempt to transition their industries towards a sustainable economy and adopt sustainability practices, a better, future may be achieved where the world is more environmentally responsible (Peel et al., 2017).

2.3.3.9 Politics and Ethical Considerations for Responsible Technological Development

With technological developments reshaping the world around us, it is fundamental to deal with ethical and legal issues of technology development and deployment. Robust frameworks that encourage responsible innovation should be created by policymakers that must prioritize environmental integrity, and sustainable practices (Srivathsa et al., 2023). Included is the formulation of incentives for the adoption of clean technologies, and promotion of research and development of sustainable industries and stringent waste management and resource efficiency standards. And ethical issues in areas like privacy, security of data, and displacement of labour are to be carefully dealt with so that the technological progress approximates social value and the overall good (Fisher et al., 2023).

2.3.4 ***Green technologies: a beacon of hope?***

Clean technology, or green technology, or sustainable technology, is a very wide range of new technology geared towards saving the planet from not only human interaction, but from human interaction itself. These technologies are depicted to contribute towards reduction of pollution, conserving natural resources, and minimising waste. Moreover, they are essentially focused on seeking to balance economic growth with ecological sustainability (Sovacool, 2009).

At the core of green technology is the concept of efficiency. By optimising energy and resource utilisation, these technologies aim to reduce consumption and minimise environmental footprints. Renewable energy sources, such as solar, wind, and hydropower, are quintessential examples of green technologies. They harness natural forces to generate electricity without producing harmful emissions (Jacobson and Delucchi, 2009).

Furthermore, green technologies extend beyond energy production. They encompass advancements in transportation, agriculture, waste management, and building design. Electric vehicles, for instance, reduce greenhouse gas emissions compared to traditional gasoline-powered cars. Precision agriculture employs data-driven techniques to optimise crop yields while minimising environmental impact (Jacobson and Delucchi, 2009). And sustainable building practices incorporate energy-efficient designs and materials to reduce carbon footprints.

The roots of green technology can be traced back to the early awareness of environmental challenges. The Industrial Revolution, while driving economic progress, also brought about significant pollution and resource depletion. This realisation sparked initial efforts to develop technologies that could mitigate these negative impacts. The 1960s and 1970s marked a turning point with the emergence of environmental consciousness. Public opinion about such events as the publication of Rachel Carson's 'Silent Spring' and the first Earth Day in 1970 were largely changed and governments were called out to practice environmental regulations. Jacobson, and Delucchi (2009) credit these early efforts for the eventual development of green technologies.

It was during the oil crisis of the 1970s that the search for alternative energy sources was accelerated. Countries lengthened their quest for reducing dependence on fossil fuels by advancing solar and wind power technologies during this period. However, these early technologies were quite inefficient and very expensive and their widespread use was thus limited. The gradual improvements in the green technology during the subsequent decades were also due to a combination of factors. The growing concern about the environment and rising energy cost gave rise to a large market for sustainable solutions. Stimulating innovation and investment also played an important role through the government policies, subsidies and tax incentives. In the late 20th and early 21st centuries, solid development of green technology was realized. Breakthroughs in various fields were made due to the advancement in materials science, electronics and computer modelling. For example, solar panels became much more efficient, therefore solar energy was more viable. Applications with longer range and improved battery efficiency became commercially available for electric vehicles.

Furthermore, the increasing awareness of climate change has increased the focus of the attention of green technologies. The reports of Intergovernmental Panel on Climate Change (IPCC) have served as very strong evidence of the human induced climate change which has led to global efforts on reducing greenhouse gas emissions. Such an impetus has been created for the development and deployment of clean energy solutions (IPCC, 2019). Early, experimental green technologies have become an important element of the worldwide transition to a future sustainable tomorrow. Much work is left to be done, but it is encouraging that progress has occurred in the last few decades. More research, development and another round of investment are crucial to hasten the adoption of green technologies and in cutting climate change’s wicked effects.

In the last two decades, the notion of green technologies has risen with the confluence of several drivers such as increased awareness of the environment, technological enhancement and most importantly, the need to steer towards a sustainable future. The first part of this chapter examines how green technologies have developed historically, the performance related drivers which have accelerated their adoptions, and the multitude of environmental, economic viability and social well being benefits which they provide. Green technologies have deep roots in the historical activities of early call for protecting the environment in the 20th century from the earlier impacts of industrialization and lethargic exploit of natural capital. Nevertheless, these technologies did not begin to gain momentum till the latter half of the century when a convergence of scientific advances, policy actions and societal sensitivity to tiredness associated with environmental protection (Adoption of green finance and green innovation towards circularity: An exploratory review and directions for the future).

When the consequences of climate change and resource depletion started to be apparent, many key drivers emerged in order to develop and adopt green technology. Some of these are; the increasing importance of meeting sustainability objectives as well as environmental regulations, disseminating the reason of industries and consumers as well to adopt more environmentally friendly alternatives. Secondly, the climbing prices of the conventional energy sources and the realisation of potential economic rewards over a longer period of time push for green technologies (Rasoulineshad and Taghisadeh_Hesary, 2022). This transition is based on the possibility of green technologies to achieve extensive environmental benefits. However, the technologies provides a potential means to reduce greenhouse gas emissions and marginalise the impact of conventional energy while prioritising renewable resources, such as solar energy, wind energy, and hydroelectric power.

Additionally, a harnessing of energy-efficient practices and adoptive use of sustainable materials in various sectors such as manufacturing and construction have the ability to reduce continuing resource consumption and waste generation to a great extent, at the same time giving pressure off the planet’s scarce resources (Li et al., 2023). Green technologies offer not only environmental advantage but also excellent economic opportunities. The problem of resource scarcity and environmental degradation is forcing the global economy to face the consequences, and the development and implementation of sustainable solutions could be the means by which economic growth and job creation, as well as long term cost savings, will be possible. By embracing green technologies, governments and industries can create a position for themselves as leaders in the emerging green economy by gaining access to new revenue streams, increased market share and competitiveness (Kumar et al., 2023).

In addition, the green technology has social impact. An emphasis on the developing of resilient and sustainable communities can aid in the improvements of quality of life, public health and equitable distribution of resources through the use of these technologies. Finally, as the economy transitions into a trend of a green economy, there is the likelihood that such a change would lead to the creation of new employment opportunities in sectors such as renewable energy, sustainable infrastructure and green product development (Krevor et al., 2023). In this regard, the emergence of the green technologies is being seen as a ray of hope to address the steep challenges of climate change and resource depletion with the hope of a future that is less risky and sustainable.

2.3.5 ***Types of Green Technologies***

2.3.5.1 Renewable Energy: Powering a Sustainable Future

Green technologies are empowered with the idea that their usage does not impact the existing reserves of minerals and fossils that are determined to be finite for energy conversion. Therefore, green technologies and renewable sources include solar energy, captured through photovoltaic cells and concentrated solar power plants, offering a clean and inexhaustible energy source. Furthermore, wind power harnessed by towering turbines particularly in regions blessed with consistent wind patterns (Krevor et al., 2023). Moreover, hydropower, geothermal energy, and bioenergy derived from organic matter marginalise the reliance on fossil fuels and other finite resources for energy conversion as well that leads to sustainability (Rasoulineshad and Taghisadeh-Hesary, 2022). Meanwhile, the preceding study also stated that the involvement of renewable energy sources marginalises carbon emission contributing to a sustainable future with marginalised environmental cost of operations.

2.3.5.2 Energy Efficiency: Optimising Resource Utilisation

The inclusion of expansion of renewable energy sources is backed by its marginalised carbon emission and lack of impact on existing sustainability of the environment while incorporating efficiency measures to conserve the existing finite resources in the world. Furthermore, incorporating energy efficient solutions such as insulation in building allows the temperature maintenance without involvement of energy consumption for heating or cooling the internal capacity. Meanwhile, in the industrial capacity, it is noticed that the involvement of waste reduction and energy optimisation practices allows marginalised usage of energy leading to controlled carbon emission and environmental cost of businesses (Rasoulineshad and Taghisadeh-Hesary, 2022).

2.3.5.3 Sustainable Materials and Circular Economy

The green future is empowered through circular economy where the environmental cost of operation is sufficiently integrated in businesses (Li et al., 2023). Eco-friendly materials such as bioplastics, recycled composites, and sustainably sourced timber provide alternative to the existing energy sources resulting in increased efficiency while adhering to the modernised market conditions. Waste minimisation through resource recovery, and closed-loop systems, is crucial for sustainable industrial practices while empowering the necessities for adherence of principles of circular economy.

2.3.5.4 Green Transportation: Driving Towards a Low-Carbon Future

Transformational changes are taking place in the sector of transportation towards its sustainability, due to the innovations of green transportation technology. The advancement is primarily powered by EVs, and its use in diversified type of vehiclesthat powered by rechargeable batteries or fuel cells–which cut tailpipe emissions and break dependence on fossil fuels. Furthermore, hybrid electric vehicles, that is, electric motors combined to internal combustion engines, is better for fuel mileage. In addition, the lightweight material, aerodynamical design, intelligent transportation system have been advanced to promote the sustainability of the transportation sector.

2.3.5.5 Waste Management: Transforming Waste into Resources

Waste is the primary contributor of negativities associated with environmental degradation where prevalent techniques such as burning of waste through incinerators and other techniques contribute to extensive carbon emission and results in depletion of ozone layer as well. Furthermore, waste sorting techniques including the likes of effective management of waste and controlling the environmental cost results in increased efficiency in managing carbon emission for a particular business (Kumar et al., 2023). Moreover, inclusion of waste-to-energy systems and the development of biodegradable materials enables effective management of energy resources that enables extensive capacity to manage environmental requirements and ability to address business requirements as well.

2.3.5.6 Water Conservation: Preserving a Vital Resource

Currently, water is being used in industrial processes as well as a vital resource for livelihood of human life. However, water scarcity has increased the concerns associated with quality of life and enables extensive challenge for the prevalent practices in agricultural sector. Therefore, effective management of the resource is found to be vital for the development of sustainability to conserve water while extensively advocating for resources that are finite as well (Krevor et al., 2023). Furthermore, inclusion of power through renewable energy can enable desired level of sustainability while optimising resource utilisation, embracing circular economy, and adopting green transportation, waste management, and water conservation practices, we can pave the way for a harmonious coexistence between human progress and environmental preservation (Li et al., 2023).

2.3.6 ***Case Studies and Critical Evaluation***

As the adoption of green technologies continues to gain momentum across diverse sectors and geographic regions, it is essential to examine real-world implementations and critically evaluate their impact, challenges, and limitations. This chapter presents a curated selection of case studies that showcase successful green technology initiatives, shedding light on their practical applications, contributions, and the lessons learned through their deployment.

Among the examples of such large integration of renewable energy technologies goes to tech big guns such as Google or Apple. Such corporations have invested greatly in solar and wind power systems, thereby reducing their dependence on nonrenewable sources and showing economic viability of such transitions (Adoption of green finance and green innovation for achieving circularity: An exploratory review and future directions). These industry giants have indeed taken a great stride to help set the precedent for others by showing that it is possible to combine environmental stewardship with business objectives through adopting sustainable practices and using energy efficient technologies to adopt. The second case study that stands out is from the agricultural sector where the use of digital monitoring and smart farming technology has completely changed the way environmental practices for management are been done.

These technologies have been put to large scale implementation of which they have enabled optimisation of resource usage especially water and increased yields without compromising the integrity of the land (Kumar et al., 2023). The integration of technological advancements with ecological conservation efforts refutes the former and unquestionably shows the possibility of sustainable development in agricultural sector. Additionally, the use of green finance mechanisms, including green bonds have acted as a channel for the investments into environmentally sustainable projects. While some of those pruning have been challenging and have led to misuse of the financial instruments, rigorous monitoring regimes and standard practices of voluntary certification have, so far, allowed the financial instruments to effectively support the implementation of net-zero emissions and clean energy solutions consistent with the principles of sustainable development (Rasoulineshad and Taghisadeh-Hesary, 2022). It is worth to recognize the IKEA case of commitment to the principles of sustainable supply chain management and circular economy. Through prioritising sustainable sources for raw materials and incorporating circularity into its business model, the company has shirked its environmental foot print and relaxed the business risks and the supply chain uncertainties. Such an exemplary approach serves as testimony of the symbiotic relationship between the environment and economic competitiveness.

Despite this, scaling up production and implementation continues to be a tremendous barrier, and includes financial barriers, logistical barriers, and a comprehensive regulatory framework (Krevor et al., 2023). In addition, the possibility of green technologies to entirely phase out conventional systems in the timeframe and on scale frames not still envisaged by them. Thus, they contend that the pace of development and deployment may fall short of the urgency of climate crisis, as limitations of production capacity, workforce readiness, and resource availability are major ones (Adoption of green finance and green innovation for achieving circularity: An exploratory review and future directions). Currently, the world is facing multiple challenges caused by environmental degradation as well as depletion of natural resources, and a path to sustainable future needs a good and critical assessment of green technology. The case studies teach the modernised business environment with the importance of consideration of ecological environment and environmental needs as well. We are in this technical dark room, trying to find lights that will lead us out. This room is not just full of technical solutions but also green technologies, which are the lights we are searching for. Towards the end of this chapter we have discussed emergence, benefits, variety, and instantiation of green technologies both the hype and downsides to the adoption and utility of such technologies.

All of these have converged to make green technologies both developed and proliferated; a concerted effort to fight climate change, protect the environment and drive a circular economy has come about. Although not an exact replica, this list of technologies is much larger than the preceding name. Some technologies related to these topics include increased energy from renewable energy sources and energy efficiency innovations, green transportation technologies, waste management solutions, sustainable materials and processes to name a few. Undeniably, there are potential benefits from green technologies, but such technologies will only reach the scale and real promise of widespread use and widespread efficacy if formidable barriers to their use are overcome.

To overcome financial constraints, regulatory uncertainties, logistical complexities and to address the complexity of aligning economic incentives with ecological imperatives, it calls for strategic interventions and cooperation from the ministry involved, neighbouring states, stakeholders from different sectors and among different regions. In this chapter we have presented the case studies that exemplified how green technologies have transformed the globe, and how that transformation has been successfully realised in real world situations and how valuable lessons have been learned. These are just some of the examples that demonstrate how the industry giants see to adopt green technologies to enable positive change through embracing renewable energy, green finance mechanisms and innovative agricultural initiatives. Nevertheless, such critical evaluation of the problems and limitations in scaling up production and implementation, ensuring workforce readiness and resolving interplay among economic rationale and environmental requirements is necessary. The ways in which green technologies are today able to replace conventional systems is the point of the debate of their capacity to replace them on comprehensive basis within the given timeframes and ranges of implementation.

Despite this, the pressing urgent to address the problems of climate change, resource depletion and environmental degradation keeps getting more imperative as the day passes by. And this is a crucial step toward this journey of the adoption of green technologies, which are a perfect blend of technological innovation, economic feasibility and ecological responsibility. This is possible through an environment geared towards research, development, and investment of green technologies, and through supporting conducive policy that allows for the development of supporting policy and encouraging cross sectoral collaboration. A holistic and holistic approach based on scientific insights, economic prudence and environmental concerns, can pave the way to a sustainable and resilient future that human progress can coexist with the balance of ecosystems of the planet.

2.4 The Role of Governments and Regulations

The observation that governments and regulations should be prompt via sustainable orientation has come to center stage in the growing debate in the world industry as the world grapples with the pressing challenges of climate change and environmental degradation. In this research paper the interplay among existing environmental regulations, policy frameworks, international cooperation with the government incentives affecting a greener and more sustainable future are discussed in detail. Using a thorough analysis and cross comparing of academic and empirical research findings and studies to examine the effectiveness of current environmental regulations from both an international and national level. It seeks to identify the weaknesses and deficiencies that must be eliminated in order to come to a more robust ecological sustainability. The research also explores the barriers face by green technology and what has to be included in policy frameworks to tackle them.

In addition, the paper provides an historical account of this process of international environmental cooperation, explaining the importance that global organisations and multilateral agreements play in furthering the goals of sustainability. It attempts to examine with which grounds of international cooperation of divergent socio-economic conditions and priorities the cooperation can reach the point of substantive cooperation, and after identifying the dilemma, it proposes the strategies to better collaboration among nations. Also, the study presents the essential position of government incentives and subsidies in allowing a transition to clean energy and environmental technology adoption. Based on the economic effect of different types of financial instruments (tax credits, grants and subsidies) on increasing sustainable practices in different sectors, it provides an analysis. The research uses economic analyses and case studies to inform about the best design and implementation of incentive mechanisms that will strike an optimal balance between the economic viability and environmental benefits.

2.4.1 Existing Environmental Regulations and Their Effectiveness

Environmental regulations represent a crucial role in the reduction of the degradation of ecology and the enhancement of the practices of sustainability. Yet the success of their effectiveness hinges on many things, including the degree to which their design is complete, the degree to which they have been carefully implemented and how the underlying socio economic dynamics of the nations or regions on which they are applied. For instance, at the international level binding commitments to take action against climate change were first made at Paris Agreement (2015) and then Glasgow Climate Pact (UNFCCC, 2021). These agreements no doubt have helped bring awareness and usher in policy changes, but their effectiveness surely falls quite far back when confronted by misapplication and differences in enforcement and compliance from stapling nations. For example though their official aims are ecological sustainability, G7 countries continue to put money into fossil fuels and so slow the pace of moving away from fossil fuels to renewable energy sources.

Regulatory frameworks have been at best mixed within the national and regional levels. Comprehensive initiatives, such as the European Green Deal and the Emission Trading Scheme, have significantly impacted the firms to adopt substantive sustainable practice involved in reducing green house gas emission. Among its budgetary priorities for the 2021 legislative phase, the EGD and the ETS are important pillars that will help achieve climate neutrality for the European Union 2050. It wants to promote the transition of the EU's economy to a sustainable, low carbon model that is also just and inclusive for all. The EGD is an EU wide plan for a green future. Furthermore, under the ETS, companies are provisioned with limitations in emission allowance (Euopean Commision, 2024). The ETS is a market based concept (a market based mechanism) and is for putting a price on carbon emissions.

Case studies from various nations highlight both the successes and limitations of environmental regulations. For example, while feed-in tariffs and auction systems have effectively promoted renewable energy adoption in countries like Germany, Brazil, and South Africa, policy barriers such as discontinuity, split incentives, and lack of transparency often impede the deployment of these technologies. Moreover, the phenomenon of 'pollution havens,' where industries relocate to regions with lax environmental laws, continues to undermine global sustainability efforts.

Environmental regulations are a complex set of economic, political and social factors, and there is a significant challenge in their implementation. It takes compromise between preserving ecological environment and pursuing economic growth, both of which attract resistance from vested interests and public scepticism of so-called short term disadvantages. But further compounding the enforcement of regulations is the fact that factors were also technical efficiency, global inequality, energy consumption, foreign investment among others. Furthermore, however, institutional investors and corporate ownership structure could promote or hinder real sustainability move, and require complete policy objectives and robust monitoring program. Even though existing environmental regulations have made great progress in advancing sustainability, the way to sufficiently operationalize and realize aggressive goals is full of barriers. Therefore, it is depicted that the gaps are crucial for development of a sustainable future with environmental accountability for all sectors of businesses.

2.4.2 The Need for Policy Frameworks to Promote Green Technology Adoption

In the time of impending environmental disasters, including climate change, resource degeneration and pollution, green technology development has become a vital approach to sustainable development. Green technologies are a lot of innovations in order to minimise the environmental impact and improve the resource efficiency. Renewable energy sources such as solar and wind power, sustainable agriculture and the others mentioned here count as these technologies. Nevertheless, green technologies are nonetheless not widely adopted across regions and sectors despite the obvious benefits. This inconsistency serves as a call for practical policy framework that can help and accelerate the green technology transition (MacKay, 2009). Green technology is not an unimportant step, because it is able to bring multiple advantageous things, including a great reduction in carbon dioxide emissions, greater energy security and the creation of jobs and the improvement of public health. David J.C. MacKay (2009) in his book 'Sustainable Energy – Without the Hot Air' suggests that the transition towards sustainable energy system is not only possible but also necessary for a liveable future on future generations. The challenges however, in making the path to widespread adoption of green technologies. One of the main challenges in applying Consumer Priciples services involves financial constraints, technological uncertainties and regulatory hurdles, which can slow down the progress.

A poor policy environment is the most formidable barrier to the adoption of green technologies. Policy frameworks are key in determining how the tech will be adopted in the landscape which provides the clarity and support mechanisms, along with incentives. The creation of an environment that is favourable to the market of green technologies can attract investment in their production, help fuel research and development in this area, and lead to the formation of such effective policies that would stimulate the investment in green technologies. Green technology adoption across the board has advanced greater among countries that have successfully implemented robust policy frameworks. One example is of Germany's Feed-in Tariff policy having helped promote renewable energy globally and thus being number one in solar and wind power generation.

First, the study must understand the environment of green technology adoption before it can determine why there is a need for policy frameworks. Uptake of renewable energy technologies has been a trend that has been encouraging globally. The International Renewable Energy Agency (IRENA) 29% increase from 2020 in the usage of renewable energy to instigate sustainability from preceding year (IRENA, 2021). However, this growth is not homogeneous, with most countries in developing regions slowing down to adapt green technologies. However, there are barriers to progress which include lack of financing access, lack of technical expertise, and lack of infrastructure.

Besides these barriers, lack of awareness and perception about green technologies exist in public as well. A gap of this kind breeds resistance to change, reluctance to adopt new technologies, even where those are viable. Public engagement and education are key components to successful green technology adoption as noted in 'The Green New Deal' by The Green New Deal Group (2024). Without knowing all the benefits and feasibility of green technologies, individuals and business may not think about investing on the sustainable solutions.

Furthermore, standards and guidelines that enable the use of green technologies must be set up, and regulatory measures follow. According to emissions standards, for instance, an industry must conform to the environmental regulations by adopting cleaner technologies. The European Union's Emissions Trading System (ETS) provides framework for adherence of integration for renewable energy sources in an effective manner while offering regulatory compliance standards. This is done by putting a price on the emissions of carbon, and by doing so rewarding companies to decrease their emissions and invest in green alternatives.

Effective policy frameworks also have supports for research and development. In this regard, governments can aid innovation by backing up research institutes and funding green technology projects. According to Lee, in ‘Green Technology: Principles and Practices,’ public investment in R&D not only promote technological development, but also reduce the risks to private sector investment regarding new technologies (Lee, 2015).

Additionally, public awareness campaigns are necessary to close the gap in knowledge in environments concerned with green technologies. So, governments and organizations should proactively establish relationships with communities to learn what benefits are necessary to make them realise how sustainable practices are important. Through showcasing success stories and highlighting the advantages of green technologies, these campaigns can produce a culture of sustainability and lead the people and the businesses to take charged decisions.

Nevertheless, policy frameworks are clearly needed but will need to overcome multiple challenges when being implemented. A successful set of policy initiatives to promote green technology adoption depends greatly on the presence of political will. Therefore, it is important for policymakers to first prioritize environmental sustainability and commit toward long term routes to switch to green technologies. Collaboration of all stakeholders, i.e. government agencies, industry representatives, civil society organizations is need for this commitment.

Policy development also is determined by economic considerations. The switch to green technologies usually comes with initial cost that can block many businesses and individuals. To facilitate such a transition, financial mechanisms must be put in place for low interest loans, grants as well as other sources of funding for policymakers. According to the literature, the long term savings in energy efficiency and renewable energy investments generally exceed the costs of the investments and financial support is necessary to encourage adoption.

Dynamic such as technological innovation must be considered by policymakers as well. As the development in the green sector remains fast, it can be difficult for the existing policies to remain relevant. Consequently, policy frameworks have to be responsive to new technology and evolving market environment. This can be through regular reviews and updates of policies to keep them up to date with the trends in green technology in practice. Collaborative efforts among different stewards are highly essential to create effective policy programs. Industry leaders, researches, and community managers should be connected with policymakers to help gain insights and viewpoints that will aid policy designing. Collaborative paths can generate a sense of ownership and responsibility on the part of stakeholders, hence enabling to an enhanced execution of policies. Additionally, the policy design also requires flexibility. Policymakers should be open to pilot programs and even in pilot programs, use of experimental approaches that will allow them to test out new ideas or new technologies in real world settings. Therefore, monitoring and evaluation mechanisms are also crucial to evaluate the effectiveness of policy initiatives. Metrics and benchmarks should also be set by policymakers as to how much progress needs to be made toward green technology adoption. They can also provide information to allow for needed adjustments in policies.Thus, policy frameworks that are instrumental in the adoption of green technologies are as much, if not more, needed now. In response to pressing environmental challenges facing the world, there is the path to a more sustainable future through the transition to sustainable technology. The ability of effective policy frameworks is in creating the right conditions for innovation, investment and green technology takeoff. A sustainable future can be paved for through the elimination of barriers, provision of financial incentives and public awareness.

2.4.3 International Cooperation on Sustainability Initiatives

Sustainability and the need to protect the environment has become a global issue that is beyond national borders, thus the need for joint international cooperation and team work. With the reverberations of climate change and ecological degradation spreading around the globe, a unified response that goes beyond the national and regional levels is becoming essential. The United Nation (UN) Sustainable Development Goals (SDGs) constitute one of the important frameworks for international cooperation on sustainability which were adopted in 2015. The 17 goals and 169 targets set out in the 2030 Agenda for Sustainable Development defines a comprehensive challenge to tackle the global challenges.

The partnerships, both within and between countries, are emphasised to yield successful results. According to Ban Ki Moon, the former UN Secretary General, as seen by Sachs (2015) achieving the SDGs is the work of all governments, civil society, and the private sector. The

SDGs form a guiding framework for countries to frame national policies to core global sustainability goals. Sustainability is assisted by international agreements and treaties. The landmark accord against climate change was a Paris Agreement adopted in 2015. This is a collective determination by countries to hold the increase in global average temperature to well below 2 degrees Celsius above pre industrial levels, while pursuing efforts to limit the temperature increase to 1.5 degrees Celsius. National determined contribution (NDC) agreement stresses the importance of the national plans to combat climate change. Readers are referred to Christiana Figueres and Tom Rivett-Carnac's 'The Future We Choose' for an analysis of how the Paris Agreement will depend upon the ability of countries to work together, to share and learn, and to mobilise resources to meet agreed climate targets (Figueres and Rivett-Carnac 2020).

The Convention on Biological Diversity (CBD) was agreed upon in 1992, and the aims resulting from it are the conservation of biological diversity, the rational use of its components, and the equitable and fair benefits sharing for genetic resources. It is an example of the kind of ecological work that needs to be undertaken with international cooperation to protect habitats and species that cross national boundaries. 'In 'The Biology of Plants,' Peter Raven notes the loss of biodiversity stirs greatly important risks to ecosystem services that are crucial to human survival, and that therefore international cooperation is necessary.' The use of financial mechanisms is essential for international cooperation on sustainability matters (Raven, 2005).

The Green Climate Fund (GCF) is established under the UN Framework Convention of Climate Change (UNFCCC) to provide support to developing countries to respond to the challenge of climate change. Yet, serving this purpose, the GCF is intended to use its financial resources to finance climate adaptation and mitigation projects; this is to provide for sustainable development as required by vulnerable people. In line with the 'Financing for Development' by the World Bank, innovative financing models such as public private partnership are essential to raise the required resources for sustainability initiatives (World Bank, 2015). International cooperation in sustainability also involves education, capacity building. The promotion of education for sustainable development (ESD) is something that the UN Educational, Scientific and Cultural Organisation (UNESCO) has been at the front end of. UNESCO's objective is to use education systems to foster the integration of principles of sustainability in people and communities so that they may adopt action for sustainability.

This view is reflected by John Blewitt in 'Understanding sustainable development' in which education is characterized as a powerful tool to spread awareness, stimulate behavioral change and support informed decisions (Blewitt, 2014). Although progress has been made in international cooperation to work on sustainability initiatives, there are some challenges. In addition to this, one of the major difficulties is the disparity in national priorities and capacity or ability. Different country sometimes have various kinds of economic development, political stability and institutional capacity that make collaborative works more difficult. This can lead to tensions and conflicts in achieving sustainable development goal (SDG) (Homer-Dixon, 2006) as Thomas Homer – Dixon in 'The upside of down' stresses. Such disparities need to be recognised and addressed by international cooperation for the benefits to be equally shared. Additionally, sustainability challenges are complex and interdependent to the point of closing cooperation around them. The problem of climate change, biodiversity loss, social inequality etc. are closely interlinked and need urgent resolution, which calls for a holistic outlook and assessing across different dimensions. The sustainability challenges that the contemporary world face, as outlined by Donella Meadows in 'Thinking in Systems' are something that calls for systems thinking and collaboration between sectors and disciplines (Meadows, 2008).

The international cooperation needs to move toward integrative approaches that supersede the classical silos and give continuity to crosssectoral cooperation. A second important factor governing the success of international cooperation on sustainability initiatives is political will. National government commitment to put sustainability at the heart of the policies, actions and processes is a necessary if not a sufficient condition for collaboration to be effective. This was highlighted by the United Nations Environment Programme (UNEP) in 'Global Environment Outlook' which called political instability, corruption and lack of transparency as factors that undermine efforts to realize sustainability goals. These challenges can be overcome only building trust and promoting cooperation at the level of nations (UNEP, 2019). There are several ways to boost the international cooperation in terms of sustainability efforts. One is fostering dialogue and engagement among the stakeholders.

Furthermore, technology and innovation can significantly improve the sustainability cooperation process. If the global businesses rely on digital technologies like data analytics and remote sensing, businesses can get some useful information regarding environmental changes as well as the impact of pursuit of sustainability initiatives. 'The Fourth Industrial Revolution,' Klaus Schwab points out, can aid in the integration of technology into sustainability efforts to help it promote collaboration and support decision making and be transparent (Schwab, 2017). Moreover, capacity building, knowledge and skills transfer is needed to bring about effective international cooperation. Those countries with more developed expertise should provide what experience and best of practices they have acquired to developing nations. According to the United Nations Development Programme (UNDP) in 'Human Development Report', institutions can be strengthened in order to help countries tend more efficiently sustainability problems through technical support and strengthening of capacities. Finally, there should enhance a culture of accountability and transparency in international cooperation for establishing trust. Accountability measures and reporting mechanisms are mechanisms for monitoring and reporting progress of sustainability initiatives so that ensure that commitments are met. In 'Sustainability Reporting Guidelines' and 'As emphasised by Global Reporting Initiative,' transparency in reporting can encourage the public to trust and participate in doing more on sustainability.

In all, international cooperation on initiatives of sustainability is important for solving the complex and intertwined challenges of today. Reason being, climate change, biodiversity loss, and resource depletion are of utmost urgency and must be tackled in collaboration among nations in a manner of achieving sustainable development. The SDGs, international agreements, financial mechanisms and those education initiatives, if used well, have a role to play in keeping countries united in working to create a sustainable future. This, however, calls for innovative strategies and commitment to collaboration in order to address challenges such as nation priorities, political will, and complexity of the sustainability issues. By dialogue, technology, capacity building, and transparency the global community can improve cooperation to create the real progress on the process of sustainability.

2.4.4 The Role of Government Incentives and Subsidies

The quest for sustainability as a central tenet instigates the need for environmental management and modernised economic interest that prioritises circular economy in an efficient manner. With resource depletion, climate change, and social inequality as realities we face as a world, more and more governments are looking towards incentives and subsidies as ways to facilitate a transition towards more sustainable practices. The behaviour to which these mechanisms can add their weight can just as effectively shape behaviour, help you with generating ideas, and can encourage investment in sustainable technologies. This research looks into the use of government incentives, subsidies, to enhance sustainability in all sectors, challenges its adoption in all these sectors and what kind of the result it has to pursue sustainability in entire world. The government provides regulatory relief and other tax benefits for firms that comply with modernised standards of environmental sustainability. These tools are designed to foster certain behaviours or investments in line supporting sustainability goals. Simply, in the energy space, the subsidies on renewable energy sources like solar and wind power have been a leverage to reduce dependency on fossil fuel. The International Renewable Energy Agency (IRENA) in its report ‘Renewable Energy and Jobs’ says that government support has hugely cut down the costs of renewable technologies, which are now cheaper than traditional sources of energy (IRENA, 2020).

Therefore, from the preceding context, it is understood that the incorporation of renewable energy is beneficial for the inclusion of environmental sustainability. ‘The New Climate War’ book, climate scientist Michael Mann states that the transition to renewable energy sources is essential to avoid disastrous climate impacts (Mann, 2021). Governments can use incentives for developing renewable energy to spur market growth and the private sector participation. For instance, in the case of the adoption of solar and wind energy projects, the United States has seen the outcome of the Investment Tax Credit (ITC) and the Production Tax Credit (PTC) that, respectively, have catalyzed the surge of its deployment. These are what we refer to as government incentives to spur private investments to sustainable energy solutions.

Another important field where influence of government incentives and subsidies with respect to promoting sustainability lies is agriculture sector. The environmental health, food security and rural livelihoods are of huge consequence of agricultural practices. David Orden discusses in his book ‘Agricultural Policy in a Globalized World’ ways in which subsidies can stabilize farmers’ incomes as well as encourage sustainable practices (Orden, 2018). One example of this would be to support financially farmers who adopt such environmentally sound practices as organic farming, crop rotation, integrated pest management etc.

However, the agricultural incentive can play a role in enhancement of deforestation due to increased interest of investors in farming that can cause soil erosion as well that leads to environmental degradation. In his blog, ‘Agricultural Subsidies and Globalisation’, economist Tim Josling points out that the poorly planned subsidy programs can distort market incentives (Josling, 2015), resulting into unsustainable land use practices and loss of biodiversity. For a subsidy program to promote sustainability effectively, it must carefully be designed to ensure that environmental goals are reflected in the programs along with properly designing the incentive for sustainable practices rather than to just subsidize existing production methods to promote sustainability.

Similarly, the government has positively used incentives to promote sustainable practices in the transportation sector. The case of subsidies in driving adoption of a cleaner technology is a good example of the shift to the electric vehicles (EVs). Many governments all over the world will give tax credits, rebates and subside for EV charging infrastructure in order to encourage purchase of EVs, as mentioned in ‘Electric Vehicles: The Future of Transportation’, McKinsey

(2020). The incentives also take away the upfront costs of consumers and make charging networks a burgeoning EV alternative for the general public.

The government incentives provide a key mechanism for stimulating innovation and research in sustainable technology fields. Drucker (1985) argues, 'Innovation and Entrepreneurship', it stated that innovation is the fundamental ingredient of economic growth and long term sustainability. Government investment in research and development grants in and tax incentives to private sector investment in technologies for solving environmental problems is a means of stimulating private sector investment in innovative technologies. The energy projects that elicit innovative thinking and transform the whole energy sector are supported by the U.S. Department of Energy Advanced Research Projects Agency Energy (ARPA E). The process of these initiatives is to make breakthroughs in energy efficiency tech, advance carbon capture and renewable energy production to meet sustainability targets. Government incentives and subsidies are very effective instruments of sustainability but at the same time have certain impediments.

The main issues include inefficiency in the use of resources and misdirected allocation. Plans to run subsidy programs can be wasteful and favouritism to certain industries unless they are appropriately designed and implemented. As a basis of his book ‘Political Economy of Subsidies’, William Easterly emphasizes that subsidy programmes should have transparency and accountability to achieve their purpose free from their unintended harmful consequences (Easterly, 2002). Government efforts to encourage R&D are sensitive to the present state of the political environment. For instance, interest groups and lobbyist activities could add subsidy programs influence to produce outcome that are not consistent with sustainability goals. Swire (2016) considers in 'The Politics of Subsidy Reform, ' how entrenched interests serve to frustrate reform so that subsidies can be reallocated from unsustainable to sustainable practices.

2.5 Chapter Summary

From the usage of aforementioned strategies, it is noticed that the economies can attain sustainable development through the involvement of government intervention where taxation and policies in relation to sustainable use of technology can be integrated. Furthermore, the government can play a critical role in the development of renewable energy infrastructure that allows sustainability in economic initiatives as well while contributing to the marginalisation of environmental cost of business. Furthermore, Swire (2016) also stated that the marginalisation of environmental cost for businesses is extensively necessary due to continuous environmental degradation that has readily impacted business performance and other metrics of performance as well. Therefore, government interventions can play a critical role in the development of regulations and legislation that empower sustainable development efficiently.

3. Data and Methodology

The research methodology chapter provides an overview of the approach adopted for exploring the question: ‘Is Green Technology Really the Answer to Sustainability or Just Shifting the Problem?’ This paper uses secondary research to analyse the ideas of sustainability, the current environmental issues, and green technologies, including AI and EVs, and a shift towards renewable energy. As the study focuses on existing data and the prior literature, secondary research is suitable for this study as there has been extensive research on these topics, and newer publications offer contemporary perceptions.

This study utilizes secondary research, analysing a comprehensive collection of green technologies sourced from various databases, including scholarly books, peer-reviewed articles, government reports, and reputable newspapers and journals. Applying such technologies may often disguise sustainability problems from one sector to another; this methodology makes it possible to establish such realities.

The approach adopted enables a critical analysis of new trends, creating a firm foundation when assessing the opportunities and challenges attributable to AI, Electric Vehicles, and renewable energy. To meet the authors' objectives and provide a sufficient overview of the studied topic to answer the research question. This chapter defines why secondary research is appropriate, how and where reliable sources can be identified, how to collect the data and analyse them and the ethical considerations of the research.

3.1 Justification for using Secondary Research

Secondary research is considered suitable for this study on green technology and sustainability as it will enable the evaluation of a vast amount of gathered information and view over this issue, which can be complex and interdisciplinary. As part of its findings, the study examines key issues such as the sustainability crisis, the role of green technologies, employment dynamics, emissions, and other related phenomena, drawing upon prior research conducted by scholars, entrepreneurs, and policymakers. Secondary research is a valuable and fast way to assess the current knowledge about the selected topic based on sources like peer-reviewed journals, government reports, and industry analysis.

3.1.1 Efficiency and Breadth of Analysis

One of the main reasons for using secondary research in this study is its efficiency in covering broad subject areas. Sustainability and green technology are linked to many academic fields, such as social sciences, especially environmental science, economics, and technology. Secondary information makes it possible to get many more attitudes to these disciplines and, therefore, to have a broader vision of how the various sectors are involved in the discussion on green technology. In the view of Saunders et al. (2019), secondary research is helpful in instances where a research investigation transcends disciplinary speciality. Because it makes it possible for the researcher to conduct a synthesis on various fields, which include the application of AI in the management of scarce resources, the environmental greenhouse imprint of electric cars, and the retirement cycle of renewable power structures.

Furthermore, given that the topic of green technology remains highly relevant and is evolving rapidly, secondary research materials provide access to the latest information and publications, which are essential for an informed and up-to-date discussion of the issue. For instance, changes in the trends in the uptake of renewable energy sources and progressive innovations in AI-based environmental sensing and monitoring systems are well-documented across scholarly journals and government documents accessible through secondary research means.

3.1.2 Access to Recent and Comprehensive Data

In addition to its efficiency, secondary research provides access to the most recent information, as it does not necessitate the collection of primary data, allowing for a quicker and more timely analysis. Some of those technologies under threat, such as artificial intelligence and electric vehicles, have significantly improved in the last couple of years. There is no lack of academic papers that outline the overall potential for carbon reductions through the use of AI in different sectors or papers looking at the increasing market share of EVs (Rolnick et al., 2023). Secondary sources offer an opportunity to address a few such issues, specifically in getting updated information in a shorter span without going through the process of secondary research like surveys or experimentation.

In addition, governmental and non-governmental organisations like the United Nations Environmental Programme (UNEP) and the International Energy Agency (IEA) independently release reports on the sustainability and implementation of technologies. These reports provide vast volumes of information, making them very useful to researchers who require an initial brief on the current state of the world's environment. For example, the most recent assessment of the performance of technologies such as renewable energy in the reduction of global emissions is contained in the UNEP's annual ‘Emissions Gap Report’.

3.1.3 Cost-Effectiveness

Secondary research is cheaper than primary research, which involves time-consuming data gathering, interviews, and surveys. The information needed for this research, for example, the effects of green technologies on the environment has already been compiled in the form of existing material, it is unbeneficial to replicate that work. According to Bryman (2016), the convenience of secondary research makes it suitable for use in projects that involve assessing vast amounts of data in a short period, as is the case in this study of green technologies' sustainability (Bryman, 2016).

3.1.4 Reliable and Peer-Reviewed Data

One of the main advantages of using secondary data sources is that the information used in the study has been proven to be accurate by peers. All the information used in the completion of this paper is, therefore, primarily sourced from peer-reviewed scholarly materials and reputable publications. For instance, journals such as Nature Sustainability and Energy Policy release materials based on peer reviews, which makes the information accurate and the results unquestionable. This is because these types of sources are subjected to peer review by scholars who had similar ideas tested before, enhancing the study's validity. In addition, industry reports like the IEA and UNEP are more extensive and data-based and provide an understanding of how green technologies are used and constrained. These sources are instrumental in evaluating green technology's contemporary and potential future effects on sustainability (International Energy Agency., 2023).

Therefore, secondary research appears the best approach for this green technology and sustainability study based on its efficiency, scope, cost, and utilisation of peer-reviewed materials. Since there are a plethora of studies on AI, Electric Vehicles, and Renewable Energies, gathering secondary data permits an evaluation of all the advantages and disadvantages of such technologies. This methodology leverages credible sources from various fields, ensuring a comprehensive and multidisciplinary approach. A more elaborate analysis can be made concerning whether green technology is a natural solution for the sustainability issue or a way to shift the burden.

3.2 Selection Criteria for Credible Sources

In any research project, the credibility of the sources used plays a pivotal role in ensuring the validity and reliability of the findings. For this study on the sustainability of green technologies, credible and authoritative sources were carefully selected to support the arguments and analysis. To maintain a high level of academic integrity, the following criteria were used for selecting sources:

3.2.1 The Recency of Publication

Green technology is one of the most critical growing fields, and new ideas and useful technologies are unveiled quite often. In order to present the most relevant trends and statistics in the study, sources published within the last five years (2019–2024) were preferred. This approach ensures that technologies like AI, EVs, and renewable energy systems are analysed using the latest and most accurate knowledge. Cases, where authors of the secondary work offered historical background or a theoretical concept, were exceptions. For example, several research papers that are critical in defining early milestones in sustainability were considered because they contribute to charting the substantive development of the subject.

3.2.2 Peer-Reviewed Journals and Scholarly Publications

Most articles cited in this study were retrieved from pro-research databases and meet the highest standard of research sources, namely, peer-reviewed journals. Specifically, Nature Sustainability, Energy Policy, and Journal of Cleaner Production were chosen because they receive numerous contributions submitted after rigorous peer review, thus guaranteeing that data and conclusions were reviewed by other specialists in this study area. Academic books and conference papers were also incorporated into the sample because they offer detailed and professional insights into the discussion topics.

3.2.3 Author Expertise and Institutional Affiliation

Another criterion for accepting or rejecting sources was the academic qualifications and experience of the authors. Priority was therefore given to papers written by authors who have credentials as researchers, academicians or professionals from the fields of environmental science, renewable energy, artificial intelligence and automotive technology. Specifically, authors from recognised academic institutions, government and research institutions were given preference for their articles. For example, the works of authors affiliated with such institutions as the University of Cambridge or organisations such as the International Energy Agency (IEA) are helpful because of the reliability of the corresponding institutions (IEA, 2023).

3.2.4 Publisher Reputation

The publishing entity aspect was also considered considering the author's credibility. There are many top scholarly producers globally, including Oxford University Press, Springer, and Elsevier, whose principal business is to publish quality research. Some of the reports from such industries as the United Nations Environment Programme (UNEP) and the International Energy Agency (IEA) were also assumed to be reliable (International Energy Agency, 2023). Such organisations work both internationally and locally and are famous for their efforts to provide genuine and empirical reportage of reality, which is of great use to various stakeholders, such as policymakers, businesses, and researchers.

3.2.5 Objective and Balanced Perspectives

Given the widespread controversy surrounding green technology and sustainability, I chose to consider sources that provide impartial perspectives. While some sources are aimed at the positive effects of such technologies as AI, EVs, or renewable energy, others are open to these technologies' negative impacts and externalities. Further, the study minimises potential bias by choosing sources that present both the benefits and drawbacks of green technologies. For instance, when approving papers on the life cycle environmental footprint of battery electric vehicles or the energy demand of artificial intelligence, the advantages and possible disadvantages were considered.

3.2.6 Empirical Data and Case Studies

Priority was given to sources that provide statistics or discuss cases. CO2 emissions, specific energy efficiency factors, or other indices of technologies' performance shall be considered as real-world data enabling the assessment of the effectiveness of green technologies. They offer solutions at the field level based on given AI, EVs, and renewable energy solutions and their global impact. For instance, work that empowers quantitative evidence in addressing the carbon reduction capability of renewable energy schemes or the resource utilisation effectiveness of AI systems presents facts to support the argument.

3.3 Data Collection and Analysis Methods

This study will employ secondary data collection and analysis methods to investigate whether green technology is the answer to sustainability or merely shifts the environmental problem. Secondary research allows access to various established, reliable, and authoritative data sources, making it the most appropriate for this investigation. The research will focus on three major green technologies: artificial intelligence (AI), electric vehicles (EVs), and renewable energy. Below is a detailed explanation of the data collection and analysis methods that will be used, supported by credible sources.

3.3.1 Data Collection Methods

The data for this research will be collected from various academic databases, including *Google Scholar*, *JSTOR*, *ScienceDirect*, and *Wiley Online Library*. These platforms offer topics such as peer-reviewed journals, scholarly books, and industry reports that are credible sources of information about sustainability. Nature Sustainability, Renewable and Sustainable Energy Reviews, and the Energy Policy are named among the perspective journals to be considered due to their reputability and the proximity of themes to the topic under analysis. Pointing to Bryman (2016), these databases contain practically any empirical studies and literature reviews that will give holistic ideas about green technologies' environmental and economic effects.

Searches will be conducted using keywords such as ‘sustainability,’ ‘green technology,’ ‘artificial intelligence and sustainability,’ ‘electric vehicles and environmental impact,’ and ‘renewable energy and carbon reduction.’ These search terms will help to filter the collected

literature based on its relevance and up-to-date; the aim is to include significant articles published in the last five years to cover the most recent trends and advancements in this field.
Besides scholarly publications, this study will also employ reports from governmental and intergovernmental organisations, including the IEA, UNEP, and IPCC. These organisations are acclaimed for their special magazines and very accurate methods of gathering data. For example, the International Energy Agency's annual Global EV Outlook reports offer data on EV uptake rates, battery manufacturing, and environmental consequences. UNEP and IPCC (2023) annual or periodic reports on global sustainable development initiatives, such as the unique empirical evidence on the use of technologies such as artificial intelligence, renewable energy, etc., on combating climate change.
Industry newspapers, journals, and previous case studies will also be analysed, with a peculiar focus on green technology development-engaged firms. For example, Tesla and Siemens continue to release more white papers and reports explaining the furtherance of technologies seen in electric vehicles and renewable energy sources. These two case studies will present the application of green technologies, their impact and the implications of going green.

3.3.2 Data Analysis Methods

The research will choose qualitative content analysis as a coherent methodology to analyse the collected data. Explorative research, which includes secondary data analysis, forms the basis of qualitative content analysis due to its ability to identify key themes and trends systematically across the body of documents (Krippendorff, 2018). This will include searching the literature for patterns of the effectiveness of AI, electric vehicles, and renewable energy in reducing harm to the environment with possible trade-offs or negative externalities.
For instance, industries like agriculture and manufacturing welcome AI because it can lower energy consumption levels and boost productivity. However, the analysis will also examine the increasing literature on energy consumption by large-scale artificial intelligence programs and data centres (Hidalgo et al., 2023). Consequently, the research will contribute to the literature by presenting both AI's positive and negative environmental contributions.
Secondary numeric data will include reduced carbon emissions, increased energy efficiency, and green technology uptake. Utilisation: The IEA (2023) offers quantitative data on the carbon intensity of electric vehicles in comparison to internal combustion engine vehicles, while UNEP (2023) elaborates on the metrics of global additionality of renewable energy capacity. We will summarise this data in tables or charts to facilitate easy comparison and understanding.

The paper also visualises the analysed quantitative data to highlight trends, as suggested by Saunders et al. (2019).
The study will also employ a comparative analysis approach, focusing on the two leading green technologies: EVs and AI. This analysis will compare and contrast the sector's technology performance based on various environmental parameters, including energy, material, and CO2 intensity. By examining these technologies, the research will establish whether green technology truly contributes to sustainability or merely redirects the issue to a different area.

3.4 Ethical Considerations in Research

Ethical consideration is crucial in ensuring either primary or secondary research's qualm, trust, reliability and validity. When using secondary data in secondary research where data is sourced from published literature, issues related to intellectual property, accuracy of data, and bias must be handled carefully. These aspects help properly execute the research and determine its reliability. The following ethical issues concerning green technology and sustainability will be discussed in this study.

3.4.1 Intellectual Property and Copyright Compliance

Protecting users' intellectual property rights is one of the first preconditions for work in any scientific field. In secondary research, intellectual property concerns are primarily found in connection with the usage of works of third parties that are published in various forms, such as academic journals, industrial reports and government documents. This source agrees with Lee (2021), who asserts that plagiarism is one of the most significant concerns based on the nature of secondary research. This is APA-compliant research, and all authors under reference will be duly cited during this work. Correct citation acknowledges original writers and sources and allows the reader to go back to the sources themselves, increasing the research's reliability,
Furthermore, this study will respect copyright laws since they are the protector of the legal rights of authors, as well as publishers. Even though many books, articles, journals, and other works may be used freely because the authors made them open-access, some of the more heavily used items have restrictions that the author must approve each time the material is copied or used in a more complicated manner. The difference between public domain and restricted works under the act and understanding what constitutes an infringement is fundamental (Sapsford & Jupp, 2020). Consequently, the research will only use such databases

as JSTOR and ScienceDirect to ensure a legal data cess in compliance with the defined fair use sections of the copyright law.

3.4.2 Data accuracy and source credibility

Chevron's Rigorous research material in secondary research plays another critical role in ethical consideration. The reliability of the findings based on the existing literature reduces when the quality of analysed data is compromised. Studies' biases, negative selection, and poor design should be avoided when conducting Randomized Controlled Trials. As Punch pointed out in 2019, secondary data collection must rely on accurate, scholarly, peer-reviewed journal articles that have gone through strict checks to compensate for reliability (Punch & Oancea, 2019).

The main criteria for selecting sources will be the publication date of the source material within the last five years, the scholarly reputation of the publishing platform, and the reports and publications of respected organisations such as IRENA and the WRI. These institutions are well noted for their sound research techniques and the ability to provide accurate information on sustainability and environmental issues. Assuring that the sources are reputable will ensure that this research retains a high level of relevance and will be valuable to further studies on green technology and sustainability.

In addition, we will explain any shortcomings of the data compiled for the study, such as the number of people or region. At the same time, secondary data doesn't always fit different contexts or are completely unbiased. This transparency will help avoid misleading conclusions and ensure that the research remains honest and objective (Booth et al., 2024).

3.4.3 Bias and Objectivity

When we have a research bias, the study becomes imbalanced, and the results need more reliability. Bias in secondary research can be occasioned by selective materials collection, where the researcher is likely to select information that supports his theory. Since they have admitted a range of views relevant to their studies, particularly when it comes to sensitive issues like green technology and sustainability, as stated by Creswell and Creswell (2018), researchers need to remain neutral, thus ensuring they only choose the sources in a bid to represent a broad group of people.

In conducting this study, every effort shall be made to collect information from other stakeholders' viewpoints, including the positive and negative impacts of green technology initiatives such as AI and EVs. For instance, while most sources may provide positive information on the environmental impacts of grand challenges affordability, others may provide damaging information on the impacts of EVs, such as their total lifecycle emissions and sustainability of battery production. This means that by presenting as many-sided views as possible, this research will attempt to paint an accurate picture of the issue under consideration. Further, the data collected from the secondary sources would be analysed to determine whether bias existed in the first place. For instance, industry reports may be coloured by corporate bias and, therefore, give overly positive views on green technologies compared to academic reports. This sense of source bias is essential in understanding what the research results can be based on (Neuman, 2020).

3.4.4 Ethical Reporting and Transparency

Ethical reporting is essential in secondary research because it involves reporting other researchers' findings independently without twisting them in any way. In preparing this guide, emphasis has been placed on the fact that according to Flick (2020), the researcher must refrain from pursuing the so-called 'confirmation bias’ where the data collected are edited to fit only a hypothesis being argued for. In this case, all the data provided will be precise, and the pros and cons of green technologies in the current world will also be elaborated. This approach helps ensure the research does not mislead readers or create an exaggerated sense of certainty around complex sustainability issues.

Moreover, transparency will also involve acknowledging any limitations or gaps in the research. Since secondary research relies on existing data, it may only address some aspects of the research question or offer definitive answers. By being transparent about these limitations, this study will maintain its ethical integrity and provide a more nuanced understanding of the role of green technology in achieving sustainability.

4. Green Technology: Potential and Limitations

Over the years, the world has been tempted more with technology to solve what might be described as the dramatic climate change, resource exhaustion and environmental degradation. The most discussed and the most celebrated innovations in this regard are Electric Vehicle (EV) and Artificial Intelligence (AI). Typically, these technologies are depicted as green solutions that can aid in the prevention of the impacts of industrialisation and fossil fuel consumption, as a sustainable alternative to the conventional practise. But, while these technologies may seem attractive, they each have their own set of drawbacks and shortcomings that must be taken into account in any full account of their eventual place in society.

For a more in depth understanding of what this part of Electric Vehicles (EVs) and Artificial Intelligence (AI) have to offer when it comes to sustainability, to purpose and perhaps to unintended problems, this passage will cover a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis. However, although these technologies are to be embraced for their potential to enable a more sustainable future, they cannot be regarded as a panacea. These technologies will be analysed with respect to both their positive and negative aspects, as well as their feasibility over the long term, the social impact they may have and their costs in terms of the environment. These technologies will be considered as devised to address pressing environmental problems, but we will also point out the possibility for their wide spread adoption to pose new and unpredicted problems for which we will need to care and find creative solutions.

In particular, neither Electric Vehicle (EV) nor Artificial Intelligence (AI) is considered to be one of the technologies which will help in achieving the paradigm shift towards a more sustainable and low carbon economy. All of these technologies have the potential to disrupt existing sectors and bring more efficient, sustainable products.

Among such visible solutions to decrease carbon footprint of the transportation sector, which is a major contributor to greenhouse gas emissions, EVs have come to the front. Proponents of EVs argue that EV vehicles can cut down carbon dioxide emissions and air pollution, and lessen on the requirement of finite fossil fuel resources, and avoid stringency around internal combustion engine (ICE), by shifting away from ICE vehicles and on to electric power. But EVs are also a critical part of a wider set of trends in the automotive world, governments and car makers spending heavily on electric mobility to reduce climate change impact and improve air quality.

On the other hand, Artificial Intelligence (AI) is revolutionising almost every part of the economy, from healthcare and manufacturing; energy and transportation; and virtually every other part of the economy as well. A large amount of data and sophisticated algorithms powered by AI systems can optimise efficiency, support good decisions processes and develop new business models. AI has a vital role to play in the context of sustainability in managing the energy consumption, in optimising the efficiency of the electric grids, on the automation on electric grids of renewable energy plants, and on smarter urban planning. In addition, AI's capacity to predict and analyse huge information can be a beneficial tool in the fight against climate change, and also difficulty associated in environmental degradation.

All these technologies have a lot to offer. Governments, corporations and the environmental groups have championed them as the cornerstone of a green revolution. But while this is an optimistic view, it should not be devoid of a sense of the broader implications of widespread adoption.

The status of these technologies as green technologies is one of the most appealing aspects of these. As a means of reducing tailpipe emissions, EVs are heralded, AI is billed as increasing energy efficiency and optimising resource management. But as with all the technologies, there are challenges and limitations to these innovations. Although these technologies are advertised as a solution to environmental deterioration, they may also come up with their own problems, which should be solved as soon as possible.

It is for the reason why the Electric Vehicles and Artificial Intelligence's viabilities, sustainability, and long term impact have been decided to go under SWOT's (Strength, Weakness, Opportunity and Threat) analysis. However, SWOT analysis is of crucial importance in strategic sense, for systematically screening out the internal and the external factors that may impact or contribute to the successfulness and widespread adoption of those technologies.

Analysing the SWOT will help us know the best part of these technologies, the area those technologies have weakness and limitation, and the opportunities these technologies have on sustainability and innovation, and the dangers these technologies may want a multi on the life of our society and environment. Through this approach, we will be able to critique how these technologies will influence how sustainability will unfold in the future, and identify the aspects that call for additional research, innovation, and policy interventions on behalf of these technologies to make feasible all the advantages over disadvantage.

This analysis aims to yield a unifying view of the sustainability impacts of EVs and Al, where benefits of the technology are recognised as well as the issues that have to be addressed for this potential to fully materialise. We will then move onto this passage and discuss how these technologies interact in one way or another since their implementation is sometimes dependent on each other. For instance, AI could help optimising the operation of renewable energy systems when these require EVs to be truly sustainably operating on renewable energy.

4.1 Electric Vehicles

Facing the challenges brought on by climate change, resource depletion and environmental degradation, the world increasingly needs sustainable solutions in every field. In the recent years, one area that has been receiving a fair amount of attention is the transportation industry, which is major GHG and pollution contributor to the planet. In response to these challenges, electric vehicles (EVs) have come as a promising alternative to the traditional internal combustion engine vehicles. EVs can help reduce emissions and improve energy efficiency and connect with the emerging renewable energy sources, making the transportation system more sustainable.

In this passage a SWOT (Strengths, weaknesses, opportunities, threats) analysis will be conducted on electric vehicles under the sphere of sustainability. The analysis of strengths, weaknesses, opportunities and threats (SWOT) regarding EVs will present a consolidated insight into how they contribute to promoting a more sustainable future, specifically in the UK. SWOT will assist with the identification of key benefits and challenges of adopting electric vehicles to make it to the future road of sustainability and transportation.

4.1.1 Electric Vehicles: Strengths for Sustainability

One of the most radical changes that the transportation sector is in the throes of today is the transformation to electric vehicles (EVs). As the global need to deal with climate change, pollution, natural resource depletion, and so on, the proliferation of EVs has become an essential means of sustainability. On top of being regarded as an alternative to traditional internal combustion engine (ICE) vehicles, they are also believed to be the start of a drier, more resource efficient transportation system. This essay examines how electric vehicles' benefits to sustainability are in fact multiple, environmental, economical, and social, and will provide references to show how widespread EV adoption will shape sustainability.

4.1.1.1 Reduction in Greenhouse Gas Emissions

Electric vehicles are one of the main strengths of reducing greenhouse gas (GHG) emissions, which are a main cause of climate change. A good percentage of the global CO2 emissions comes from transportation, one of the most significant sectors that must be decarbonized. The transformation from gasoline or diesel powered to electric vehicles will cut emissions by a huge margin.

4.1.1.2 Tailpipe Emissions

The first way electric vehicles cut back on GHG emissions is by cutting tailpipe emissions. The result of combustion of fuel is that traditional internal combustion engine vehicles heated by petrol or diesel will release carbon dioxide (CO2), nitrogen oxides (NOx) and particulate matter (PM) directly into the atmosphere. They contribute exceedingly to global warming, urban air pollution and human health problems.

4.1.1.3 Carbon Dioxide (CO2) Emissions

Carbon dioxide (CO2) is the largest internal combustion engine vehicle greenhouse gas. UK Department for Business, Energy & Industrial Strategy (2021) noticed that transport emits almost 30 percent of the country's total GHG emissions, with road transport being the largest contributor. Hence, it has become a crucial target in decarbonisation. On average, a conventional petrol or diesel car produces between 120 to 160 grammes of CO2 per kilometre (Sierschula et al. 2020). However, electric vehicles don't emit any CO2 at the tailpipe as they are powered by stored electricity from batteries and not burning fossil fuels.

The reduction of CO2 in the transport sector can be quite significant by changing from conventional vehicles to electric vehicles. This reduction has great potential impact. Consider that ICCT estimates that transitioning the global vehicles market to electric could result in CO2 emissions reductions of 1.5 gigatonnes per year by 2030. In 2030, it is estimated that the road transport sector CO2 emissions in the UK will reduce by 14 million tonnes per year (UK Government, 2020).

4.1.1.4 Nitrogen Oxides (NOx) and Particulate Matter (PM):

Besides releasing CO2, conventional vehicles add other toxic pollutants, such as nitrogen oxides (NOx) and particulate matter (PM), which help form smog and is harmful to the public health. The most harmful form of NOx is also the one present in the largest concentration in urban areas, where traffic congestion is one of the worst offenders. NOx and PM exposure leads to respiratory diseases and cardiovascular disease, and other health problems (WHO, 2016). However, electric vehicles generate Zero tailpipe emissions of NOx and PM, providing an excellent improvement in urban air quality.

And in cities like London where air quality is an issue, the mass uptake of the electric vehicle could drastically cut down vehicle emissions of hazardous fumes. According to a Greater London Authority report in 2020, if all cars in London were to be replaced with electric vehicles, NOx emissions would be more than 90% less and PM emitted would drop by 50%. If indeed such improvements are achieved in air quality, there would be substantial health benefits such as fewer hospital admissions, less premature deaths, lower healthcare costs.

4.1.1.5 Lifecycle Emissions

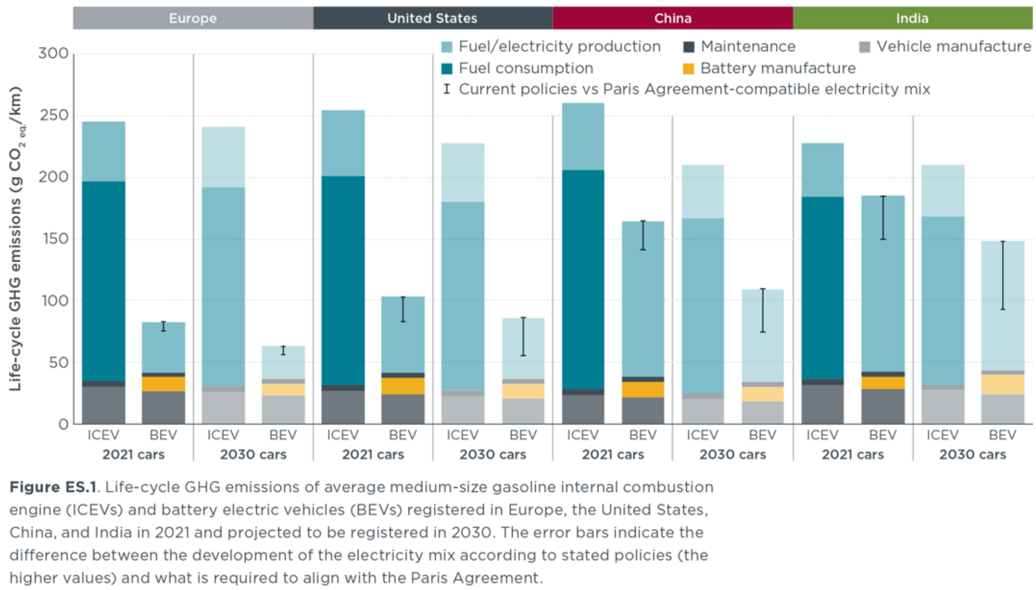


Figure 17 Life Cycle Greenhouse Gas Emissions of Combustion Engine vs Electric Passenger (Bieker, 2021)

Although EVs are often regarded as Zero-emission vehicles, it is essential to consider their full lifecycle, including the production, operation, and disposal phases. Manufacturing EVs, particularly their batteries, can generate higher emissions than the production of ICE vehicles due to the energy-intensive processes involved in mining raw materials like lithium, cobalt, and nickel. A study by the Union of Concerned Scientists (2021) found that the production of an EV can emit up to 68% more CO2 than an equivalent gasoline-powered car. However, over the lifetime of the vehicle, these emissions are offset by the lower emissions associated with

electricity-driven operation. As the global electricity grid becomes cleaner with the increased use of renewable energy, the total lifecycle emissions of EVs will continue to decrease.
In regions like Norway, where almost all electricity is generated from renewable sources, the carbon footprint of an EV is substantially lower than that of a conventional vehicle (Figenbaum, 2019). The shift to renewable energy in the electricity generation sector is thus a critical factor in maximising the sustainability benefits of electric vehicles.

4.1.2 Energy Efficiency and Lower Operating Costs

Electric vehicles are significantly more energy-efficient than internal combustion engine vehicles. The efficiency of a vehicle refers to how well it converts fuel (or electricity) into useful work, i.e., movement. In traditional gasoline-powered cars, about 20-30% of the energy from fuel is used to move the vehicle, with the rest lost as heat and friction. Electric vehicles, however, can convert 85-90% of the energy stored in their batteries into movement (U.S. Department of Energy, 2021). This results in lower energy consumption per mile traveled.

4.1.2.1 Fuel Costs

One of the key benefits of EVs is their lower operating costs, particularly in terms of fuel. The cost of electricity is generally lower than gasoline or diesel on a per-mile basis, making EVs more affordable to operate. In 2021, the U.S. Department of Energy reported that, on average, EVs cost less than half as much to fuel as a conventional vehicle. Additionally, the cost of electricity can vary significantly depending on geographic location and the source of energy (U.S. Department of Energy, 2021). In areas where renewable energy is abundant and inexpensive, the cost of charging an EV can be further reduced.

4.1.2.2 Maintenance Costs:

Electric vehicles also generally have lower maintenance costs than traditional vehicles. Because they have fewer moving parts EVs don’t need oil changes and their brakes are known to last longer thanks to the recapturing of energy use during braking via regenerative braking technology. EVs have no exhaust system, no fuel pump or timing belt either, all of which is a burden for maintenance for ICE vehicles (Higgins, 2018). With the reduction in maintenance requirements it also means that an EV owner will save on a cost basis and thus make EVs more affordable in the longer term.

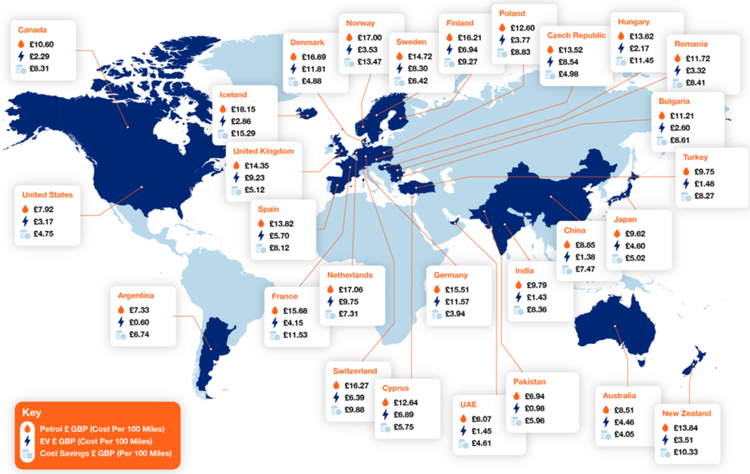


Figure 18 The cost of running an electric vehicle vs petrol car in 33 countries (Gulf) (Gulfoilltd, 2024)

4.1.3 Integration with Renewable Energy Sources

The widespread use of EVs brings a unique opportunity to integrate this transportation system with the renewable energy infrastructure. However, normally in a conventional fossil fuel powered system of transportation, energy sources are not dependent on vehicles. However, with the growing prospect of renewable energy readily available, EVs can be incorporated into sustainable energy eco system in so many important ways.

4.1.3.1 Vehicle-to-Grid (V2G) Technology

Vehicle to Grid (V2G) technology is a new technique that combines power draw from the power grid with delivering power back into the power grid. This system enables EVs to operate as mobile energy storage systems using their batteries for underutilised electric grid demand charges in addition to supplying the grid with power at high demand points when renewable energy generation is low. The study by National Renewable Energy Laboratory (2020) stated that V2G systems could contribute in equilibrating supply and demand especially as the intermittent renewable energy resources such as wind and solar become more predominant (Anon, n.d.).

In high renewable energy penetration regions, electricity from hydro or thermal power stations would otherwise be used for peak demand, meaning EVs can be charged at times of surplus renewable energy generation (e.g. during the day when solar power is plentiful) and discharged during periods of such peak demand. The electric vehicles are interdependent symbiotically with renewable energy, strengthening the grid resilience and reducing the dependency on fossil fuels.

4.1.3.2 Charging Infrastructure Powered by Renewables:

At the same time, EVs provide an incentive to further develop outlets for recharging from renewable sources of energy. There is a demand for storage stations as more consumers move to electrcar. The investments of governments and private companies in building fast charging networks based on clean energy are also on the increase. In countries including Germany, the Netherlands and the USA, efforts are being made to have a great majority of charging stations operated by solar, wind or hydroelectric power (Fremont et al. 2019). Therefore, the integration of EVs to renewable energy infrastructure contributes to make it sustainable by minimising emissions caused by vehicle operation.

4.1.4 Reduced Dependence on Fossil Fuels

Developing electric vehicles is an important component in moving away from fossil fuels around the world. Extraction, refining and consumping of oil and natural gas are causing environmental degradation, destruction of habitat as well as geopolitical tensions. Switching to electric vehicles, which can rely on electricity from various sources, including 'renewables', reduces the demand for oil, and hence reduces the environmental and social impact of extraction of fossil fuels.

Electric vehicles also provide an energy security by diversifying fuels for transportation. Whereas oceans, deserts and jungles full of oil and oil pipelines are constantly subject to geopolitical tensions, electricity can be generated from virtually any geographic location—the wind, the sun, the water, even the heat stored beneath the Earth. It is a diversification away from import dependence on oil, thus reducing the dependence of countries on this commodity and enhances the ability of the countries to bear fluctuations in the prices of oil on the global market. The International Energy Agency (2020) reports that a switch to electric vehicles would cut global oil demand by 5.3 million barrels per day by 2030. Moreover, new electric vehicles can lower geopolitical risks of oil dependence such as oil price volatility and the ensuing economic and political instability. It also serves as part of a global movement to decrease the social and environmental expense of extracting oil, a process that regrettably places its burden on the least powerful of people.

4.1.5 Promotion of Circular Economy and Sustainable Manufacturing

The principles of the circular economy are very close to the sustainable manufacturing of electric vehicles. Sustainable practises that focus on reducing resource consumption and waste generation are becoming prevalent in the EV manufacturers.

Sustainability, however, means part of the cycle is that EV batteries are recycled. One of the largest resources of an electric vehicle is batteries, and in particular lithium ion batteries. Given growing demand for EVs, it is increasingly urgent that such recycling technologies are efficient. However, luckily battery recycling is a quickly growing industry of which many companies are trying to find ways to recover materials like lithium and cobalt to use in new batteries.

EV batteries can also be recycled as well as used in second life applications. EV batteries that conclude the service life in a vehicle, retain a great deal of their capacity and can be re-used for stationary energy storage. Second life EV batteries can be used to store renewable energy at household or grid levels to create a further route towards waste reduction and the sustainability of the energy systems (Sierschula et al. 2020).

4.1.6. Social Benefits: Equity and Access to Clean Transport

Electric vehicles also offer the chance to bring cleaner transportation options to underserved communities. Poor health outcomes of low income populations are associated with historically higher proportions of air pollution from vehicle emissions. Bringing an EV can help alleviate these disparities by promoting cleaner air in urban areas as well as cheaper, cleaner modes of transportation.

Governments are also offering subsidies, incentives and rebates across the globe to persuade consumers of the EV. These incentives increase the accessibility of electric vehicles for broader group of consumers, including lower income communities. Furthermore, in underserved areas, public electric vehicle charging components can ensure an equitable adoption of EVs and support in ensuring the benefits of cleaner transportation are distributed across the entire society.

4.1.7 Conclusion

Electric Vehicles are a big step up in sustainable transportation with many environmental, economic and social benefits. Through their ability to reduce greenhouse gas emissions, improve energy efficiency, combine with renewable energy systems, they stand to be a key climate change mitigating and fossil fuel solution. Additionally, adoption of EVs contributes to the transition to a circular economy, energy security and provides considerable social gains from reducing air pollution and improving accessibility to clean transportation. We are at the beginning of a fast growing era, of EVs, as the technology gets better and better and as more and more countries adopt policies in favour of sustainability and reducing greenhouse gases, electric vehicles will definitely be playing in an increasing role to build a cleaner and more sustainable future for all.

4.2 Weaknesses of Electric Vehicles

Owing to their acknowledged importance for the development of a more sustainable, decarbonised transport sector, electric vehicle (EV) technologies are currently widely regarded. According to them, ICE vehicles have significant advantages in terms of decreased greenhouse gas (GHG) emissions, better air quality, and less dependence on fossil fuels than traditional ICE vehicles. Yet, there are weaknesses and challenges associated with these benefits that need to be dealt with fully to achieve EVs' potential for sustainability. This essay will explore the principal weaknesses of electric vehicles regarding sustainability on the basis of lifecycle emissions, resource extraction, energy generation and infrastructure limitations and equity.

4.2.1 High Lifecycle Emissions from Battery Production

Production of battery for the batteries used in most of today's modern EVs, in particular lithium ion batteries, is also one of the major challenges to the sustainable electric vehicle. EVs do No emissions them at tailpipe. However, the production process of EVs especially batteries may have huge environmental impacts.

4.2.1.1 Battery Manufacturing and Resource Extraction:

Lithium-ion batteries are powered energy intensively and raw materials for the production of the batteries such as lithium, cobalt, nickel and graphite are often mined in environmentally sensitive areas (Hawkins et al., 2013). These materials can cause tremendous environmental degradation during the extraction and processing; including habitat destruction, water pollution, and soil contamination. Specifically, extraction of cobalt as it is primarily drawn from the Democratic Republic of Congo has led to some ethical concerns regarding the use of child labour and poor working conditions in some mines.

A study by Hawkins et al. (2013) found that battery production can account for a substantial portion of an electric vehicle's lifecycle emissions. For example, the production of a typical electric vehicle battery can produce 150-200 kg of CO_2 emissions per kilowatt-hour (kWh) of battery capacity. This is a significant amount when compared to the emissions associated with the production of a conventional internal combustion engine vehicle. The energy-intensive nature of battery production can lead to a carbon footprint that is higher than that of ICE vehicles, especially if the electricity used in the manufacturing process is derived from fossil fuels.

4.2.1.2 Limited Recycling and Reuse of Batteries:

Another challenge is the limited capacity for recycling electric vehicle batteries at the end of their lifecycle. While the recycling of EV batteries is improving, it is still an emerging industry. Battery recycling facilities are often limited in capacity and the processes involved are not yet as efficient as they could be. As a result, a significant number of used batteries are either not recycled or sent to landfills, where they can leach harmful chemicals into the environment.

Although battery recycling can recover valuable materials, such as lithium, cobalt, and nickel, the current recycling rate remains low. According to the International Energy Agency (2020), only about 5% of the lithium-ion batteries used in EVs are recycled. Increasing recycling rates and improving recycling technologies will be essential to mitigating the environmental impact of battery production and reducing the need for raw material extraction (International Energy Agency, 2020).

4.2.2 Limited Availability and Sustainability of Charging Infrastructure

Availability and sustainability of the charging infrastructure are very closely linked to the widespread adoption of electric vehicles. Although the sheer number of charge points in the public and private sectors is increasing significantly in many regions, the charging infrastructure is still one of the major blocking factors to EV adoption.

4.2.2.1 Charging Infrastructure Development:

To facilitate practical uses of electric vehicles for long distance travel, there is a need for development of a robust and accessible charging network. But in many quarters, particularly in rural areas and less developed countries, charging infrastructure is lagging. Both grid upgrades and public-private partnerships need to be undertaken and both this involves investments, so charging stations installations are capitalistic intensive.

Another concern is on the geographical distribution of charging stations and the routes of the charging vehicles. Better in urban areas where the density of charging stations is high enough, however, less populated or rural regions have the potential to be challenges to find the charging points available. The lack of availability of infrastructure can result in an unlevel play field for EV adoption that stunts the growth of the electric vehicle market and limits the potential for achieving the environmental benefits of widespread EV use.

4.2.2.2 Energy Demand and Grid Strain:

With all the more electric vehicles on the road, there will be all the more demand for electricity to power them. In other words, such an increased demand could test the burden of existing electrical grids: for example, during peak charging hours when electricity needs might be matched with electricity usage for heating or cooling. In regions where grid capacity and infrastructure are limited this may result in reliability problems, grid congestion and increased energy costs.

Today, as it turns out, much of the electricity grid beyond that still relies on fossil fuels, such as coal and natural gas. The drawback for the sustainability of EV is that emissions resulting from EV operation depend largely on the power mix that is used to power electricity. Of course, decarbonising the grid is happening in many countries, but in some of the regions where grid assistance is reliant on coal or fossil fuels, the emissions they cause during the EV charging could outweigh the vehicle's environmental benefits.

4.2.2.3 End-of-Life (EOL) and Recycling Challenges

Disposing and recycling of batteries from electric vehicles poses another challenge to the sustainability of the electric vehicles. Moreover, the increasing number of EVs on the roads would lead to increasing necessity of recycling or disposal of old batteries at the end of their useful life. Opportunities to recycle EV batteries are currently lacking and the infrastructure to recycle batteries is not as efficient as it could be. Therefore, it presents itself as a significant challenge for the widespread implementation of recycling challenges and adoption of EVs across the market.

4.2.2.4 Battery Disposal and Recycling Efficiency:

Recycling of EVs is an important way of reducing the environmental impact of EVs at end of life, but the capacity of recycling process is currently limited. This has also been stated before; only about 5% of lithium-ion batteries are recycled, while most used batteries will not be recycled or end up in landfills. The recycling technologies for the batteries are still under development and the processes itself take much energy, thereby reducing the overall environmental benefit of recycling. Further, it is very difficult to make recycling more easy and cost effective when there is no standardisation in battery design (Nørgaard, 2020). To avoid a short awaited long-term sustainability of electric vehicles, the recycling rates and the recycling technologies will need to be improved. But this is a challenging problem and needs substantial investment on research, infrastructure and policy development.

4.2.2.5 Second-Life Applications for EV Batteries:

The second life applications for the EV batteries serve as an alternative to direct recycling. Second life applications involve the use of EV batteries that have reached the end of its utilisation useful life for other purposes such as stationary energy storage. Such geometries may be able to increase the lifespan of the battery and reduce the requirement for additional materials. Nevertheless, second life applications are in the early stage of development, and various issues, including risks for the safety and efficiency of second life batteries, remain to be addressed.

4.2.3 Equity and Accessibility Issues

In terms of environmental benefits, electric vehicles do have great appeal; however, there are also issues concerning equity and accessibility. The primary concern is the inclusion of sentiment of the people is the high upfront cost of EVs, especially in poor communities. Despite the drop in price of electric vehicles, they continue to be more expensive than conventional gasoline vehicles, particularly as less expensive than the price of the battery. Reducing electric car upfront cost through government incentives and subsidies is not enough to drive electric vehicle adoption by everyone.

Even with incentives, many countries' low income households and individuals may not be able to afford to make that initial investment and purchase an electric vehicle. The upfront vehicle purchase price for EVs is often higher than that of ICE vehicles largely due to the cost related to the battery. Battery prices have fallen over 80% from 2010 due to increased technological input and ability to marginalise the gap between EVs and conventional vehicles has narrowed (IEA, 2020). Additionally, government incentives and subsidies in many regions further reduce the effective cost, making EVs more accessible to a broader range of consumers. Despite these positive trends, the cost remains a crucial factor for many, and continued advancements in battery technology, alongside supportive policies, will be essential for making EVs more affordable in the future (Breets et al., 2021). This could lead to the exclusion of certain groups from the benefits of electric vehicles, reinforcing social inequalities.

4.2.3.1 Access to Charging Infrastructure:

Access to charging infrastructure is one of the critical factors influencing the widespread adoption of electric vehicles (EVs). The availability and convenience of charging stations play a significant role in addressing 'range anxiety,' the fear that an EV will run out of battery before reaching a charging point. EV owners also have easy access to charging facilities in urban areas. Nevertheless, in rural or sparsely populated regions, charge infrastructure is sparsely available, which becomes a hurdle for potential EV users in these locations (Sierschula et al., 2014).

This is also troublesome for those without access to home charging, as they would frequently be the ones with no charging options, being that the charging points are typically limited within in housing units like the multi-family or the renter. In order to avoid having EV adoption stymied by geography or housing type, it is important to have an expanding charging networks, and especially fast charging stations. Secondly, there is a need for investments in grid upgrades and the integration of renewable energy sources into charging infrastructure that will make the EVs more sustainable (IEA, 2020). Moreover, the standard of the charging network should be developed to avoid the charging network fragmentation because it will provide ease of the use to the EV owner from varied locations and manufacturers.

4.2.3.2 Conclusion

Electric vehicles offer a great promise to solve many environmental issues with the transportation sector, however they are not completely immune to their weaknesses. All these present major challenges: batteries have high emissions in their production, there is an ethical, environmental question mark over resource extraction, and the charging infrastructure is severely limited. Notably, however, the recycling options for batteries, equity, as well as accessibility should be carefully examined so that the benefits associated with the use of electric vehicles can be secured from all sides. Electric vehicle could be used for sustainability only if we have the cleaner and more efficient manufacturing process, have to invest in expanding infrastructure of charging and recycling technologies should be able to work with ethical issues of resource extraction. They will also need to establish policies that enhance equity and accessibility to make sure that the transition to electric vehicles is not only good for high income individuals, but for people from all demographic groups.

4.2.4 Opportunities for Electric Vehicles in Sustainability

Transformation to renewable energy, reduction of greenhouse gas emissions, and improvement in urban air quality are among the most promising solutions, and that is how electric vehicles (EVs) have emerged as a sustainable solution. The EVs have been seen as building on their strengths, downward progression in tailpipe emissions and lower operating cost with increased expectation of becoming a key enabler of a sustainable transportation future. Nevertheless, untapped efforts are required to fully realise the EV potential. All these opportunities fall on technological, economics, policy, or societal dimensions.

4.2.4.1 Technological Advancements and Innovation

With EV demand rising, growing forecast are for dramatic technological improvement to make EVs both cheaper and more efficient, attracting more consumers and businesses.

4.2.4.2 Battery Technology improvements:

The continued evolution of the battery technology is one of the most significant opportunities in the EV market. Solid state batteries, lithium sulfur and graphene based batteries will offer energy density enhancements, shorter charging times and longer life battery (Tarascon and Armand, 2001). This could pave the way to the more affordable, longer range EVs with better performance, and with which conventional internal combustion engine (ICE) powered vehicles will become more and more competitive. The inclusion of variety of batteries including solid state batteries provide higher energy density with controlled safety concerns leading to reduction in size and driving range for EV.

4.2.4.3 Charging Technology and infrastructure:

Charging infrastructure for EV also another key opportunity for EV tech development is the development of faster and more efficient charging technologies. Many companies are working on ultra fast charging solutions to charge an EV battery to 80 per cent in under 15 minutes, improving convenience for the users (IEA, 2020). To promote EV adoption and allow long distance travel, it will be necessary to install fast-charging stations across highways and urban areas. In addition to wireless or inductive charging, which would simplify the charging process in public spaces and commercial fleets, either is being developed.

4.2.4.4 Vehicle-to-Grid Technology:

One promising string to integrate within EVs is vehicle to grid (V2G) that could allow EVs to act as mobile or portable energy storage units. The technology allows EVs to sell excess power into the grid at times of high demand and assist in grid stability and ability of using renewable energy sources. V2G technology can develop a two way energy exchange in which EVs can not only be used as a vehicle of transportation but also as an energy asset to address intermittency challenges introduced in renewable energy generation (IEA, 2020).

4.2.4.5 Electric Vehicle Manufacturing and Supply Chain Growth:

The transition to EVs is driving significant investment in manufacturing and supply chains. As demand for EVs increases, so does the need for raw materials like lithium, cobalt, and nickel, as well as battery manufacturing capacity. The global EV market is projected to grow significantly in the coming decades, presenting opportunities for manufacturers to scale production, create new jobs, and boost economic growth (McKinsey and Company, 2020). The transition could lead to the emergence of new industries centered around battery production, renewable energy integration, and EV maintenance.

4.2.4.6 Cost Reduction through Economies of Scale:

With the expansion of the EV market, manufacturers can benefit from economies of scale, which will help reduce the cost of EV production. Battery costs, which account for a significant portion of an EV's price, have already fallen by over 80% over the past decade, and are expected to continue decreasing with advancements in battery chemistry and manufacturing techniques (IEA, 2020). As the price gap between EVs and ICE vehicles continues to narrow, EVs will become increasingly affordable for a broader range of consumers, opening up new markets for electric transportation.

4.2.4.7 Sustainable Economic Growth and Reduced Operating Costs:

The widespread adoption of electric vehicles can also contribute to sustainable economic growth. EVs offer significant savings over their lifetime compared to ICE vehicles, particularly in terms of lower operating and maintenance costs. With fewer moving parts, electric vehicles require less maintenance, leading to lower repair costs. Additionally, the cost of electricity for charging is generally lower than the cost of gasoline or diesel, offering consumers an opportunity to reduce their long-term transportation expenses (Sulivan et al., 2017). Such redistribution of wealth in favour of energy efficient technologies could be broader, particularly in local economies where the energy is transitioning into renewable sources away from fossil fuels.

4.2.4.8 Policy and Regulatory Support

Creating a good environment for electric vehicle's growth requires the involvement of government policies and regulations. EVs possess several channel opportunities from the regulatory and from the policy support.

Many governments around the world have offered a number of incentives to push forward EV adoption. They include tax credits, purchase subsidies and rebates for EV buyers and funds for charging infrastructure deployment. Governments in some regions do provide strong incentives for the reduction of the EVs incumbent upfront cost, a factor that may overcome the immediate price barrier. For instance, in the US, federal tax credits on the purchase of EVs range up to $7,500 and in Europe, Norway has tax exemptions, toll-free driving and access to bus lanes for EV owners (Sierschula et al., 2014).

The automotive industry is now being increasingly set stricter emissions standards by governments all over the world. According to IEA (2020) many European countries already have set the deadline to phase out of new internal combustion engine (ICE) vehicles, and countries like the United Kingdom and France intend to ban the ICE vehicles by 2030 and 2040, respectively. Likewise, the world's largest automotive market China has stated its intention to increase EV share in the total car market. Such regulations and policies send clear signal to automakers and consumers on the path that transportation will take in the future: it will be electrified, and hence there are more opportunities for EV adoption.

But particularly important is that EVs are contributing to the global efforts to decarbonise the energy sector. The modes of power generation (e.g., renewable energy sources) and the power delivery (e.g., smart grids) are directly served by governments and demand is supplied by the

EV users. Reduction of the environmental impact of transportation is further achieved when EVs are charged with renewable energy (IRENA, 2020). But since EV adoption is being coupled with clean energy policies, it is a huge opportunity for a low carbon, sustainable transportation ecosystem to grow out of it.

4.1.4.4 Societal Opportunities and Consumer Trends

Not only EVs are an economic and technological opportunity, but they present an opportunity to change society towards sustainability. Opportunities for EVs are based further on shifting public attitudes and environmental consciousness as well as an increase demand for discrete transportation systems, more easily through EVs.

Currently, public opinion is turning toward the eco friendly kind of consumer choices. More and more consumers are willing to pay a premium for products that share their values; and vehicles that help them reduce carbon emissions are one of these examples (Breets et al. 2021). As public attitudes towards environmental responsibility continue to evolve, demand for EVs is expected to increase, making it a powerful opportunity for automakers and governments to capitalise on this trend.

EVs are also integral to the future of urban mobility. As cities around the world face increasing congestion and pollution, EVs, along with shared mobility services such as electric ride-hailing and car-sharing platforms, present an opportunity to reshape transportation systems. EVs offer a cleaner alternative to traditional taxis and ride-hailing services, and electric buses and delivery vehicles are emerging as sustainable alternatives for public and commercial transport (Anderrson and Trait, 2019). Combined with the rise of mobility-as-a-service (MaaS) platforms, the integration of EVs into smart urban ecosystems is a key opportunity for sustainability.

In conclusion, the opportunities for electric vehicles are vast and multi-dimensional, extending beyond technological advancements to encompass economic, policy, societal, and environmental benefits. Technological innovations, including improvements in battery efficiency and charging infrastructure, combined with supportive governmental policies and growing consumer awareness of sustainability issues, are driving the widespread adoption of EVs. By harnessing these opportunities, the transition to a clean, sustainable, and electric mobility future is not only achievable but could fundamentally reshape the global transportation landscape.

4.2.5 Threats to Electric Vehicles in Sustainability

The concerns of the transportation sector and lack of sustainability due to increased carbon emission has been sufficiently answered with the use of EV that has depreciated the requirement of conventional fuel acquiring practices that resulted in environmental degradation as well. But, despite their characteristics, there are many threats to widespread adoption of EVs, which have to be carefully considered to realize the goals of sustainability for EVs. As these threats are both technical and systemic, deficiencies with resource extraction, grid demand, battery disposal, and social and economic impact are all issues that can arise.

4.2.5.1 Environmental Impact of Resource Extraction

The raw material for electric vehicle batteries is a great threat to the sustainability of electric vehicles with its environmental and social challenge including lithium-ion batteries. Lithium-ion EV batteries require the burgeoning critical minerals like lithium, cobalt, nickel and graphite which can cause environmental degradation and human rights abuses.

In many cases, mining of these raw materials comes with very severe environmental consequences. For instance, lithium extraction in Atacama Desert in Chile can lead to water scarcity due to the fact that large volumes of water are used in the process, which ends up having a negative effect on the local ecosystem (Nørgaard, 2020). Cobalt mining in the Democratic Republic of Congo (DRC) is linked to high deforestation, water contamination, and the displacement of the local people (Lu et al., 2020). Mining for these resources comes at a cost to the environment — it can, in fact, work against the same sustainability motors are trying to achieve.

Lithium mining, however, takes place in countries like Chile, Argentina and Bolivia (what is known as the 'Lithium Triangle'), depends on exploiting lithium from brines but it is much cleaner than lithium mining in deep mines or from natural clay. To do so, we still need to pump and evaporate large volumes of water to leave the brine, and concentrate the lithium. Producing one ton of lithium can require up to 2 million litters of water, as according to A 2019 report by The Guardian, which has put some water resources in these arid regions on alert. The extensive water use can lead to the depletion of local water supplies, affecting agriculture and drinking water for nearby communities.

Similarly, nickel mining also involves significant water consumption. The mining of nickel often requires the use of water to separate the nickel ore from other materials through a process known as hydrometallurgy. This process, along with the waste created during the extraction, can contaminate surrounding water systems with heavy metals and other pollutants, harming both ecosystems and local populations. A 2020 study from the International Institute for Environment and Development (IIED) highlighted the environmental challenges posed by nickel mining, which is used in EV battery production (IIED, 2020).

Cobalt mining, in particular, has been associated with significant human rights violations, including child labour and unsafe working conditions. As demand for EVs grows, the pressure on mining operations to meet supply can exacerbate these issues, making ethical sourcing a crucial concern for the industry (Responsible Cobalt Initiative, 2020). Although some companies are attempting to implement more stringent supply chain due diligence, the overall impact of raw material extraction remains a significant threat to the sustainability of EVs.

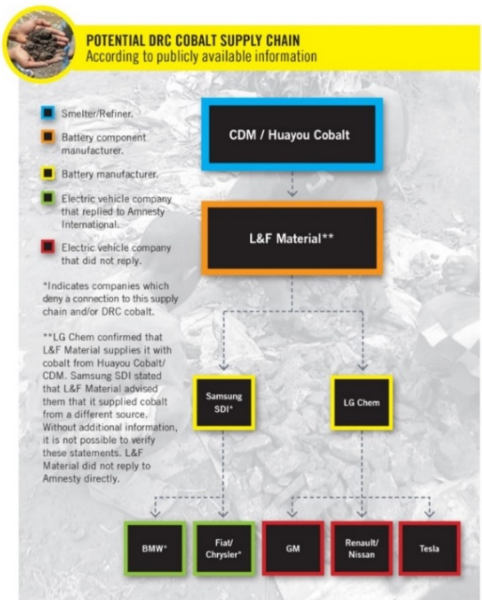


Figure 19 Electric car supply chain under scrutiny ('Without legislation that makes human rights due diligence mandatory, companies will continue to skirt the issue and benefit from child labour and other abuses.') (Amnesty International, 2016)

4.2.5.2 Energy Grid Strain and Energy Source Impacts

A critical challenge for EVs is the potential strain on energy grids as EV adoption increases. In regions where electric vehicles become a major part of the transportation sector, the demand for electricity could rise significantly, placing pressure on the existing grid infrastructure. This is particularly concerning in areas where the grid is already under stress or where the energy mix relies heavily on fossil fuels.

The rapid adoption of electric vehicles will lead to an increase in electricity demand, especially during peak hours when many consumers charge their EVs after work. Therefore, in the developed economies, the aging infrastructure can incur higher cost that becomes a resistance in the widespread adaptation of EVs in the transport industry where the consumers may be inclined to charge their vehicles at a similar time. For example, they may be willing to charge their cars after work hours resulting in significant load for the charging stations and increased waiting times. These may include expansion of transmission lines as well as raising capacity of generation, and development of smart grid systems to accommodate fluctuating energy demand (IEA, 2020).

4.2.5.3 Electric Sources and Sustainability:

The environmental benefit of electric vehicles largely depends on the sources of electricity used for charging. If the electricity grid is predominantly powered by fossil fuels, such as coal or natural gas, the net reduction in emissions from EVs may be minimal or even negative. In fact, in some countries with heavy reliance on coal-fired power plants, the emissions from charging EVs may be higher than the emissions from traditional gasoline-powered vehicles (Hawkins et al., 2013). Therefore, the sustainability of EVs is closely tied to the transition to cleaner, renewable energy sources.

4.2.5.4 Battery Disposal and Recycling Challenges

As EVs become more common, the disposal and recycling of their batteries present another significant threat to their long-term sustainability. Battery recycling is a complex and costly process, and currently, a relatively small proportion of lithium-ion batteries are recycled at the end of their life cycle.

The growing volume of EVs on the road means that, over time, an increasing number of batteries will reach the end of their life. Without sufficient recycling infrastructure, these batteries could contribute to electronic waste (e-waste), creating a significant environmental problem. Most EV batteries contain toxic materials, including cadmium, lithium, and cobalt, which could leach into the environment if not properly disposed of. Currently, only a small percentage of EV batteries are recycled effectively, and the process itself can be energy-intensive and costly (Hawkins et al., 2013).

The infrastructure for recycling EV batteries is underdeveloped, and there is a need for significant investment in establishing efficient and environmentally friendly recycling systems. Without such investments, EV adoption could lead to an accumulation of hasardous waste, undermining the environmental benefits of electric transportation (Gaines and Cuenca, 2000).

4.2.5.5 Social and Economic Impacts

While the widespread adoption of EVs presents numerous opportunities, it also poses several social and economic threats that could impact various communities, industries, and economies. The transition to electric vehicles could lead to job losses in industries related to fossil fuel extraction and refining. Workers in oil and gas sectors, as well as those in the traditional automotive industry involved in manufacturing internal combustion engine (ICE) vehicles, may face displacement without adequate retraining or support for transition (ILO. 2020). Governments will need to ensure that the transition to electric vehicles is just and equitable by investing in job retraining programs and social safety nets for affected workers.

EVs are still relatively expensive, and not everyone can afford to switch to electric transportation. This creates a potential disparity between higher-income and lower-income populations in terms of access to clean transportation. While EVs can reduce long-term transportation costs through lower fuel and maintenance expenses, the upfront cost remains a barrier. If access to EVs is limited to wealthier individuals, the environmental and social benefits of EVs may be unevenly distributed, exacerbating existing inequalities (Ajanovic, 2017).

In rural or economically disadvantaged areas, the lack of infrastructure particularly charging stations further exacerbates the problem of inequitable access to electric vehicles (Ajanovic, 2017). Without charging infrastructure in rural communities, EVs might be less adopted in places that are not urban centres. It could also be slower in low income countries for which relations receive limited resources to invest in required infrastructure.

4.1.4.6 Resource Scarcity and Ethical Concerns

The growing demand for electric vehicles has led to an increase in the demand for key raw materials used in EV production, particularly lithium, cobalt, and nickel. The extraction of these materials poses significant sustainability challenges, both in terms of resource availability and ethical concerns (Lu et al., 2020).

The growing market for electric vehicles has resulted in an elevated demand for the raw materials needed for the production of EVs. These materials are difficult to extract in a sustainable way in terms of resource availability and ethical concerns (Lu et al., 2020).

These are essential to make lithium ions batteries but extracting lithium, cobalt and nickel can be harmful to the environment. Furthemore, Lithium mining can marginalise water resources in areas with agricultural input while cobalt extraction enhances deforestation, soil erosion and contamination of natural water supplies in a region. The mining of these materials also has the capacity for contributing to biodiversity loss, since areas critical to the habitat may be destroyed in the process (Lu et al., 2020).

The extraction of battery material also has environmental and ethical issues because of the poor regulation of mining practices in countries involved. Although the vehicles themselves are cleaner options of the fuel-burning kind, the supply chain for the materials from which EV batteries must be purloined has seen ethical and human rights concerns. For example, DRC has labelled cobalt mining's exploitive labour practices that has resulted in significant concern for thedevelopment of industry and also includes unsafe working condition and involuntary child labour practices(Responsible Cobalt Initiative, 2020). Some of the children as young as 7 or 8 years old work in dangerous places without the provision of any safety equipment; they are left to carry the heavy loads full of explosives, explosives which turn deadly once discharged. They are made to be exposed to toxic chemicals, physical harm, and risks to their health (Responsible Cobalt Initiative, 2020). As these ethical issues are undermining the sustainability of electric vehicles, they are increasing suffering of humans and demanding more transparency and accountability of supply chains, therefore these ethical issues are not serving to the mobility needs of the world.

Initiatives to tackle these problems of ethics include the development of measures to make traceability of raw material and source them fairly better. For instance, and among other things, several leading automakers and downstream battery producers are advancing the development of supply chains that meet the principles of international human rights standards, including the Responsible Cobalt Initiative and the Cobalt Supply Chain Due Diligence Standard in the Refineries. But there are still challenges to overcome with those initiatives insuring that the benefits of EV adoption are not being lost out due to unethical practices.

Manufacturers including Tesla and BMW, have pledged improve and observe their supply chain in an efficient manner in pursuit to ensure effectiveness in ethical concerns associated with the EV industry. But these measures are often questioned for their effectiveness, as it is difficult to monitor and make sure that labour is practiced fairly in such regions where governance and oversight are not easy to track.

Initiatives like the Cobalt Refinery Supply Chain Due Diligence Standard and the Responsible Cobalt Initiative aim to address human rights issues in the supply chain, but challenges persist in ensuring that these standards are effectively enforced (OECD, 2016; Responsible Cobalt Initiative, 2020).

4.1.4.6 Uncertainty in EV Battery Technology and Conclusion

Technological uncertainty is one of the main obstacles for the EV market. However, as the industry becomes more competitive, multiple competing battery technologies and charging standards are being developed. This lack of standardisation could result in a fragmented market which presents consumers with compatibility problems with charging stations and manufacturers with no common technologies to develop (Breets, 2021). Such uncertainty can stall widespread adoption of the technology with its early adopters and eventually other businesses and consumers waiting for a more mature technology to emerge.

Although electric vehicles present a valuable contribution to a de-carbonised transportation approach, integrating them to the global market and society faces several major hurdles. EVs require addressing the environmental impact of the resource extraction to the energy infrastructure strain and the battery disposal challenges if they are to fulfil their sustainability potential. Other important factors in the progressing and success of the transition to the electric mobility will be also social, economic and technological. These barriers need to be hurdled by policymakers, industry and researchers working together toward a truly sustainable EV future.

	Positive	**Negative**
Origine interne	***STRENGTHS*** *Tailpipe emissions (CO^{2}-NOx) *Energy Efficiency and lower Operating costs *Reduced dependence on fossil fuels *Promotion of circular economy and sustainable manufacturing *Social benefits ***S***	***WEAKNESSES*** *High lifecycle emissions from batterie production *Limited availability and sustainability of charging infrastructure *Resource scarcity and ethical concerns * end of life and recycling challenges *Equity and accessibility issues ***W***
Origine Externe	***OPPORTUNITIES*** ***O*** *Technological advancements and innovation *Economic opportunities and job creation *policy and regulatory support *Societal opportunities and consumer trends	***T*** ***THREATS*** *Environmental impact of resource extraction * energy grid strain and energy source impacts *battery and recycling challenges *Social and economic impacts Market fragmentation and technological uncertainty

Figure 20 SWOT Analysis Electric Vehicle in Sustainability (Author, 2025)

4.3 Artificial Intelligence

4.3.1 Introduction

In the previous passage, a comprehensive SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis was made on Electric Vehicles (EVs) in order to assess its sustainability as a technology as well as the contribution such a technology can have in a greener future. Based on this framework, the next step is to take the focus to Artificial Intelligence (AI), another major technological advancement that is very popular to this day in transportation, as well as healthcare, energy, and others. AI has the potential to completely transform industries and offer many innovative solutions to global troubles, ranging from sustainability to many other challenges. However, it is essential to closely investigate conditions under which AI has a sustainable impact on the environment as well as on the society in the long run.

Just like EV adoption itself would bring challenges that have to be considered in a sustainable way, AI itself has its pros and cons, opportunities and risks that have to be handled carefully. A passage through a SWOT analysis of AI about strengths and weaknesses of AI as a technology to see if it has potential to leverage to support AI's sustainability. Additionally, the analysis will address the opportunities and threats AI may have in enabling systems to be optimised and efficiency in industries while also posing risks concerning resource consumption, displacement from jobs, and ethical issues.

Since AI is growing, it is important to consider whether AI's worldwide impact can indeed be sustainable as there are challenges like the carbonadown of data centres, energy, and responsible governance. After performing the previous analysis regarding electric vehicle, this analysis seeks to give a balanced depiction of AI's part in help in making a future friendly.

4.3.2 Strengths of AI

4.3.2.1 Data Analysis and Insights

With much environmental data available in the form of sensors, satellites and other sources, AI can analyse this data to reveal patterns, predict trends and bring great value to the decision makers of sustainability initiatives (Sands and Peel, 2018).

The ability of AI to process and interpret complex datasets enables better environmental monitoring to detect pollution, track deforestation and model climate change (Kuner et al., 2020). In the case of the environment, this can be very important because it allows for enforcing environmental regulations and keeping polluters responsible. Using predictive analytics it is possible to identify areas where environmental risk and vulnerability are present (Scotford, 2017). A demonstrative example, AI could forecast the consequences for coastal townships and developing preemptive adaptation plans. AI can be used in court when environmental damage is concerned, as the use of satellite imagery is used (Freestone and Barnes, 1999).

4.3.2.2 Optimisation and Efficiency

With AI algorithms, resource allocation, energy usage and production processes in several industries can be optimised and waste and carbon footprint reduced (Redgwell and Roggenkamp, 2018).

Smart grids powered by AI can maximise the energy distribution, minimising energy losses and making use of renewable energy sources better. It can be used in supporting the transition to a low carbon economy. Supply chains can also be optimised by AI which will reduce the waste and improve resource efficiency. It can also bring to the circular economy and decrease the environmental impact of production and consumption (Brack, 2003). As rare earth minerals are finite, the fact that materials can be optimised for its use in manufacturing through the application of AI is useful, since this allows manufacturers to reduce the amount of minerals being mined. Bodansky et al. (2017), this can reduce the environmental impact of mining. AI powered system can help implement and monitor regulating carbon emissions and resource efficiency better (Bodansky et al., 2017).

4.3.2.3 Precision Agriculture

Data from real time enables AI to be used in agriculture to optimise water and fertiliser usage for the maximised crop yield with the least impact on the environment (Scott, 2019). Artificial intelligence (AI) integrated precision agriculture is changing how the sustainable farming practises are run, especially improving resource allocation and minimising environmental degradation. AIs can be used by farmers to get detailed information on the health of their crops, soil and weather conditions using real time data from all kinds of sensors, drones and satellite imagery. By this approach, based on this data driven, the use of water and fertilisers is highly targeted, but this has significantly reduced the overuse of water and fertilisers (Alazzai et al., 2024).

With its ability to analyse complex datasets, AI can create predictive models that predict crop needs and the need for all resources in the resource chain pre-emptively to allow for proactive resource management. An example of this is AI powered systems that are used to monitor soil water levels and weather forecast to calculate just how much water is needed to irrigate, thus avoiding overuse of water and water running off (Brears, 2024). Like this, the AI can analyse the nutrient levels in the soil and optimise fertiliser application to prevent chemical runoff into the water potentially polluting it. Not just increasing yields, this precision also reduces the ecological footprints of agricultural practise.

AI also initiates early detection of pests and diseases and gives the farmer the option of tailoring the treatment, sparing pesticides from being used indiscriminately. Images of crops can be used as inputs for computer vision and machine learning algorithms to identify stress, infestation, and so on, which can be acted upon in a timely manner, preventing damage to an even larger population. Considering this approach leads to integrated pest management, where it will reduce on chemical pesticides and keep biodiversity intact.

AI in essence assists the farmers to understand what is best for the maximisation of resource use and sustainable farming (Sharma et al., 2023). AI further increases the productivity of agriculture by using irrigation, pests and fertilisation in a more precise manner, while causing less environmental damage. It is this technological advancement that will help meet the rising demand for food while preventing damage to the planet's resources.

4.3.2.4 Renewable Energy Management

Introducing artificial intelligence (AI) for management of renewable energy sources in particular, solar and wind powered, constitutes a paradigm shift in the quest for sustainable energy systems. There are inherent variability in these sources which poses great challenges to grid stability, and AI offers a highly sophisticated solution based on its predictive analytics and real time optimisation (Redgwell and Roggenkamp, 2018). AI algorithms can accurately forecast fluctuations in solar and wind power generation by analysing huge datasets comprised of weather patterns, historic energy production, and current grid conditions. This predictability is critical for the grid operators, allowing them to foretell imbalances between supply and demand and thus, address the problem at an early stage. That is very important if one thinks about the increasing quantity of distributed energy resources getting installed on national grids. As AI gets more and more accurate forecasting becomes more and more important.

Moreover, AI driven optimisation is really important to improve grid integration efficiency. The use of AI systems to dynamically distribute and store the energy can improve renewable energy usage to the maximum and reduce dependencies on fossil fuel based backup power. This is also extended to the energy storage system management in which AI algorithms can identify the best charging and discharging cycles given the expected availability and demand of the energy (Heffron and McCauley, 2016). This provides stored energy when needed, stabilising and strengthening the grid. This optimisation kind will also to be used more and more in micro grids, as well as in localised energy production.

The legal and regulatory issue of which is multifaceted. By streamlining its application into grid operations, AI systems may necessitate adaptation of the existing regulatory frameworks governing grid stability and energy supply. For instance, regulations around grid connexion and balancing will have to be revised to adjust to the variable nature of AI powered energy management. Secondly, the application of AI in energy trading and market operations gives rise to issues of transparency, fairness and accountability for which such regulatory safeguards are required. Even though the AI systems will be producing the data that will turn into valuable assets, it probably won't be an exemption from data protection and data ownership regulation. Furthermore, the application of AI to renewable energy management carries great import for international climate change law and policy. The integration of increasingly high proportions of renewables can be assisted by AI-powered grid optimisation which helps realise national and international climate targets. Firstly, AI can also be used to monitor the effectiveness of climate change targets, and secondly AI can monitor the effectiveness of renewable energy targets. AI can be used to improve reliability and efficiency of renewable energy systems and thus accelerate the transition to a low carbon economy in support of the Paris Agreement and other climate initiatives (Hancher et al., 2012).

In other words, one of AI's most prominent contributions in enabling renewable energy sources' potential in the creation of a sustainable future is based on its effective management of the same. AI is reshaping the way we harness and use renewable energy by giving us tools to accurately predict energy production, perfect grid integration, and improve energy storage.

4.3.3 Weaknesses of AI

Artificial Intelligence (AI) is commonly heralded as a ground-breaking tool to help tackle issues of global sustainability like maximising resource use and combating climate change. But at the same time, it does have a number of drawbacks when it is deployed. The weaknesses of AI in fostering sustainability discussed in this thesis is around its impact on the environment, dependence on resources, and socio-ethical limits. This thesis proposes that, if current trends prevail, AI will magnify existing environmental degradation and deepen existing socio-economic disparities, rather than mitigating them as intended. These weaknesses need to be addressed in terms of robust regulatory framework, interdisciplinary collaboration and commitment to ethical and sustainable AI development.

4.3.3.1 High Computational Cost

While AI's potential in sustainability initiatives is hugely promising, it also carries with it inherent challenges in its implementation. There is however, one significant weakness in that training and running complex AI models require a high computational cost. The computational intensity this represents means that a lot of energy is being consumed, and in some sense, there is an issue with the very sustainability goals AI is said to be advancing. There exists a paradox in using energy intensive technologies to mitigate environmental impact (Strubell et al., 2019). Deep learning models for such sophisticated environmental monitoring or optimisation tasks require large datasets and complex neural network architectures, and these models must be trained. In fact, these models are trained through various iterative process, which is generally extensive process and requires heavy processing power, even specialised hardware like graphics processing units (GPUs) or tensor processing units (TPUs) (Schwarts et al., 2020). These hardware components can be quite energy intensive, enabling significant carbon emissions during training (also powered by non-renewable energy sources).

For instance, even the great large language models need big compute for training and create a lot of carbon footprint (Bender et al., 2021). In addition, the energy consumption of the operational phase of AI models, that is, when they are run on prediction or control systems, also needs considerations. Continuous operation of AI systems, even when less intensive than training, demands substantial computing power in cases such as smart grids or precision agriculture. AI processing distributed to multiple devices, where it decreases latency, but increases overall energy consumption if not managed efficiently, is an example of proliferation of edge computing.

The computational cost of AI's environmental impact is not limited to direct energy usage. Because of resource intense and committing manufacturing processes and needing rare earth minerals, the making of AI hardware including GPUs and TPUs can be incredibly environmental and social costly. Biodegradable waste from outdated AI hardware also presents a challenge as it contributes to electronic waste and pollution (Patterson et al., 2021).

Multi-faceted approach is needed for addressing the high computational cost of AI in sustainability. The first and the most important is to develop more energy efficient AI algorithms and hardware. Researchers are looking at a variety of techniques such as model compression, quantisation, and pruning, that enable the reduction in computational requirement of AI models without affecting the model's performance. Moreover, this requires development of specialised AI hardware focused on energy efficiency (Wu et al., 2019).

Secondly, if we are to transition energy sources used to power AI infrastructure to renewable energy. The greatest use of AI processing occurs in data centres that house the bulk of it, and it should be done using solar, wind, or other clean energy sources. This transition needs a large amount of investment and support to policy, however, it is crucial to mitigating the carbon footprint of AI (Wu et al., 2019).

The third, the lifecycle of AI hardware has to be more sustainable. Repairs and reuse of AI hardware need to be expanded as much as possible, while circuit boards remain as recyclable as possible. Also, more sustainable manufacturing practises should be applied on the company level, using less harmful materials and less waste.

Finally, it is highly important to have greater transparency and accountability towards the environmental impact of AI (Avgerinou et al., 2017).

Ultimately, the above factors conspire to make AI a very expensive pursuit as it relates to sustainability. The energy consumption of AI is a critical consideration when the tools it provides can both exacerbate the problems it aims to solve (Avgerinou et al., 2017). With the development of the more efficient AI technologies, change to the renewable energy sources, and use of the sustainable hardware, we can use the power of AI to make a future more sustainable.

Artificial intelligence (AI) is a powerful tool that has emerged as one of the fastest advancing technology to support technology in solving sustainability challenges. However, an obvious drawback (that removes its effectiveness when the complex AI models become transparent and explainable) is the lack of transparency and explainability of complex AI models. As with many AI systems, especially deep learning models, such deep learning systems are deliberately made 'black box', which makes it hard to know exactly why they are making their decisions, posing a huge impediment to trust, accountability, and the successful implementation of sustainability initiatives (Doshi-Veles and Kim, 2017).

Under normal circumstances, an AI model is not expected to provide the solution to a specific problem it is expected to generate a clue. In support of this cue, it is necessary to be able to understand how an AI model arrived at a particular conclusion in an unsustainable context, where decisions often involve complex trade-offs and have substantial social and environmental impacts. As an example, when an AI algorithm suggests a specific land management strategy or resource allocation policy, the stakeholders ought to know how it came to recommend that, in order to evaluate its reasonableness as well as the implications of such a suggestion. Without this transparency, the public will be, in essence, leaning blindly into this new AI driven decision making and potentially misspend much needed public trust on it.

Many AI models (in particular deep neural networks) have incredibly intricate architectures, so there lacks explainability. Such this model learns over lots of datasets in a complex patterns through multiple layers of interconnected nodes and it is difficult to locate the causality between input and output. Due to necessity of high accuracy, this complexity is usually necessary but comes at the expense of interpretability (Lipton, 2018). This lack of transparency has severe consequences in sustainability applications. For instance, if an AI model observes an anomaly or predicts a pollution event, it must be clarified how these events have been calculated (Rudin, 2019). Specifically, this information is key to pinpointing the root cause of the problem, implementing the efficient mitigation measures, and ensuring the polluters are held accountable. Likewise, in resource management if an AI algorithm gives some suggestion about how some resource should be allocated, stakeholders should grasp the empirical assumptions and standards of a fair and efficient allocation.

Furthermore, regulatory compliance and legal accountability are also strongly compromised by lack of explainability. For environmental regulations often require transparent and auditable decision making process. When AI systems are employed to assist in determining regulation, which is what this is, their obscurity raises significant legal and ethical questions. For instance, if the decision generated by an AI causes environmental damage, it's difficult to recognise who is accountable, and what must be done to remedy the damage (Wachter et al., 2017). To address the lack of transparency and explainability of the AI for sustainability, a joint effort from the researchers, developers and policymakers is needed. By the way, there is an approach to develop the explainable AI (XAI) techniques that could provide us with an insight into the inner workings of the AI models. XAI methods attempt to empower human users to transparently understand AI decisions by explaining AI decisions in ways that are human understandable. These are methods such as feature importance analysis, rule extraction and visualisation.

From another point of view, the goal should be to develop AI models which are inherently transparent and interpretable. An example of this is that deep neural networks are less transparent than rule-based systems or decision trees — although this may come at the expense of accuracy or complexity. Interest in hybrid models, however, has been on the rise in memorizing the accuracy of deep learning with the interpretability of rule based systems (Rudin, 2019).

Additionally, rules and norms for using AI in sustainability should be set (Selvaraju et al., 2017). In fact, according to these frameworks, these should be centred on the need for transparency, accountability and human oversight (Brynjolfsson and Mitchell, 2017). Issues such as data privacy, bias, and fairness of the application also need to be addressed by them (Selvaraju et al., 2017). A key mistake is not requiring companies and organisations implementing AI systems to disclose their decision making process and have a mechanism to act on mistakes when there is an error or an unintended result. Finally, it is important to facilitate interdisciplinary collaboration between AI researchers, environmental scientists, social scientists and policymakers (Brynjolfsson and Mitchell, 2017). This collaboration will help assure that when AI systems are developed and deployed, they will act in the contribution to sustainability goals and in accordance with social values (Goodman and Flaxman, 2018).

Overall, the transparency and explainability deficit in complex AI models is a hindrance for effective use of the corresponding complexity in the sustainability. Addressing this weakness is subtle and requires a multi-dimensional technique such as introduce XAI techniques, propagate inherently interpretable models, formulate ethical rules, or foster interdisciplinary relationship (Wachter et al., 2017). We can make the most of the power of AI for a sustainable future by prioritising transparency and explainability (Goodman and Flaxman, 2017).

4.3.3.2 Data Bias and Fairness Concerns

Data bias is manifested in a variety of ways such as historical bias, representation bias, and measurement bias. If information in data represents past discriminatory practises, historical bias occurs and the AI model will learn from this historical bias and keep on reproducing this inequality (O'Niel, 2016). Say environmental data is skewed towards affluent regions, as AI algorithms are likely to put a focus on those areas' pressing needs over the environmental vulnerabilities of the marginalised. When data used to train machine learning models are biassed towards one group or another, then representation bias forms, and the model's outcomes are skewed (Barocas and Selbst, 2016). Measurement bias applies when the process of gathering data is biassed, like when sensors are placed more frequently in some areas and less frequently in others, leaving such areas unrepresented and hence not being truly speaking the environmental conditions (Mehrabi et al., 2021).

The consequences of data bias are severe in the context of sustainability. For example, AI based environmental risk assessment can underestimate the climate vulnerabiltiy of marginalised communities like flooding or heat wave if these communities' data from marginalised communities is underrepresented. Likewise, AI based resource allocation system may reserve resources for affluent places, resulting in an unfair aspect of clean energy or water resources (Mehrabi et al., 2021). The data collected by AI algorithms for environmental monitoring activities could become sites for reinforcement of discriminatory practises in the enforcement. For instance, facial recognition technology used to detect illegal dumping may be biassed towards detecting members from certain racial or ethnic groups present in the training data. Such enforcement, it can bring about, may be uneshaken and reinforce existing social imbalances.

AI driven environmental decision making also poses ethical and legal concerns of lack of fairness. Environmental justice principles involve the equitable distribution of environment advantages and disadvantages. Perpetuating discriminatory outcomes is a violation of these principles; it can erode public trust in sustainability initiatives by exposing the sources of discrimination in the technologies that power sustainability initiatives. A multi-facetted approach is necessary in order to address the data bias and fairness in AI for sustainability. The first requires a better sense of the risk and bias in the AI algorithms and data. To control this bias, researchers and developers need to be trained to identify and mitigating bias during the lifetime of AI development.

Secondly, efforts should be made to overcome the quality and representativeness of environmental data. It's about gathering data from various places and sustaining marginalised people. Data gaps can be filled with the help of the community based data collection initiatives and all stake holders will be taken cognizance. Third, computer algorithms must be unbiased and explainable. Here, it consists of devising ways of detecting and eliminating bias in AI models, for instance, by implementing fairness aware machine learning or explainable AI. Machine learning algorithms that are fairness aware aim to reduce differences between different groups in outcome and explainable AI techniques give an insight into the decision process to allow for the identification of bias (Hutchinson and Mitchell, 2019).

Finally, it is important to set out ethical guidelines and policies for the use of AI for sustainability. It should be highlighted that these frameworks put the emphasis of fairness, transparency and accountability. Finally, they should address problems like data privacy and security to ensure that people's and communities' rights are protected (Crawford & Schults, 2014). There is the need for fostering interdisciplinary collaboration between AI researchers on one side, and environmental scientists, social scientists, policymakers on the other side. Thus, this collaboration would make it possible that AI systems are developed and deployed in a way that is in line with sustainability goals and societal values.

Within its limits, data bias and the issue of fairness with regards to the use of AI for sustainability issues are a challenge for the responsible use and objective of this type of AI.

4.3.4 Opportunities of AI

In energy, agriculture, water management, climate modelling and waste reduction, Artificial Intelligence (AI) has vast possibilities in advancing sustainability. Organisations, governments, NGOs and any other interested party can utilise AI driven insights to optimise resource use, minimise environmental footprint and drive innovation towards a more sustainable future.

4.3.4.1 Smart Cities Development

Smart city practises using AI enable better resource optimisation of urban infrastructure and thus help achieve sustainability as well as reduced congestion and better air quality. To this end, AI powered traffic management systems analyse real time data to cut down traffic congestion resulting in reduced emissions from vehicles. For example, by reducing carbon footprints, Singapore and Amsterdam have successfully put into use AI based smart transportation system (Kröger et al., 2020). Sustainable building management due to HVAC by AI. Smart buildings adopt AI driven energy management solutions that consume less power and results into less greenhouse gas emissions (Suboff, 2019).

A number of smart city initiatives have sprung up in the Middle East that use artificial intelligence (AI) to help thrive the urban experience; sustainability; and economic diversification. As a flagship smart city initiative, NEOM project is the first phase of Saudi Arabia’s ambitious plan to transform the country’s economy by using cutting edge technologies like AI, robotics and advanced mobility (NEOM, 2025). NEOM is situated in the north-western part of Red Sea aiming at becoming a global innovation hub to develop AI for optimising the urban planning, energy management, and service delivery (Rev 9 Solutions, n.d.). The United Arab Emirates is investing very heavily in smart city projects especially in Abu Dhabi and Dubai (Government of United Arab Emirates, 2025). City planning, public transportation and other services are being improved by use of AI in these initiatives. AI-enabled projects taking place in Dubai include self-driving vehicles, predictive policing and smart health systems with these efforts aimed at improving urban living and security (Benito, 2024).

4.3.4.2 Sustainable Supply Chains

The integration of artificial intelligence (AI) in sustainable supply chain management can offer a transformative opportunity to tackle environmental as well as ethical concerns in supply chain management in the global production networks (Schwab, 2016). With AI's analytical abilities, businesses can push through the paces of unprecedented levels of transparency, efficiency and accountability so that sourcing, production and distribution are more sustainable and responsible. The ability of AI to process and analyse large amounts of data from different sources, such as sensor data, satellite imagery and blockchain records, means that supply chain operations are monitored in full. This capability is critical in detecting and counteracting environmental risk including deforestation, pollution, and depletion of resources. For example, these may monitor the origin of raw materials, environmental conditions at production sites, etc. which will track carbon footprint of transportation routes. The granular level of such visibility lets businesses find and fixing the sustainability bottlenecks in their supply chain. Moreover, AI algorithms can optimise resource allocation and production processes to reduce the waste and maximise the efficiency. AI systems can analyse historical data and also real time information to predict the demand fluctuation, reduce inventories and better manage logistics operations. Reduction of the environmental impact as well as the economic performance are realised by this optimisation. For instance, AI is used to optimise transportation routes in order to minimise fuel consumption and emissions. It can also be used to predict when maintenance is required and prevent equipment failure before time and minimise downtime.

The second critical aspect of a sustainable supply chain is ethical sourcing, and AI can greatly contribute to eliminate the black sheep of the industry by ensuring responsible practises in sourcing materials from fair labour. AI based systems are able to watch working conditions at supplier facilities and watch for labour standard compliance and assesses the social impact of source decisions. By combining blockchain technology with AI, traceability and transparency are improved by verifying records of product origins and labour practises. It can also assist in fighting against trafficking of humans, child labour and illegal logging.

AI implementation in sustainable supply chains also promotes the adoption of the principles of the circular economy. First it analyses of product lifecycles and material flows, which allows it to pinpoint recycling, reuse and remanufacturing opportunities for products. It can also assist in cutting down the amount of waste and minimise our dependence on virgin resources. For instance, as in Carter et al. (2008), reverse logistics processes can be optimised by way of advanced aids including AI. There are several additional factors that go into building sustainable supply chains: collaboration is essential, as is transparency. For businesses, working closely with their suppliers, customers, as well as other stakeholders would need to share data and best practises. In addition, they should be transparent in what they are doing on the sustainability front and have verifiable proof of their progress (Gold et al., 2010).

In order for businesses to fully leverage AI in sustainable supply chains the infrastructure and expertise need to be funded. Some of it includes developing strong data management systems, train employees using AI technologies and form partnership with AI experts. Interestingly, gold et al (2010) state that governments and international organisations also have a role to promote the adoption of AI in sustainable supply chains. Policies involving incentives for sustainable practises, regulations for transparency and accountability, initiatives aiding in research and development, among other things, are some ways that this can be achieved.

In short, AI provides a tremendous toolkit for making supply chains engines for sustainability. It will improve transparency, optimise the use of resources and encourage ethical sourcing.

In closing, it is worth noting that AI offers transformative opportunities for changing the future towards increased sustainability on all levels. AI can be used for the optimization of energy efficiency and climate monitoring, smart agriculture, sustainable farming, waste reduction and water conservation.

4.3.4.3 Climate Change Mitigation

As the importance of mitigating climate change rapidly increases, we need innovative and powerful tools and artificial intelligence (AI) is playing a very important part in this area. With its capability to engage with huge data, find intricate patterns, and develop predictive models, AI can significantly help mitigate risks in climate change and optimise strategies for doing so. AI has the potential to help predict extreme weather events, increase human resilience and reduce the impact of climate change by optimising carbon capture (Bengio et al., 2019). Anticipating and preparing for extreme weather events is one of the most pressing challenges in climate change mitigation. Predictive models driven by AI can take history of weather patterns, climate data, and such environmental factors to predict likelihood and severity of events like hurricanes, floods, drought, and heat waves. Such predictions can serve as the basis for early warning systems that can help communities reactively taking preventive measures to save lives and infrastructure. For instance, AI can use satellite imagery and sensor data to predict how a hurricane will move, and how strong, so evacuations can happen as soon as possible and resources are distributed. In addition, it can help policymakers create adaptation strategies for coastal communities based on the modelling of how sea level rise will affect them.

Aerial is also involved in optimising carbon capture and storage (CCS) technologies with the help of AI. Carbon dioxide emissions from the industrial sources are captured and stored underground to stop those emissions from entering the atmosphere. Geological data can be processed with AI algorithms to locate suitable storage sites, determine the optimal injection rate and monitor storage process stability over time scale. Optimising these processes with AI can boost the efficiency and efficiency in which CCS can mitigate Greenhouse gas emissions (LeCun, 2015).

4.3.5 Threats of AI

Artificial Intelligence (AI) is an important contributor for sustainability, and at the same time, there exist a number of threats resulting from AI that can harm environmental, economic, and social sustainability.

4.3.5.1 Cybersecurity Risks

Despite the great opportunities that come with the increasing integration of artificial intelligence (AI) into sustainability initiatives (Goodfellow et al., 2014), there are also enormous cybersecurity risks. Since AI systems rely on large amounts of data to be able to operate, attack them is quite easy as they are increasingly being integrated into more and more situations in which the system needs to know very much in order to accomplish the task in hand. This would be a serious problem both to the integrity and reliability of any AI subsidised sustainability solution (Papernot et al., 2016). And the nature of AI systems, like those employed in smart grids, water management systems, and environmental monitoring networks is such that their cyberattack entry points are interconnected and complex. An effective assault renders sensitive data compromised, changes making decisions, and even interferes with the running of physical operations. For instance, an AI powered smart grid may become a victim to a cyberattack causing power outages or a water management system's fairytale being compromised creating contaminated water supplies.

Monitoring, and therefore securing, AI models, in particular deep learning systems, is a hard problem due to the complexity of these models. However, these models can be exploited by malicious actors if there were vulnerabilities in them, like they can inject adversarial inputs, manipulate training data or even steal intellectual property. In sustainability applications, adversarial attack can lead AI systems to make incorrect predictions or take unintended actions to have potential catastrophic consequences. As an example, adversarial attacks on AI enabled environmental pollution monitoring systems could result in false alarms or missed detections that undermine the effectiveness of pollution control efforts (Sissis and Lekkas, 2012).

Such proliferation of Internet of Things (IoT) devices, rather than helping in data collection for information about AI systems, increases the attack surface (Sissis and Lekkas, 2012). IoT devices are full of compromises, or rather, many IoT devices have limited security capabilities thus rendering them vulnerable to hacking and exploitation. A successful attack on an IoT network can break the data integrity reduction, hence rendering the data collected biassed or inaccurate, affecting AI models. An example of this might be resource inefficiency and environmental damage in a precision agriculture system where manipulated sensor data occur. Specifically, cyberattacks have the potential to interfere with key sustainability operations. Essential services from energy distribution, waste management and transportation are more and more automated and optimised through the use of AI. An attack on these systems that is successful can disrupt and be damaging to the environment in a great number of people. For example, if a cyberattack occurred on an AI powered waste management system, it could be used to improperly remove hasardous materials and contaminate public health and the environment.

In addressing cybersecurity risks in AI for sustainability, a multi-faceted approach is needed.

First of all, it is important to introduce secure mechanisms for all the parts of the AI ecosystem: hardware, software, and data (Liu et al., 2016). In this case, it involves protecting sensitive data and systems through encryption, authentication and access control mechanisms. One of the other key aspects is for having regular security audits and vulnerability assessments on hand to identify weaknesses and eliminate them.

For the second time, it's imperative to build AI models that are not prone to cyberattacks. The specifics of this include incorporating security in the AI model design and while training (Schneier, 2015). Adversarial training involves training with adversarial inputs to the AI model, increasing robustness to attacks. AI is used for anomaly detection with the objective of identifying unusual patterns or behaviours that could possibly be a signal for a cyber-attack.

Third, it is vital to set up incident response plans as well as set protocols in case of cyberattacks. It deals with setting up procedures for detecting, preventing, containing and recovering from attacks as well as communicating with various stakeholders and the public. That incident response plans are effective can be regularly verified through regular cybersecurity exercises and simulations.

The fourth is to encourage collaboration among stakeholders, government agencies and industry as well as research institutions. Such practise involves sharing their best practises, threat intelligence and technological expertise. Particularly, public private partnerships have a critical role to play in helping in standardising and Guideline development and implementation in cybersecurity (Anderson, 2020). Finally, it is important to promote cybersecurity risks in AI in the context both of development and use, as well as to policymakers. This consists in giving training and training in cybersecurity best practises and research and development in AI security (Schneier, 2015).

4.3.5.2 Job Displacement Concerns

In addition to a brand new technological revolution, sustainability falls victim to a big threat of job displacement. Consequently, AI's ability to automate tasks that were previously performed by humans becomes a matter of concern regarding the large number of work resulting in job losses more broadly in sectors that depend on routine and repetitive work (Ford, 2015). Mass unemployment is a potential that demands good workforce transition strategies for responsible mitigation of its social and economic consequences (Brynjolfsson and McAfee, 2014). AI automated automation has the potential to replace workers in manufacturing, transportation, agriculture and in customer service (Ford, 2015). AI powered robots and automated systems in manufacturing can perform tasks like assembly, quality control, packaging, among others, at greater speed and precision to human workers. In the case of transportation, self-driving cars and AI optimised Logistics systems can eliminate the need of human drivers and delivery employees. For the agriculture sector, AI in Precision farming is used to automate planting, Harvesting and crop monitoring. However, in customer service, AI-driven chatbots and virtual assistants are capable of clarifying the routine issue and transaction personal, making human customer service representatives (Autor, 2015) redundant.

More especially, the potential for job displacement worries workers in low skilled and in routine based jobs, which are more at risk of being replaced by automated using AI. It can worsen existing social inequalities and increase unemployment, poverty. Moreover, job displacement has repercussion across the economy which cuts down consumer spending and slows down economic growth (Acemoglu and Restrepo, 2017). It can also deprive sustainability efforts of the social and economic consequences of job displacement. A widespread unemployment can generate social unrest, instability in politics and destroy the environment. This can lead unemployed people into doing unsustainable practises like illegal logging or poaching out of desperation to meet their needs. Additionally, job displacement decreases the tax base available to government to finance sustainability initiatives.

The displacement of employment concerns need to be addressed proactively and comprehensively (Acemoglu and Restrepo, 2017). Depending on what the workforce looks like in the future, workforce transition strategies have to include retraining and upskilling workers for jobs of the future. This entails making available education and training programmes in those in demand skills — (such as data science, AI development and renewable energy technologies) — to gain a competitive edge in the market. These programmes must be developed and implemented jointly by governments, businesses and educational institutions (Autor, 2015).

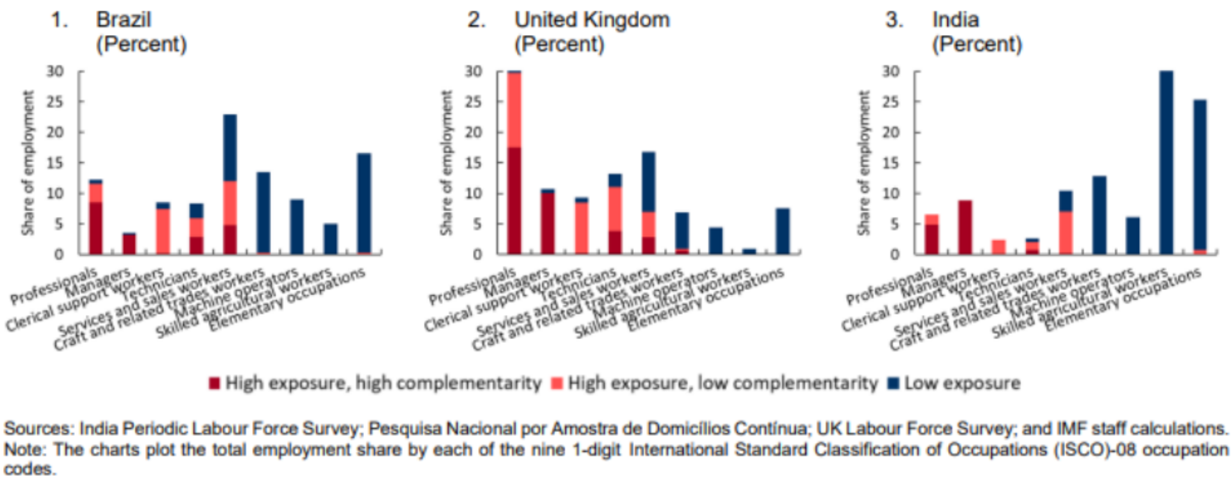


Figure 21 Employment Share with AI Exposure (Arène, 2024)

Not surprisingly, the International Monetary Fund said that AI technologies will affect nearly 40 percent of jobs worldwide. About 60 percent of the jobs harmed by AI are in high income countries, and half of them may be positively affected in order to increase productivity, the estimate said. New job opportunities in sectors that are emerging, such as the green economy, are how it is necessary to create. Renewable energy, sustainable agriculture, remediation investments can generate new jobs and boost economy. In addition, governments promote entrepreneurship and innovation by funding and backing startups and small businesses. Job displacement also means social safety nets are important to bear the impact of the job displacement, for instance unemployment benefit and social assistance programmes. Such programmes will assist temporary support to employees who had lost their job so they can retrain and seek new jobs. Additionally, it is also vital that these programmes are available to all workers regardless of background or location.

There is a fundamental reset of thinking required to transition to an AI driven economy: work and education (Manyika et al., 2017). The model of lifelong employment in a single job has to be replaced by lifelong learning and adaptability for a career. That is why it is about building a culture of continuous learning and opportunities to upgrade skills all over a worker's career. Ethical considerations are also paramount. The benefits of AI powered automation are to be ensured in equitable distribution and the costs are never to be placed disproportionately on the vulnerable populace. This is difficult to do and requires careful thinking and developing policies, but also a lot of dialogue with stakeholders (Manyika et al., 2017).

It is important to emphasise that for effective workforce transition strategies development and implementation, collaboration and knowledge sharing are essential. It's a case of governments, businesses, labour unions and educational institutions together must share best practises and come up with innovative solutions. In addition, international cooperation is necessary to solve global challenges of the job displacement. Job displacement concerns are a major threat to sustainable future of AI age. However, we can manage the social and economic consequences of automation if we diligently develop and implement appropriate workforce transition strategies, so that the advantages of AI are not dictated only by those with the resources to exploit and capitalise on it.

4.2.5.3 Regulatory Uncertainty

The lack of rules around development and use of AI makes for a risky environment that can thwart the use of sustainable AI. It creates regulatory void that fosters ambiguity, stifles innovation and undermines public trust, which undermine AI's full potential to be exploited for environmental and social good (Mittelstadt, 2019). This makes the situation in the use of or with AI a 'wild west', for lack of clear regulations — where AI developers and users go their own way, without a template of what is right or wrong. Inconsistent practises, unethical acts, and no accountability (Floridi et al., 2018) can follow from such ambiguity. As an example, if no laws surrounding data privacy and security are in place, an AI used to monitor the environment or manage resources might sift and analyse sensitive data without viable security. It could result in privacy breach, misuse of information and eventually loss of public trust.

It stifles innovation in sustainable AI when there is no clear regulations. That means that developers/nearshore programming teams that ARE developing and deploying AI solutions are quite likely to be risking their sanity over legal and regulatory constraints. It can discourage investment in research and development into the creation of new and innovative sustainable AI technologies (Floridi et al., 2018). This means, for example, such developers of AI powered carbon capture technologies will be reluctant to invest into large scales of deployments, should they not be sure about whether to store and monitor carbon. Additionally, as regulatory clarity is lacking in the field of sustainable AI solutions, the public procurement of and adoption by governments of such solutions become difficult. If the legal and ethical implications of AI powered systems are not clearly sensed, government agencies may be reluctant to incorporate such systems. As such, the adoption of AI solutions for public services like waste management, transportation and energy distribution (Jobin et al., 2019) can be slowed down.

It also means that there's no clear regulation and public trust in AI can suffer. Using full automation for sustainability can prompt scepticism and resistance from the public as they are concerned with fairness, transparency, and bias. As one general example, if communities do not fully understand the data and algorithms being used in AI-driven environmental risk assessments, such assessments might not be accepted by these communities. The lack of trust can hamper the deployment of effective AI-driven policies regarding sustainability (Taddeo, 2018). Proactive approach and collaborative are needed to address the regulatory uncertainty. The development and use of responsible AI should be the outcome of a combination of clear, comprehensive government, industry, and academia regulations. They must address such key issues as privacy data, security, transparency, fairness, and accountability.

Regulatory development one of the most important part include of establishing ethical guidelines of AI (Taddeo, 2018). By following these guidelines, these should frame the development and uses of AI systems, in a way that is consistent with what is considered to be towards societal values and ethical principles. In addition, it should discuss problems like bias, discrimination, problems of unintended consequences. It needs crucial development in standards and best practises for AI development and deployment. The standards should not, for example, fail to provide very clear guidance on things like data quality, model validation, and system security. Interoperability and allowing data to share, should also push them into building inclusive AI solutions for sustainability (Jobin et al., 2019).

Well-regulated regulatory sandboxes can also serve as a means to test and evaluate new AI technologies in enclosed style. They enable developers to test out innovative AI solutions and regulators to weigh in on potential impacts of those solutions. It can also be of benefit to inform the development of regulations and standards. Another factor leading to regulatory uncertainty is the need for international cooperation. It is from the global technology, and the development and use of AI do not have borders in the national. For this reason it is crucial to put in place standard and guidelines at international level in order to guarantee consistency and interoperability (European Commission, 2019).

It is only through public engagement and consultation, will trust build and the regulations match socially relevant values. Stakeholders should be brought on-board by governments to participate in a collaboration with civil society organisations, industry representatives and the public in order to better understand the input and feedback on regulatory proposals (European Commission, 2019). Thus, in conclusion, the regulatory uncertainty threatens the adoption of sustainable AI solutions. To make the AI's potential of driving sustainable development possible, we have to build up a healthy regulatory environment by developing clear and elaborate regulations; setting out the clear and basic ethical guidelines; enhancing the standards and best practises; and furthering the international collaboration.

Overall, AI brings in both transformational and detrimental opportunities for sustainability, and therefore all its threats need to be seen and addressed through the energy efficient AI models, ethical AI governance, misinformation counter measures and robust regulatory policies. If nothing is done, AI’s environmental, social and ethical risks may exceed its benefits, posing a threat to its role as a force for sustainable development. This addresses how, with responsible AI frameworks, societies can leverage AI for its potentials, while avoiding its risks to the global sustainability. In fact, the AI Action Summit 2025 raised the issue of a huge tension in the international approach to artificial intelligence between the need to innovate and the need to regulate (AI Action Summit, 2025). While AI was discussed by the summit to improve its possibilities of sustainable development, there was no unification of the regulatory framework. Important was the fact that key nations would not sign the final declaration showing the, not very deep, divide amongst nations on how to govern AI. The lack of firm, internationally recognised rules on the ground renders this space open to all manner of risks, from ethical breach, overuse of data, and the allocation of AI systems with outcomes that cannot be anticipated.

To be aware of the risks of AI’s rapid development and to follow the warnings of the expert community, it is important to be vigilant. Recent rapid development of artificial intelligence (AI) has spurred real concerns among experts, policymakers and world leaders about the dangers of the technology, says AI Safety Centre, which is a statement. Just as with powerful technologies, the risks and the potential must be handled with great responsibility to manage the risks associated with advanced AI underscores these concerns. Sadly, as the capabilities of AI, specifically machine learning and deep learning grow exponentially, so do difficult challenges like ethical behaviour and the absence of robust regulatory frameworks to implicitly constrain such capabilities. The resulting disparity is one in which the risk of unintended consequences and abuse are maximised. The range of warning that the experts are issuing includes algorithmic bias, job displacement, privacy violations, and, ultimately, autonomous weapons systems. Also, absence of explainability and transparency in complex AI models is inconvenient in understanding and controlling their decision making process. For this reason, a sense of proactivity and collaboration is required to tackle these risks and AI is developed and deployed responsibly and ethically. Investing in AI safety research, developing international standards and regulations, and broadly discussing how -- and whether -- AI should be used with social and political institutions are all included. To me, it is imperative to prioritise the development of AI systems that promote human values and aim for the common good.

	Positive	**Negative**
Origine interne	***STRENGTHS*** *Data Analysis and Insights *Optimisation and Efficiency *Precision Agriculture *Renewable energy Management ***S***	***WEAKNESSES*** *Hight Computational cost *Data Bias and fairness Concerns ***W***
Origine Externe	***OPPORTUNITIES*** ***O*** *Smart Cities Development *Sustainable Supply Chains *Climate Change Mitigation	***T*** ***THREATS*** *Cybersecurity Risks *Job displacement Concerns *Regulatory Uncertainty

Figure 22 SWOT Analysis for AI (Author, 2025)

5. Discussion and Implication

Sustainability has become a global priority in the face of escalating climate change, resource depletion, and socio-economic inequalities. The rapid advancement of technologies such as Electric Vehicles (EVs) and Artificial Intelligence (AI) has been widely heralded as a solution to environmental concerns. However, while these technologies offer considerable promise, they alone are insufficient in achieving true sustainability. This discussion examines the limitations of a technology-centric approach and highlights the need for systemic change through policy, social transformation, and ethical governance.

The pervasive narrative surrounding electric vehicles (EVs) and artificial intelligence (AI) often paints them as technological saviours, pivotal solutions to the escalating challenges of sustainability, carbon emissions, and climate change. Indeed, as demonstrated through analyses of their strengths and opportunities, both technologies possess undeniable potential to mitigate environmental degradation and foster a more sustainable future. However, a critical examination reveals that these technologies are not without their inherent weaknesses and threats, casting a shadow over their purported status as unequivocal solutions. While EVs and AI offer compelling advantages, a holistic assessment necessitates acknowledging their potential to generate negative impacts across the environmental, social, and governance (ESG) components of sustainability.

The allure of EVs lies in their promise of reduced tailpipe emissions, a critical factor in combating urban air pollution and mitigating greenhouse gas emissions. However, the environmental footprint of EVs extends beyond their operational phase. The production of EV batteries, particularly lithium-ion batteries, is resource-intensive and carries significant environmental consequences.

The exponential surge in global battery demand, driven primarily by the burgeoning electric vehicle (EV) market and the increasing reliance on renewable energy storage, presents a complex environmental challenge (Gaines et al., 2018). Despite advancements in battery recycling technologies, the sheer scale of production necessitates a corresponding escalation in ore extraction to procure essential raw materials such as lithium, cobalt, and nickel. This dependency on virgin ore underscores a critical tension within the sustainable energy transition: while EVs promise to mitigate tailpipe emissions, their production relies on resource-intensive mining practices that can inflict substantial ecological damage. The extraction processes often disrupt fragile ecosystems, contaminate water sources, and contribute to soil degradation, raising concerns about the true environmental cost of electrification. Furthermore, the recycling of spent batteries, while crucial for resource recovery and waste reduction, is not without its environmental footprint (Harper et al., 2019). Current recycling methodologies, often involving pyrometallurgical or hydrometallurgical processes, can generate significant air and water pollution, releasing heavy metals and other hasardous substances into the environment. This counterintuitive consequence highlights the need for continuous innovation in recycling technologies to minimise their environmental impact and develop more efficient and less polluting methods. The challenge is compounded by the fact that the composition of batteries is constantly evolving, with new chemistries and materials being introduced, which may necessitate tailored recycling processes. Consequently, the development of a robust and sustainable battery lifecycle management system requires a holistic approach that considers not only the reduction of reliance on virgin ore but also the minimisation of pollution associated with both battery production and recycling. The necessity for a more sustainable approach is backed up by many studies that show the current mining techniques are not sustainable. The increasing demand is also causing a strain on the supply chain, and causing geopolitical tension.

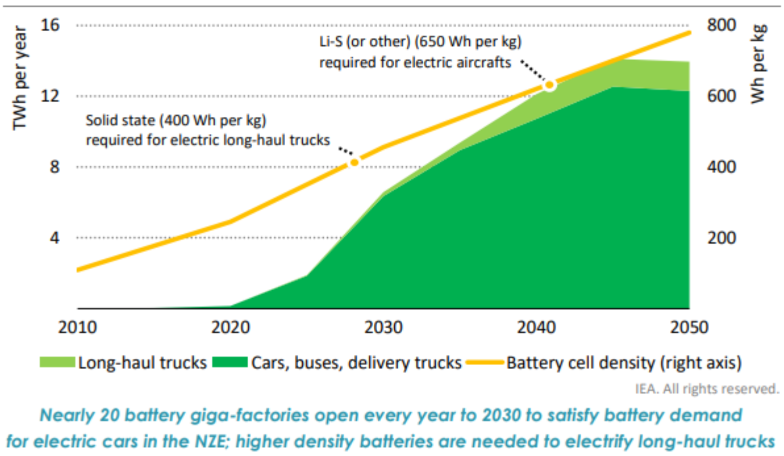


Figure 23 Battery Demand Growth in transport and battery energy density in the NZE (International Energy Agency, 2021)

The extraction of raw materials such as lithium, cobalt, and nickel often involve destructive mining practices that can lead to habitat destruction, water contamination, and soil degradation. The energy-intensive manufacturing process of batteries also contributes to greenhouse gas emissions, particularly when powered by fossil fuels. Furthermore, the disposal and recycling of spent batteries pose significant challenges, as they contain hazardous materials that can leach into the environment if not properly managed (Siemann and Goonan, 2012). This lifecycle perspective underscores the importance of considering the entire environmental impact of EVs, from raw material extraction to end-of-life disposal, rather than solely focusing on their operational emissions.

The increasing dependence on specific materials, such as lithium, crucial for the development and production of green technologies (Greentech), creates a new form of geopolitical dependence. This dependence is manifested by a concentration of the extraction and processing of these materials in a limited number of countries, often different from those that dominated the fossil fuel market. Thus, we are witnessing a transfer of geopolitical dependencies, moving from oil-producing countries to those rich in minerals essential for green technologies. This transition is accompanied by a considerable increase in the consumption of these resources, fuelled by the growing demand for batteries for electric vehicles, renewable energy storage systems, and other technological applications. This situation raises important questions concerning supply security, price stability, and potential geopolitical tensions related to access to these strategic resources. It is therefore imperative to consider these geopolitical implications when evaluating the sustainability of green technologies.

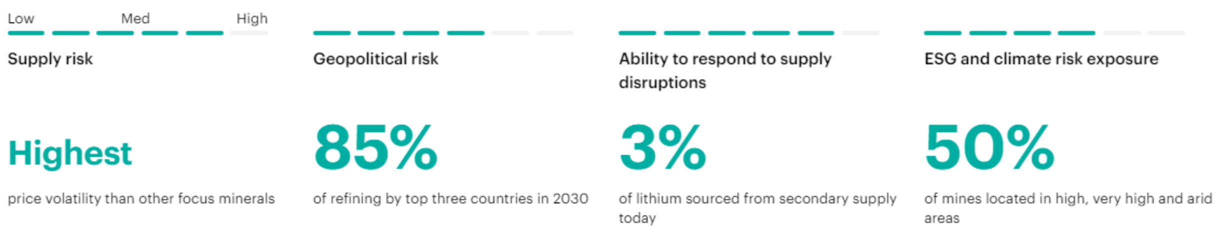


Figure 24 Clean energy transition risk assessment (International Energy Agency, 2021)

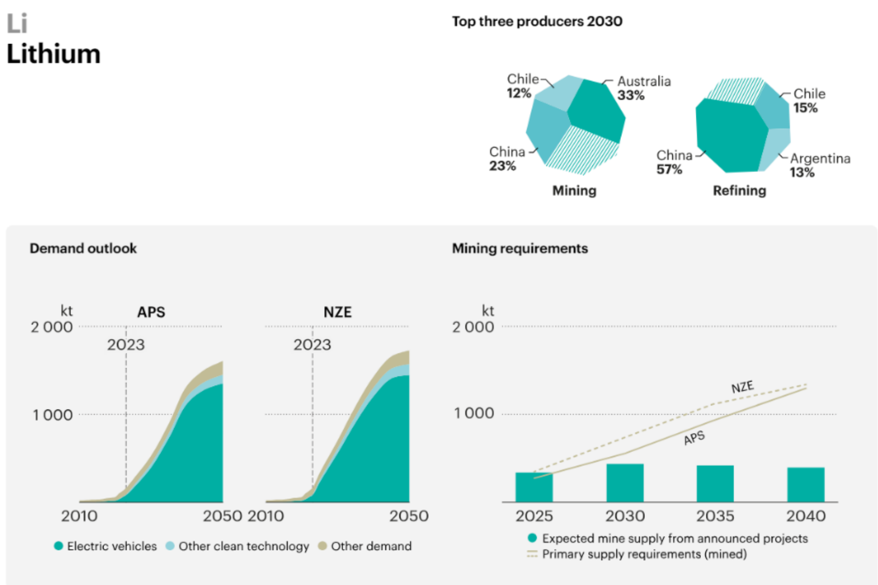


Figure 25 Cleantech demand 2021-2024 (International Energy Agency, 2021)

Similarly, AI's potential to optimise resource allocation, enhance energy efficiency, and facilitate sustainable practices is undeniable. However, the high computational cost associated with training and running complex AI models raises concerns about their energy consumption and carbon footprint. The development of large language models and deep learning algorithms requires vast amounts of computing power, often powered by fossil fuel-based energy sources. This energy consumption contributes to greenhouse gas emissions and can undermine the very sustainability goals AI purports to achieve. Moreover, the manufacturing of AI hardware, including GPUs and TPUs, involves resource-intensive processes and the use of rare earth minerals, which can have significant environmental and social consequences. The disposal of outdated AI hardware also poses challenges, as it can contribute to electronic waste and pollution. As shown by the French study on the footprint by 2050, with digital technology which is closely linked to AI, data centres, etc., we find that the impact of green technology in the digital sector is insufficient on its own to reduce or even eliminate its carbon impact. It is the restriction of usage that could have a positive influence on CO2 emissions

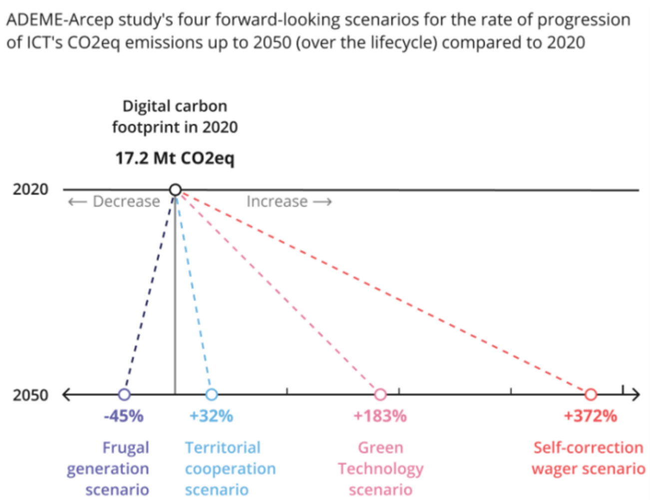


Figure 26 ADEME-Arcep study's four forward-looking scenario for the rate of progression of CO² emissions up to 2050 (over the lifecycle) pour la France (ARCEP, 2023)

According to this study, the impact of green technology in the digital sector is insufficient on its own to reduce or even eliminate its carbon impact. It is the restriction of usage that could have a positive influence on CO2 emissions.

Beyond environmental considerations, both EVs and AI raise significant social and governance concerns. The transition to EVs has the potential to exacerbate social inequalities. The high upfront cost of EVs can create a divide between affluent consumers who can afford to adopt these technologies and low-income individuals who cannot. This disparity can lead to unequal access to clean transportation and perpetuate existing social inequities. Furthermore, the shift towards EVs may lead to job displacement in the traditional automotive industry, particularly for workers involved in the production of internal combustion engine vehicles. This necessitates the development of workforce transition strategies to mitigate the social and economic consequences of job losses.

AI's potential to automate tasks and optimise processes also raises concerns about job displacement. The increasing capability of AI to perform tasks previously performed by humans can lead to widespread job losses in various sectors, particularly those reliant on routine and repetitive work. This can exacerbate social inequalities and lead to increased unemployment and poverty. Furthermore, the lack of transparency and explainability of complex AI models can lead to concerns about bias and discrimination. AI algorithms are trained on data that may reflect existing societal biases, leading to discriminatory outcomes in areas such as environmental risk assessment and resource allocation. This lack of fairness can undermine public trust in AI-driven sustainability solutions.

Governance challenges also arise from the rapid development and deployment of EVs and AI. The lack of clear regulations surrounding AI development and use can hinder the adoption of sustainable AI solutions. This regulatory uncertainty can create a ‘wild west’ scenario, where AI developers and users operate without consistent guidelines or standards. This ambiguity can lead to inconsistent practices, ethical lapses, and a lack of accountability. Similarly, the lack of standardised regulations for EV battery production, disposal, and recycling can hinder the development of a circular economy for EV batteries. Furthermore, the interconnected nature of AI systems and EV charging infrastructure creates vulnerabilities to cyberattacks, which can compromise critical sustainability data and disrupt essential operations.

The ethical implications of AI and EV technologies also demand careful consideration. The use of AI in environmental monitoring and resource management raises questions about data privacy and security. The collection and analysis of sensitive environmental data must be conducted in a responsible and ethical manner to protect the rights of individuals and communities. Similarly, the deployment of autonomous vehicles raises ethical dilemmas regarding liability and decision-making in accident scenarios. These ethical considerations underscore the importance of developing ethical guidelines and regulatory frameworks for the responsible use of AI and EVs.

In conclusion, while EVs and AI offer promising avenues for addressing sustainability challenges, they are not without their inherent weaknesses and threats. A holistic assessment necessitates acknowledging their potential to generate negative impacts across the environmental, social, and governance components of sustainability. To fully realise the potential of these technologies for a sustainable future, it is crucial to address these challenges through responsible innovation, ethical considerations, and robust regulatory frameworks. This involves investing in sustainable battery production and recycling, developing energy-efficient AI algorithms, mitigating job displacement, ensuring fairness and transparency in AI systems, and establishing clear regulations for AI and EV technologies. By addressing these challenges, we can ensure that EVs and AI contribute to a more sustainable and equitable future for all.

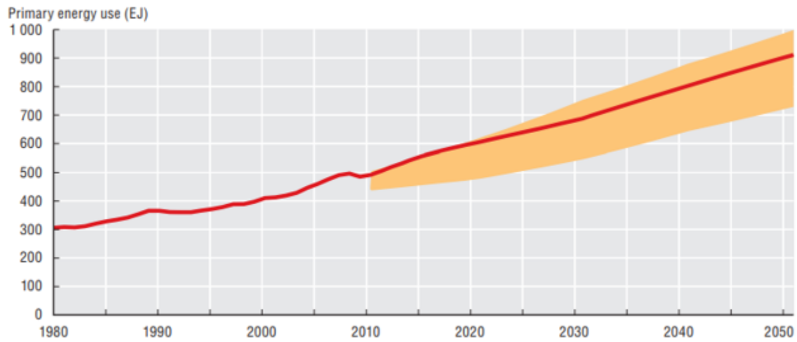
5.1 Economic Growth Hinders Sustainability Progress

The imperative for sustained economic growth across all nations fundamentally necessitates an augmented level of consumption and economic activity, a principle that, while seemingly straightforward, carries profound implications for the planet's finite resources. Consequently, the seminal ‘Limits to Growth’ report by Meadows et al. (1972), which warned of the catastrophic consequences of unchecked exponential growth on a finite planet, remains strikingly relevant, albeit with the crucial caveat that technological advancements have significantly altered the data landscape. While technological innovations have undoubtedly provided temporary reprieves and expanded resource utilisation efficiencies, the core thesis of the Meadows report, emphasising the inherent conflict between exponential growth and planetary boundaries, persists. It is evident that the pursuit of sustained economic growth inevitably precipitates a surge in technological demands, creating an enduring and complex trade-off between the desire for increased consumption and the critical need to control the consumption of the Earth's resources. This perpetual tension manifests in various forms, from the increased demand for raw materials to the escalating energy requirements of industrial processes and consumer goods.

The relentless pursuit of economic expansion, as posited by neoclassical economic models, hinges on the continuous stimulation of demand, which, in turn, fuels production and generates wealth. However, this model often overlooks the ecological costs associated with such growth, leading to a systematic depletion of natural capital and an accumulation of environmental externalities. The technological advancements that have facilitated economic growth, such as improved extraction techniques and more efficient manufacturing processes, have, in many instances, merely postponed the inevitable confrontation with planetary limits. For instance, while renewable energy technologies offer a pathway to decarbonisation, their widespread deployment necessitates a significant increase in the extraction of minerals and rare earth elements, which, in turn, generates its own set of environmental and social challenges. In this context, the concept of 'ecological modernisation,' which proposes that technological innovation can reconcile economic growth with environmental sustainability, faces significant empirical and theoretical challenges (Mol. 1996). The evidence suggests that while technology can mitigate some environmental impacts, it cannot entirely decouple economic growth from resource consumption.

Furthermore, the globalised nature of modern economies exacerbates the tension between consumption and resource control. The interconnectedness of supply chains and the transnational flow of capital and goods create a complex web of environmental impacts that are difficult to trace and regulate. The pursuit of competitive advantage often leads to a 'race to the bottom,' where companies and nations seek to minimise costs by externalising environmental impacts and exploiting regulatory loopholes. This phenomenon underscores the need for robust international cooperation and governance mechanisms to ensure that economic growth is pursued in a manner that is consistent with planetary boundaries. The challenge is not merely technological but also institutional, requiring a fundamental shift in the way we govern economic activity and manage natural resources. The necessity for this shift is shown in the ever-increasing amount of pollution created by the ever-increasing amount of manufacturing (Steffen et al., 2017).

The growing demand for resources, particularly in emerging economies, further intensifies the pressure on planetary boundaries. As populations grow and living standards rise, the demand for energy, water, and raw materials is projected to increase significantly. This demographic and economic shift necessitates a transition to a more circular and resource-efficient economy, where waste is minimised and resources are reused and recycled. However, the transition to a circular economy requires significant investments in infrastructure, technology, and policy, as well as a fundamental shift in consumer behaviour. The complexity of this transition is highlighted by the continuing increase of waste produced by humans (Geyer et al., 2017).



Notes: A widely accepted method for the accounting of primary energy use from different energy sources does not exist. Here, the methodology proposed by the IEA is used, which assumes a 33% efficiency for nuclear power and 100% for renewable power. Alternative methods may lead to slightly different contributions of nuclear power and renewables to the energy mix. The shaded area indicates the 10-90th percentile literature range.

Source: *OECD Environmental Outlook Baseline*; output from IMAGE.

StatLink http://dx.doi.org/10.1787/888932570259

Figure 27 Global primary energy use: baseline, 1980-2050 (OECD, 2012)

Additionally, the transition to a sustainable economy requires a paradigm shift in our understanding of economic growth. Rather than focusing solely on quantitative measures of growth, such as GDP, we need to adopt a more holistic approach that considers qualitative measures of well-being, social equity, and environmental sustainability. This shift necessitates the development of new economic indicators and accounting frameworks that reflect the true costs and benefits of economic activity. The concept of ‘degrowth,’ which advocates for a deliberate reduction in economic output to reduce environmental impacts, has gained traction in recent years, highlighting the growing recognition that traditional growth models are unsustainable (Jackson, 2012).

The difficulty of this is shown in the continuing rise of global emissions, despite many international agreements (Friedlingstein et al., 2022). In essence, the continued pursuit of global economic growth demands a profound reconsideration of our relationship with the planet's resources, acknowledging the enduring relevance of the Meadows report and the perpetual trade-off between consumption and control.

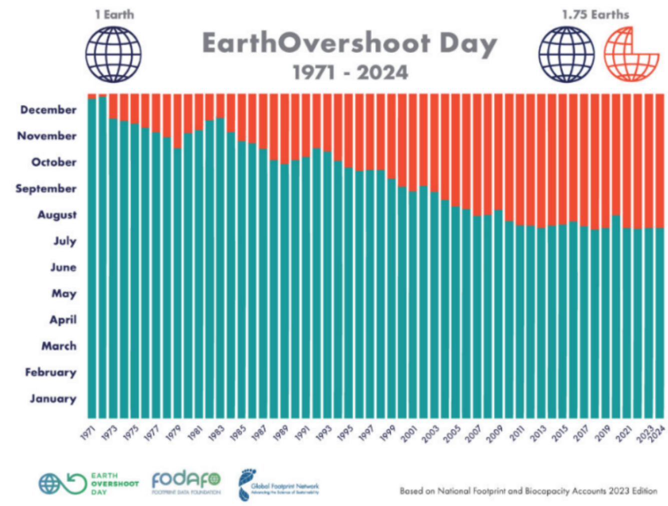


Figure 28 Evolution du Earth overshoot Day from 1971-2024 (Global Footprint Network, 2025)

5.2 Dependence on Technology and Innovation

The prevailing narrative of progress often champions economic growth, technological innovation, and relentless advancement as the cornerstones of societal well-being and problem-solving. Yet, a critical examination of our current trajectory reveals a starkly contrasting reality: our unwavering dependence on these very pillars may fundamentally be driving us towards an unsustainable future. The unyielding pursuit of economic expansion, often measured by gross domestic product (GDP), necessitates a continuous increase in consumption and production, which inherently strains the planet's finite resources. The trade-offs inherent in this model, as exemplified by the complexities surrounding artificial intelligence (AI) and electric vehicles (EVs), illustrate the paradoxical nature of our predicament. While these technologies offer potential solutions to specific environmental challenges, their development and deployment often generate new and unforeseen sustainability dilemmas. The promise of AI to optimise resource allocation and enhance efficiency is frequently overshadowed by its voracious energy consumption, data bias concerns, and potential for job displacement. Similarly, the allure of EVs as a means to decarbonise transportation is tempered by the environmental and social costs associated with battery production and raw material extraction. This pattern of trading one set of problems for another underscores the limitations of relying solely on technological fixes to address systemic sustainability challenges.

The fundamental flaw in our approach lies in the assumption that technological innovation can perpetually decouple economic growth from environmental impact. This belief, often rooted in the concept of 'ecological modernisation,' overlooks the inherent limitations of resource efficiency and the rebound effect, where increased efficiency leads to increased consumption. Furthermore, the focus on technological solutions often diverts attention from the need for fundamental societal and behavioural changes, such as reducing consumption, adopting circular economy principles, and promoting sustainable lifestyles. The relentless pursuit of innovation, driven by market forces and consumer demand, can also lead to the proliferation of unsustainable products and services, creating a culture of planned obsolescence and excessive waste. The speed of technological change can outpace our ability to assess and mitigate its environmental and social consequences, leading to unintended and potentially irreversible impacts. The ever-increasing amount of e-waste is a prime example of this (Baldé et al., 2017).

The globalised nature of our economies further exacerbates these challenges. The interconnectedness of supply chains and the transnational flow of capital and goods create a complex web of environmental impacts that are difficult to trace and regulate. The pursuit of competitive advantage often leads to a 'race to the bottom,' where companies and nations seek to minimise costs by externalising environmental impacts and exploiting regulatory loopholes. This phenomenon underscores the need for robust international cooperation and governance mechanisms to ensure that economic growth and technological innovation are pursued in a manner that is consistent with planetary boundaries. The challenge is not merely technological but also institutional, requiring a fundamental shift in the way we govern economic activity and manage natural resources. The continuing rise of global emissions shows that current international agreements are not enough (Friedlingstein et al., 2023).

Figure 0.3. **Global water demand: *Baseline*, 2000 and 2050**

Note: This graph only measures "blue water" demand (see Box 5.1) and does not consider rainfed agriculture. The country groupings BRIICS and RoW are explained in Table 1.3 in Chapter 1.

Source: OECD *Environmental Outlook Baseline*; output from IMAGE.

StatLink http://dx.doi.org/10.1787/888932571171

Figure 29 Global Water Demand (OECD, 2012)

Moreover, the focus on technological solutions often neglects the social and ethical dimensions of sustainability. The potential for AI to exacerbate existing inequalities, the displacement of workers due to automation, and the ethical dilemmas surrounding autonomous systems highlight the need for a more holistic and inclusive approach to innovation. The increasing use of AI within the work place, is leading to an increase of surveillance on workers, and a degradation of working conditions (Suboff, 2019). The pursuit of technological advancement without considering its social and ethical implications can lead to unintended consequences and undermine public trust. Furthermore, the emphasis on technological fixes can divert attention from the need for social and political reforms, such as addressing inequality, promoting democratic participation, and fostering a culture of sustainability. In essence, our dependence on growth, innovation, and technology, while offering potential solutions, may fundamentally be perpetuating unsustainable practices. The trade-offs inherent in these approaches necessitate a paradigm shift towards a more holistic and integrated understanding of sustainability, one that recognises the limitations of technological fixes and prioritises social equity, environmental stewardship, and ethical considerations. We need to move away from a linear model of progress and embrace a more circular and regenerative approach that prioritises well-being over consumption and respects the planet's finite resources.

6. Conclusion

In concluding this analysis, it is imperative to acknowledge the limitations inherent in our examination, which, while focusing on the critical roles of AI and EVs in sustainability, has not fully encompassed the expansive and rapidly evolving landscape of contemporary technologies. The burgeoning influence of digital technologies, encompassing the vast interconnectedness of the internet, the proliferation of data centres, and the pervasive presence of smart devices, represents a significant omission. Similarly, the burgeoning field of space research, with its resource-intensive endeavours and potential for both environmental monitoring and extraterrestrial resource exploitation, warrants deeper consideration. Furthermore, other cutting-edge technologies, such as advanced materials, biotechnology, and nanotechnology, each present unique opportunities and challenges to sustainability. This oversight underscores the complexity of evaluating sustainability in an era of rapid technological change, where the boundaries of innovation are constantly expanding.

The analysis has revealed a disconcerting trend: while certain localised reductions in GHG emissions are achieved through the adoption of green technologies; the overall consumption of terrestrial resources continues unabated. The shift towards new technologies necessitates the extraction and processing of different, often rarer, materials, leading to a reconfiguration rather than a reduction in environmental impact. This phenomenon highlights the fundamental disconnect between the pursuit of economic growth and the imperative for environmental sustainability. The prevailing economic model, which prioritises consumption and market expansion, remains fundamentally incompatible with the principles of inclusivity, social equity, and global peace. The pursuit of material prosperity, as presently conceived, inevitably leads to resource depletion, environmental degradation, and social disparities, creating a cycle of unsustainable development.

The warnings and potential dangers associated with even seemingly benign green technologies, as demonstrated in the preceding chapters, underscore the need for a more cautious and nuanced approach to technological innovation. The ‘Limits to Growth’ report by Meadows et al. (1972), despite its age, remains remarkably prescient, reminding us that the Earth's carrying capacity is finite and that unchecked growth will inevitably lead to ecological overshoot. While technological advancements have undoubtedly altered the parameters of this equation, the fundamental principle of planetary limits remains unchanged. It is therefore crucial to revisit and update the insights of the Meadows report, incorporating the technological realities of the 21st century, to develop a more accurate and comprehensive understanding of our current trajectory.

The reality, as our analysis suggests, is that sustainability, as conventionally defined, may be an elusive goal in the context of current economic, societal, and technological paradigms. Technological advancements, while offering potential solutions to specific environmental challenges, often generate unintended consequences and create new sets of problems. Green technologies, in particular, should not be viewed as panaceas but rather as tools within a broader sustainability strategy. They can help mitigate certain environmental impacts, but they cannot address the systemic issues that drive unsustainable consumption and production patterns. The global modus operandi, characterised by a reactive approach to environmental damage, is fundamentally flawed. We continue to 'repair' the disorders caused by human activity, rather than proactively preventing them. This reactive approach is shown by the ever-increasing amount of climate change related disasters.

The prescient observations of Hugh Montefiore and David Baltimore resonate deeply in this context. Montefiore's assertion that 'technology can be used for better or worse' highlights the inherent duality of technological progress. Baltimore's question, 'Will we be able to choose the elements of technology that improve the quality of life and avoid those that deteriorate it?' encapsulates the central dilemma of our technological age. The answer, as this analysis suggests, lies in a fundamental shift in our values and priorities. We must move beyond a narrow focus on technological innovation and embrace a more holistic and ethical approach to development.

Sustainability, particularly through the lens of green technology, offers a partial response to Baltimore's query. However, the protection of future generations requires more than just technological solutions. It demands a collective awakening, a global consciousness of our interconnectedness with the planet and with each other. Every individual must recognise their impact and act responsibly, respecting all forms of life and embracing diversity and peaceful coexistence. This necessitates a profound transformation in our cultural norms, consumption patterns, and social institutions. It is not enough to simply shift to cleaner technologies; we must also shift to a more equitable and just society.

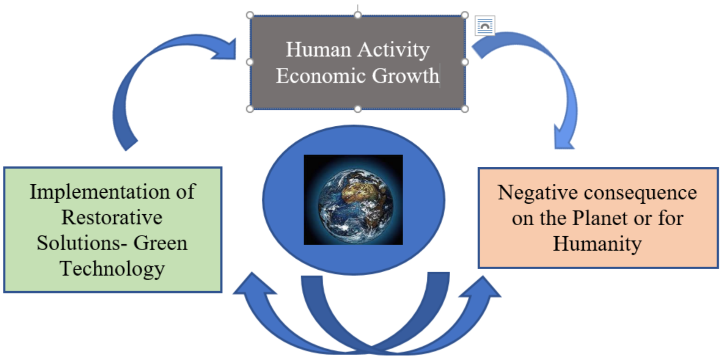


Figure 30 Relation between Human Activity, Negative consequence and Green Technology (Author, 2025)

The question of whether green technology is a genuine solution to sustainability or merely a displacement of the problem remains a critical one. This analysis has demonstrated that while green technologies play a vital role in mitigating certain environmental impacts, they are not a substitute for fundamental changes in our economic and social systems. The analogy of green technology as a medicine that relieves symptoms but does not cure the underlying disease is apt. These technologies can provide temporary relief and buy us time, but they cannot address the root causes of unsustainability. To achieve true sustainability, we must implement robust international regulations, promote sustainable consumption patterns, and foster a culture of ecological stewardship. Furthermore, we need to move towards a circular economy, where resources are reused and recycled, and waste is minimised. We need to invest in research and development to create technologies that are not only efficient but also environmentally benign and socially equitable. Ultimately, the path to sustainability requires a collective commitment to a more just and sustainable future, where the well-being of both people and the planet is prioritised.

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