FACULTY OF EDUCATION
DEPARTMENT OF PEDAGOGICAL CURRICULAR AND PROFESSIONAL STUDIES

IMPACT OF LIFE CYCLE ASSESSMENT-BASED EDUCATION ON SUSTAINABLE DECISION-MAKING

AN INTERVENTION STUDY WITH PROFESSIONALS IN WIND AND SOLAR TECHNOLOGY FIRMS

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Supervisor:	Anna Nyström Claesson, Ebba Lisberg Jensen, Maria Lindqvist
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Abstract

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Aim: The purpose of this study is to develop and implement an educational program designed to empower professionals in the wind and solar energy industry to make knowledge-based sustainable decisions. The program achieves this by identifying the climate change and global warming impacts of wind and solar energy projects using the Life Cycle Assessment (LCA) methodology. The learning outcomes of the program are analysed through the lens of post-humanistic ecology.

Theory: This study is grounded in an integrated conceptual framework based on the theories of transformative learning and post-humanist ecology. Transformative learning theory is the learning process based on the idea that learners can critically adjust their beliefs and perspectives based on new information and is utilized as the guideline of the educational program structure and approach. The post-humanistic ecology which doubts the dominant anthropocentric perspective and promotes the holistic view of the entanglement of humans, non-human entities and the environment, works as the base theory for analysing the learning outcomes.

Method: This study adopts a qualitative approach, employing an intervention study design where an educational program is developed and implemented for professionals in the wind and solar energy sector. The methodology integrates content analysis and thematic analysis to gather and categorize data on climate change and global warming impacts in wind and solar technologies through LCA. The collected data are then organized into tables, highlighting the key findings. Additionally, the study includes the use of pre- and post-intervention questionnaires to capture participant feedback on their knowledge and decision-making abilities.

Results: Greenhouse gas (GHG) emissions intensity (gCO2-eq./kWh) is higher in solar technology compared to wind technology. Among the five life cycle phases of wind and solar power projects, the Manufacturing phase contributes the highest GHG emissions intensity, while the Decommissioning phase shows the lowest GHG emissions intensity. The remaining phases - Construction, Operation and Maintenance, and Transportation - exhibit varying levels of GHG emissions intensity, with their ranking shifting depending on the specific power project. Moreover, educational program participants enhanced their knowledge of LCA application in wind and solar power projects and developed critical skills for sustainable decision-making in their daily work. Lastly, analysed from a post-humanistic ecology perspective, the educational program fostered a broader awareness of the interconnections between humans and their activities and non-human entities and ecosystems.

Foreword

The primal idea and inspiration behind this master thesis are rooted years ago, in my naïve childhood. Growing up in an era and a society dominated by unsustainable practices, I felt overwhelmed by the widespread pollution and the absurdity of burning fossil fuels to produce energy. When I first learned about the concepts of sustainability and renewable energy, I knew what I wanted to do when I grew up.

Nowadays, as an electrical engineer in the renewable energy sector, I feel ready to fulfil some of my childhood dreams. My goal is to contribute to a world where electricity is entirely renewable, sustainable and has the minimum possible ecological impact. Renewable energy is considered clean and sustainable, but perfect is the enemy of the good. There is always room for improvement and optimization. That's why I am deeply passionate about advocating for even more sustainable practices in the industry.

The aim of this work is to empower and motivate individuals in the renewable energy sector, especially those working in wind and solar power projects, to make sustainable, knowledge-based decisions in their daily professional routines. By equipping my colleagues with the necessary tools and knowledge, I hope to foster a culture of sustainability and informed decision-making within the renewable energy industry. The first step brings the second and I would like to see this study contributing to advancing renewable energy practices, pushing for higher standards of sustainability across the sector.

I would like to express my gratitude to all those who have supported me throughout this journey. Their guidance, patience and encouragement have been invaluable, and this thesis would not have been possible without their contributions. In addition, I would like to express my admiration for all those great scientists, whose revolutionary ideas progressed humanity and the world one step further and inspired the next generations like me to get involved in scientific research.

So, dear reader, please fasten your seatbelt, turn the page and embark on a journey through sustainability, renewable energy, life cycle assessment, transformative learning and post-humanistic ecology. I hope you find both inspiration and enjoyment - welcome to the pursuit of a more sustainable world. This world is a shared place, one that doesn't belong to any single individual or group, and it is in all of our best interests to maintain and sustain it for future generations.

Table of contents

Introduction 6
Research Aim and Questions 9
Literature Review 11
LCA and GHG emissions in Renewable Energy 11
Educational Interventions in Sustainability 11
Research Gap 12
Theoretical Framework 13
Transformative Learning 13
Philosophical Background 14
Post-humanist Ecology 14
Humanism 14
Humanistic Ethics on Ecology 14
Critique of Humanism on Ecology 15
Post-Humanism 15
Post-Humanistic Ethics on Ecology 16
Life Cycle Assessment: Methodology and Articles 18
Methodology 18
Goal and Scope Definition 19
Inventory Analysis 20
Impact Assessment 20
Interpretation 22
Articles 22
GHG emissions at Wind Power Projects 23
GHG emissions at Solar Power Projects 25
Method 29
Data Collection 29
Search Process 31
Scopus Database 31
Web of Science Database 32
Google Scholar 33
Further Literature 34
Questionnaires 35
Data Analysis 36
Research Ethics 37
Educational Program 38

Participants 38
Program Design 39
Program Implementation 41
Data Collection 42
Results – LCA implementation in Educational Program 43
LCA Results 43
Educational Program Implementation Results 45
Discussion 50
Addressing Climate Change Impacts in Wind and Solar Projects 50
Implementation of the Educational Program – Empowering Decision Making 51
Discussion of results through post-humanistic perspective 52
Challenges and Opportunities 53
Conclusion and Recommendations 56
References 59
Appendices 63
Appendix 1 – Questionnaires 63
First Questionnaire – Pre Education Program 63
Second Questionnaire – Post Education Program 64
Appendix 2 – Lecture Presentation 67

Introduction

Energy serves as a fundamental and indispensable requirement for all life forms. From the smallest microorganisms to the largest organisms, energy is essential for development, growth, and sustenance. The evolution of humanity, marked by increases in population and technological advancement, has resulted in an exponential rise in energy demands, particularly since the Industrial Revolution (Jelley, 2020).

In meeting these escalating demands, various forms of energy play crucial roles. Among them, electrical energy, or electricity, stands out as a cornerstone of modern civilization. It powers homes, industries, transportation, and virtually every aspect of daily life. However, the heavy reliance on fossil fuels as the primary source of electricity production poses significant challenges. Firstly, the finite nature of fossil fuel reserves raises concerns about their future availability. Additionally, the combustion of fossil fuels releases pollutants and greenhouse gas (GHG) emissions, exacerbating environmental degradation and contributing to global warming and climate change (Jelley, 2020).

In response to these challenges, the exploration and utilization of renewable energy sources have gained momentum. Renewable energy sources, such as wind, solar, biomass, hydropower and geothermal energy, offer sustainable alternatives with minimal environmental impact (Jelley, 2020). This master's thesis focuses specifically on two renewable energy technologies: wind energy - wind turbines and solar energy - photovoltaics (PV).

In terms of electricity production, wind and solar energy are classified as green and clean energy sources, because they are renewable and have low GHG emissions throughout their lifetime (Jelley, 2020). Despite that, according to life cycle assessment (LCA) approach for GHG emissions, even renewable energy sources are not totally clean during their lifetime, from start to end of life (Mudersbach et al., 2023). While their lifetime total GHG emissions are significantly lower compared to conventional fossil fuel energy, renewable energy sources still generate a considerable amount of GHG emissions which are not zero, or near zero (Mudersbach et al., 2023). When energy sources for electricity production are

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ranked based on their GHG emissions contribution from lowest to highest, hydropower takes the top spot, followed by nuclear energy, wind energy, solar energy and then the other forms of energy sources (Rabaia et al., 2021).

GHG emissions are directly linked to the environmental impact of global warming and climate change, which is a major challenge for sustainability (Jelley, 2020). Although wind and solar technologies are already considered sustainable, there is room for further improvement by reducing their lifetime GHG emissions and consequently the environmental impact which are linked to.

As the term "sustainability" is introduced, it is important to define and describe it. Sustainability refers to the concept of development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs (Purvis et al., 2018). Various dimensional frameworks have been proposed to structure sustainability, but the widely accepted conceptualization revolves around three pillars: environmental, economic and social. This model aims to balance trade-offs between these three pillars, recognizing their interconnectedness and the importance of addressing all aspects for long-term well-being (Purvis et al., 2018).

The environmental dimension encompasses the conservation of ecosystems, biodiversity and natural resources. It focuses on maintaining ecological balance, minimizing pollution and mitigating environmental degradation to ensure the health and resilience of ecosystems for present and future generations (Purvis et al., 2018). The economic dimension refers to sustainable economic growth that promotes prosperity while ensuring equitable distribution of resources and minimizing negative impacts on the environment and society. It involves fostering innovation, efficiency and responsible consumption and production practices (Purvis et al., 2018). The social dimension focuses on fostering social equity, justice and inclusivity. It involves promoting human rights, reducing inequalities, and enhancing quality of life for all members of society (Purvis et al., 2018).

This study explores mainly the environmental dimension of sustainability in the context of wind and solar technologies. Wind and solar power plants, when evaluated using a "cradle to grave" approach, encompass five main life cycle phases: raw material extraction and equipment manufacturing, equipment transportation, construction phase of the plant, operational and maintenance phase, and end-of-life decommissioning (Oebels & Pacca, 2013). Within each of these phases, there exists the potential for various environmental impacts to emerge. Environmental impacts associated with wind and solar power projects can vary. The life cycle assessment (LCA) approach serves as a widely accepted method for categorizing environmental impacts (Baumann & Tillman, 2004). According to Baumann & Tillman (2004) key categories of environmental impacts include:

1. Resources: This category assesses the consumption and depletion of natural resources, including energy, materials, water, and land use. It quantifies energy consumption, raw material usage, water consumption and potential pollution, as well as impacts on land, including habitat loss and degradation.
2. Human health: LCA focuses on the impacts of products or processes on human health, covering toxicological and non-toxicological impacts, as well as occupational health and safety hazards. It evaluates potential health risks associated with exposure to toxic substances, as well as non-toxic impacts such as noise, radiation and thermal stress.
3. Ecological consequences: This category addresses environmental impacts on ecosystems and biodiversity, including global warming, depletion of stratospheric ozone, acidification, eutrophication, photo-oxidant formation, ecotoxicological impacts and habitat alterations. It examines the contribution to climate change, release of substances depleting the ozone layer, acidic compound emissions, nutrient enrichment in water bodies, formation of photochemical pollutants, potential harm to ecosystems and wildlife and changes to natural habitats and loss of biodiversity.

From the three aforementioned categories of environmental impact, this master thesis focuses on the ecological consequences and specifically on global warming – climate change impact. The metric of global warming impact is GHG emissions (Baumann & Tillman, 2004). While carbon dioxide (CO_2) is the most well-known GHG, other gases such as SO_2, NO_x, and CH_4 also contribute significantly to the greenhouse effect. The greenhouse effect of a particular gas is typically quantified by its global warming potential (GWP) relative to CO_2, allowing it to be expressed as a CO_2-equivalent (CO_2-eq.) for ease of comparison (Peng et al., 2013).

To facilitate the comparison and assessment of environmental impacts across various power generation technologies, the indicator of **GHG emission intensity** acts as a standard for evaluating sustainability, greenness, and cleanliness within different electricity production systems. The GHG emission intensity signifies the quantity of greenhouse gases emitted per unit of electricity generated. It is calculated by dividing the total GHG emissions by the electricity generated throughout its lifecycle. This metric is expressed as CO_2-eq./kWh (Peng et al., 2013).

The thesis uses the CO_2-eq./kWh indicator to compare and analyse GHG emissions intensity in wind and solar power projects. As research references, four relevant articles are chosen for wind technology, and another four relevant articles are chosen for solar technology - PV respectively. The choice to focus

exclusively on global warming and climate change environmental impact through GHG emission intensity metric is made for the following reasons:

1. Quantifiability: CO_2-eq./kWh emissions are a quantifiable measure, allowing for precise measurement and comparison across different projects or activities. This makes it easier to track progress towards emissions reduction goals and to assess the effectiveness of mitigation measures (Baumann & Tillman, 2004).
2. Global Relevance: CO_2-eq./kWh emissions are a global concern with far-reaching implications for climate change. Unlike metrics such as biodiversity or land transformation, which can vary significantly depending on local factors, CO_2-eq./kWh emissions have universal relevance and contribute to a shared global challenge (Baumann & Tillman, 2004).
3. Consistency: CO_2-eq./kWh emissions provide a consistent basis for comparison across different regions and industries. Other metrics, such as water usage or habitat loss, may be important in specific contexts but can be difficult to standardize and compare across diverse projects or geographic regions (Baumann & Tillman, 2004).

Research Aim and Questions

It is urgent to establish a process towards a more sustainable future by understanding the GHG emissions causes in wind and solar energy technologies and motivate people who relate to these two technologies, for adopting even more sustainable practices, aiming to eliminate further their environmental impact.

In line with this need, this study aims initially to sensitize and educate the professionals in wind and solar technologies about the global warming and climate change impact of these two technologies (Mudersbach et al., 2023) and subsequently to empower and motivate them to make more environmentally sustainable and knowledge-based decisions in their daily working routine in the wind and solar energy sector.

For achieving this aim, the structured approach should have three main steps. The first step is the identification of the global warming and climate change impacts in wind and solar energy projects, by using the LCA as the methodological tool. The second step is to develop and implement an educational program grounded on transformative learning theoretical framework, teaching the learners about the identified global warming and climate change impacts in wind and solar power projects and aiming to empower them to make environmentally sustainable decisions in their daily working routine, based on the gained knowledge. Finally, as the research aim is targeting exclusively the environmental dimension

of sustainability, the third step is to analyse the learning outcomes of the education program, through the lens of the pro-environmental theoretical framework of post-humanistic ecology.

Consequently, based on the aforementioned research aim and structural approach, the following two research questions will guide the research process:

1. Which are the dominant factors contributing to the climate change impact of wind and solar power projects, as evaluated by LCA, for integration into an educational program?

To answer this question, the climate change and global warming impacts of wind and solar power plants were identified and analysed by using the LCA method, and the five main lifecycle stages from start to end life (Oebels & Pacca, 2013). Emphasis was placed both on the phases with the highest impact and the size of this impact (according to LCA metric tool of GHG emissions intensity - CO_2-eq./kWh indicator).

2. To what extent does the implementation of the educational program designed based on transformative learning and post-humanistic ecology empower the target audience to make sustainable and knowledge-based decisions in their daily work?

An educational sustainability program, incorporating the results of the first research question, is designed, empowering the target audience (professionals in wind and solar energy sector) to make sustainable and knowledge-based decisions in their daily work in wind and solar power projects. The results and observations of implementing this program are then analysed through the perspective of post-humanistic ecology.

Literature Review

The literature review examines the previous research that has been conducted until now in two fields. The first field is the one of LCA methodology application to calculate the GHG emissions intensity in renewable energy sources, including the wind and solar energy sources. The second field is the education interventions in topics which land in the broad range of sustainability spectrum. Subsequently, the research gap is identified, and the contribution of this study is explained.

LCA and GHG emissions in Renewable Energy

There is a wide range of previous scientific research in comparing the GHG emissions intensity of different power generation technologies, through LCA methodology application. Especially the idea to compare renewable energy sources to conventional fossil fuels is used in many studies (Nugent & Sovacool, 2014; Hertwich et al., 2014; Pehl, 2017; Rabaia, 2021). Research has consistently demonstrated that renewable energy power projects produce significantly lower GHG emissions than fossil fuel-based energy generation (Pehl et al., 2017). As the renewable energy sources in the studies include among other forms of energy, both wind and solar energy, the comparison between them shows that solar power projects exhibit higher GHG emissions intensity compared to wind power projects (Pehl, 2017; Rabaia, 2021). This difference is mainly attributed to the energy demanding production of photovoltaic panels, which require mining, processing and manufacturing of raw materials such as silicon and rare metals. In contrast, wind power relies primarily on steel, concrete, and fiberglass, which results in a comparatively lower GHG emissions intensity (Rabaia, 2021).

Educational Interventions in Sustainability

Although no existing educational intervention studies focus specifically on teaching professionals in wind and solar companies about GHG emissions intensity through LCA, previous research has explored educational interventions with other subjects of sustainability. For instance, Richardson et al. (2017) conducted a scenario-based learning (SBL) intervention in nursing and midwifery education, integrating sustainability concepts into clinical practice. It was grounded in social learning theory which emphasizes that learning occurs through social interaction, observation, and engagement in shared experiences. The realistic scenarios which were applied in the intervention effectively enhanced both cognitive (knowledge-based) and affective (attitude-based) learning outcomes (Richardson et al., 2017).

Similarly, Samant et al. (2016) examined the impact of different educational interventions on consumer understanding of sustainability-related food labels. The study compared active learning, where learners

engage in peer discussions, with passive learning, where information is delivered through reading materials or authoritative lectures. Some interesting findings occurred which suggest that structured, authoritative educational interventions (such as expert lectures) may be more effective in shaping attitudes and reinforcing trust in sustainability concepts, whereas active learning may be better suited for enhancing critical thinking and debate (Samant et al., 2016).

Research Gap

Despite the extensive application of LCA in assessing the environmental impacts of electrical power generating technologies and in particular renewables energy, there are not any prior studies to investigate educational interventions, aimed to instruct professionals in wind and solar technological firms, about the GHG emissions intensity of these technologies. Even more, it seems that there are no studies to compare exclusively the lifecycle phases of wind and solar power projects between them. While there are educational intervention studies in other sustainability related fields (Richardson et al., 2017; Samant et al., 2016), their application in educating industry professionals about LCA findings in wind and solar power projects remains unexplored.

This study aims to address this gap by developing and implementing an educational program which integrates data of the wind and solar power projects' GHG emissions intensity, both in total and distributed across their five main lifecycle phases, as well (Oebels & Pacca, 2013). By empowering professionals in the wind and solar technological firms with LCA knowledge, this research contributes to the broader goal of facilitating knowledge-based decisions which supports more environmentally sustainable practices.

Theoretical Framework

This thesis is grounded in two theoretical frameworks, transformative learning and post-humanist ecology. These frameworks set the philosophical foundations and the guideline principles of the educational program and the interpretation of its learning outcomes. The following sections provide an overview of these frameworks.

Transformative Learning

Transformative learning is a learning theory that focuses on how individuals critically reflect on their assumptions, beliefs and worldviews, leading to an evolving shift in perspective. A perspective transformation which by its turn leads to a learning transformation (Mezirow, 2000). According to Mezirow (2000), this transformation is typically triggered by a disorienting dilemma, an experience that challenges an individual's existing beliefs and assumptions. Through reflection and dialogue, learners reassess their previous meaning patterns (belief system, values, behaviour, emotions) and integrate new, more inclusive perspectives into their worldview (Mezirow, 2000).

Furthermore, transformative learning is an inherently democratic process (Wals, 2012). Mezirow (2000) argues that education should empower individuals to become autonomous thinkers who are engaged actively in society. By applying critical reflection and discourse, learners raise their awareness of their social and political context, reinforce their personal empowerment and take collective action. They become autonomous, socially responsible individuals who can take knowledge-based choices. Supplementary, the teachers are viewed as cultural activists who challenge power structures and encourage democratic participation (Mezirow, 2000).

Following the direction of self-empowerment, freedom and social awareness, transformative learning is not merely about acquiring knowledge but about fundamentally altering one’s worldview. It promotes emancipatory learning over instrumental learning (Mezirow, 2000). The instrumental perspective in education emphasizes the practical application of knowledge and skills to achieve specific goals or outcomes. From this point of view, teachers are typically regarded as experts who impart knowledge to students, who are expected to absorb and apply this knowledge in a practical manner (Wals, 2012). In contrast, the emancipatory learning emphasizes critical thinking, empowerment and social transformation. Here, education is viewed as a process of liberation from oppression, inequality and social injustice. Teachers and students are seen as coinvestigators of knowledge, engaging in

collaborative inquiry and dialogue. The focus is on fostering agency, autonomy, and social change by challenging existing power structures, norms and inequalities in society (Wals, 2012).

Philosophical Background

Sustainability, within the framework of its three pillars, leans towards a human-centric perspective, prioritizing human needs above all else (Purvis et al., 2018). However, this is just one among various philosophical approaches. This thesis strives to adopt a more inclusive viewpoint, examining the world through the lens of a symmetrical to all life beings' position, advocating for equality of rights among all living beings. Every living being deserves equal rights, eliminating any privileged position for humanity over other forms of life (Taylor, 1981). This analysis is specifically explored in the following sector through post-humanistic theories leading to post-humanistic ecology as the theoretical foundation of the master thesis analysis perspective.

Post-humanist Ecology

Post-humanist ecology theory presents an ecological approach viewed through the lens of a post-humanist perspective. To fully understand post-humanist ecology, one must first comprehend the humanist approach to ecology. This requires delving into the theoretical framework, philosophical principles and ethics of humanism in ecology, while also acknowledging critiques of humanism. Subsequently, the theoretical framework, philosophical principles and ethics in post-humanism ecology are closing this sector.

Humanism

Humanism emerged as a cultural movement during the Renaissance in Italy and has since evolved into the philosophical theory known today. It emphasizes the idea that human beings have the right and responsibility to determine their own lives. Its philosophical core is based on the values of human reason, free inquiry and an anti-theistic approach. Humanism prioritizes critical thinking, logical analysis and evidence-based reasoning. It encourages open-mindedness, curiosity and promotes questioning and investigation, advocating for the exploration of ideas and beliefs without constraint. Humanism rejects theistic beliefs and supernatural explanations of reality, instead emphasizing the potential of human capabilities to foster progress and understanding (Wilson & Edwin Jeevaraj, 2023).

Humanistic Ethics on Ecology

Humanist ethics on ecology emphasizes the centrality of humans in shaping ethical considerations concerning the environment. While recognizing that morality stems from biological roots and social

instincts and behaviours are present in animals (Bekoff, 2004), humanistic ethics assign humans the responsibility for moral decision making. Humanism encounters the form of life in a hierarchical approach, where it places humans at the top of this hierarchical pyramid (Wilson & Edwin Jeevaraj, 2023).

Critique of Humanism on Ecology

The critique of humanist ethics on ecology rises primarily from its anthropocentric perspective, as noted by Kopnina (2019). Humanism often upholds human exceptionalism and superiority, prioritizing human welfare above all else. This hierarchical worldview overlooks the intrinsic value of non-human beings and ecosystems, neglecting their rights and agency in ecological matters. Additionally, humanist ethics may perpetuate social and environmental injustices by favouring the needs of privileged human groups over marginalized communities and non-human beings (Haraway, 2016).

Furthermore, Wilson and Jeevaraj (2023) emphasize that humanist ethics prioritize human progress and happiness at the expense of non-human entities or ecosystems. This prioritization often fuels consumerism, which, in turn, increases the likelihood of environmental exploitation and degradation. This narrow focus on human interests fails to consider the wide-ranging ecological impacts of human actions, leading to environmental destruction and biodiversity loss.

Nature through its evolution has established a stable equilibrium with a self-sufficient cradle-to-cradle life cycle process. Operating within a closed, organic ecosystem, nature minimizes waste through natural breakdown and absorption processes. This organic system lacks an initial or end state, everything within it functions as interconnected links. Waste is not unnecessary, as any byproduct is broken down and absorbed by subsequent levels of living creatures, creating a continuous circulation within the system (Wei & Kewen, 2010).

In contrast, consumerism, and anthropocentrism, which prioritize human welfare and material progress, contribute to an unsustainable cycle. The pursuit of economic growth and capital accumulation results in the unsustainable exploitation of natural resources and the generation of significant waste, including harmful carbon emissions. Driven by capitalist pro-humanist ideologies, this focus on production and consumption depletes natural capital and diminishes ecological health (Wei & Kewen, 2010).

Post-Humanism

Post-humanism is a philosophical and theoretical framework that challenges traditional anthropocentric perspectives (Kopnina, 2019). It questions the idea of human exceptionalism and emphasizes the entanglement of all entities, humans and non-humans. Post-humanism explores the relationships

between humans and technology, animals, the environment, material world and other non-human entities, viewing them as interconnected and interdependent (Wilson & Edwin Jeevaraj, 2023). It encompasses a diverse range of theoretical perspectives and approaches, including new materialism, affect theory, assemblage theory, and multi-species thinking, all aimed at rethinking human identity, ethics, and ontology in the context of our increasingly technologized and interconnected world (Weldemariam, 2022).

Philosophical post-humanism encompasses a three-tier approach to human conduct within the post-human worldview (Wilson & Edwin Jeevaraj, 2023):

- Tier 1: **Post-humanism**. The first tier, post-humanism, addresses the intrinsic inequalities and injustices within the human species. It emphasizes the need to treat all human beings with respect and dignity, regardless of their social status, gender, race, or other characteristics (Wilson & Edwin Jeevaraj, 2023).
- Tier 2: **Post-Anthropocentrism**. Moving to the second tier, post-anthropocentrism focuses on embracing a biocentric morality (Taylor, 1981). It accepts and values other species on Earth and within the ecosystem. This tier challenges anthropocentric views and advocates for a broader understanding of morality that includes consideration for non-human entities (Wilson & Edwin Jeevaraj, 2023).
- Tier 3: **Post-Dualism**. Finally, at the third tier, post-dualism seeks to transcend binary views of reality that privilege one aspect over another. This includes rejecting dualistic distinctions such as mind-body, nature-culture, and human-non-human. Instead, post-dualism fosters a view of reality that acknowledges the entanglement of all entities, promoting unity and symbiotic relationships within the ecosystem (Wilson & Edwin Jeevaraj, 2023).

Post-humanism, as outlined by Aretoulakis (2014), aims to deconstruct humanism. However, humanism's deconstruction does not imply its negation. The idea is not to discard humanist principles but rather to critically analyse them. Post-humanism acknowledges the limitations of human-centric views, uses humanistic principles as core ideas and expands them aiming to include non-human entities and ecosystems. By deconstructing humanism, post-humanism fosters a more inclusive and ethically responsible approach to our world (Aretoulakis, 2014).

Post-Humanistic Ethics on Ecology

Post-humanistic ethics on ecology shifts away from traditional anthropocentric perspectives and leans towards a more inclusive and interconnected approach to environmental ethics (Weldemariam, 2022). Humans are not perceived as the primary and most important agent on the planet, neither are regarded

as an autonomous, self-sufficient and omnipotent subject (Taylor, 1981). Instead, they are viewed as an entangled entity in a symbiotic relationship with the animals, the ecosystems and the material world, operating as an equal important agent among all the others (Weldemariam, 2019). The other agents include a wide range of life and non-life entities, spanning from animals and ecosystems to natural processes, the material world, technological entities, and the potential emergence of artificial intelligence in the future (Haraway, 2016).

Nature is not viewed as a passive background for human activities but as a dynamic network of relationships in which humanity is one among many actors. This perspective induces a revaluation of traditional environmental narratives, emphasizing the need to cultivate empathy, care and reciprocity towards non-human beings. (Weldemariam, 2019).

Practically, post-human ecology encourages us to rethink our interactions with the environment and to develop more sustainable and ethical practices. By cultivating the values of empathy, care, responsibility, and response-ability (Weldemariam, 2019) towards all beings, a transformative framework is provided for addressing environmental challenges and fostering harmony within ecosystems (Taylor, 1981).

Life Cycle Assessment: Methodology and Articles

This section is dedicated to Life Cycle Assessment (LCA), as it is the methodology to extract the required scientific data and to which the educational program is grounded. It consists of two parts. In the first part, “Methodology”, the LCA method is described. In the second part, “Articles”, the summarised descriptions of the eight articles in total are presented, defining the key characteristics of the analysed projects. This part is separated in two sub-parts, the first containing the four wind power projects’ articles and the second containing the four solar power project articles. All those eight articles provide the scientific evidence answering to the first research question, which are integrated in the educational program.

Methodology

Life Cycle Assessment (LCA) is a structured methodology for evaluating the environmental impact of a product or service throughout its entire life cycle, from raw material extraction to disposal, in a “cradle to grave” approach (Baumann & Tillman, 2004). The following figure 1, describes the principal elements and processes of LCA. It involves four main phases: goal and scope definition, inventory analysis, impact assessment and interpretation.

In the first phase, the product or service under study is defined, along with the objectives and boundaries of the assessment. Next, in the inventory analysis phase, data on resource usage, emissions, and waste generation are collected for each stage of the life cycle. During the impact assessment phase, this data is evaluated across various environmental impact categories. Finally, the interpretation phase involves analysing these results to identify impacts and suggest areas for environmental improvement, supporting more informed, sustainable decision-making. The International Organization for Standardization (ISO) has developed a series of standards for LCA, such as ISO 14040-14043, starting from 1997 onwards (Baumann & Tillman, 2004).

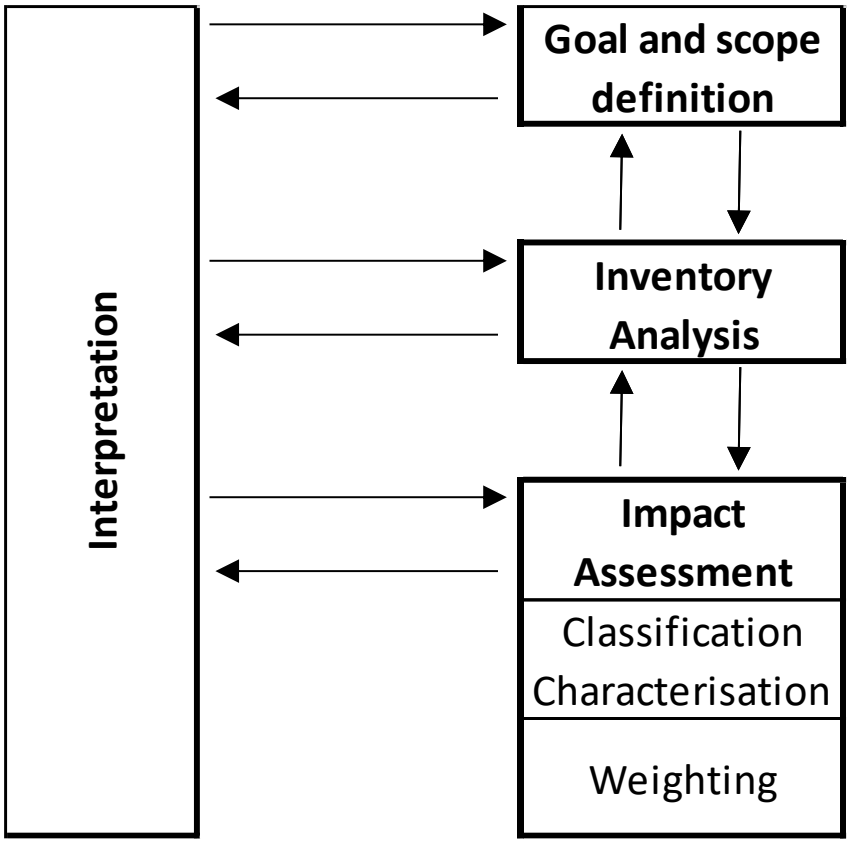

Fig. 1. Modified table LCA (Baumann & Tillman, 2004).

Goal and Scope Definition

The goal and scope definition phase of LCA is the initial step that lays the foundation for the entire study. At this phase, the context and the purpose of the LCA study should be defined precisely, answering in detail the three following questions. Why is it done? How are the results going to be used? And who is the target audience? (Baumann & Tillman, 2004).

The product or products (when referring to products includes the concept of service) should be chosen, as well as the holistic system which encompasses all the products and their different phases. An initial flowchart could be helpful to design the holistic system of the products and processes. Following that, it is time to define the functional unit. This entails establishing the reference flow to which all other modelled flows or the entire system are related (Baumann & Tillman, 2004).

Following the establishment of the functional unit, attention turns to determining the type of environmental impact and selecting the appropriate assessment method. This involves identifying which environmental indicators will be evaluated, such as greenhouse gas emissions, resource depletion, or

toxicity. Additionally, the method for quantifying and assessing these impacts is chosen (Baumann & Tillman, 2004).

Subsequently, the system boundaries are specified. These boundaries extend to natural systems, including ecosystems and biogeochemical cycles, geographical considerations to account for regional variations in environmental conditions and resource availability, and a defined time horizon to capture temporal aspects of impacts over the life cycle (Baumann & Tillman, 2004).

Furthermore, system boundaries must address production factors, including capital and personnel involved in the product life cycle. Consideration is given to the impacts of other products' life cycles, ensuring that any interdependence or co-products are appropriately accounted for through allocation methods. System subdivision may also be necessary to manage complexity, particularly for multifaceted systems with diverse processes and interactions (Baumann & Tillman, 2004).

Inventory Analysis

Inventory analysis entails constructing a system model in accordance with the specification outlined in the goal and the scope definition of LCA. This model represents a flow diagram of a technical system delineated by specific boundaries. Key activities within the life cycle inventory analysis (LCI) include the following (Baumann & Tillman, 2004):

1. The first step involves constructing a flow model according to the predetermined system boundaries. Typically documented as a flowchart, this model describes the activities within the analysed system, including production, processes, transportation, use and waste management. By visually representing the flows between these activities, the flow model provides a clear overview of the system's components and interactions (Baumann & Tillman, 2004).
2. Data collection is essential for capturing inputs and outputs associated with each activity within the product system. This includes gathering information on raw materials, energy carriers, products, solid waste, and emissions to air and water. The aim is to compile a detailed inventory of used resources and emitted pollutants throughout the life cycle (Baumann & Tillman, 2004).
3. Once data collection is complete, the next step involves calculating the environmental loads, including resource use and pollutant emissions, of the system relative to the defined functional unit. (Baumann & Tillman, 2004).

Impact Assessment

The Life Cycle Impact Assessment (LCIA) phase of an LCA study aims to illustrate the environmental consequences of the environmental loads identified in inventory analysis. This involves translating the

environmental loads documented in the inventory results into tangible environmental impacts, such as acidification, ozone depletion, and effects on biodiversity (Baumann & Tillman, 2004).

This translation process serves multiple purposes. Firstly, it enhances the environmental relevance, comprehensibility, and ease of communication of the results. Additionally, it aims to improve the readability of the findings. The abundance of inventory parameters, often numbering in the dozens, can present challenges in understanding the results. Through LCIA, this complexity can be mitigated by grouping the environmental loads into approximately 15 impact categories or even consolidating them into a single metric through weighting. Moreover, LCIA aids in making the results more comparable. Comparability can be problematic when alternatives possess vastly different environmental profiles. Translating inventory parameters into broader impact categories serves as a means to overcome this issue of incomparability (Baumann & Tillman, 2004).

When categorizing main impact categories in LCIA, there is not only one universally accepted classification method. However, a commonly referenced approximation outlined by Baumann & Tillman (2004) includes the following categories:

1. Resources: This category encompasses the consumption and depletion of natural resources throughout a product's life cycle. It includes:
    a. Energy and materials: Quantifies the energy consumption and raw material usage associated with production, use, and disposal.
    b. Water: Evaluates the water consumption and potential pollution throughout the product life cycle.
    c. Land (including wetlands): Assesses the land use impacts, including habitat loss and degradation.
2. Human health: Focuses on the impacts of a product or process on human health, covering:
    a. Toxicological impacts (excluding work environment): Evaluates the potential health risks associated with exposure to toxic substances emitted during the life cycle.
    b. Non-toxicological impacts (excluding work environment): Considers non-toxic impacts such as noise, radiation, and thermal stress that may affect human health.
    c. Impacts in work environment: Examines occupational health and safety hazards encountered during production, use, and disposal.
3. Ecological consequences: Addresses the environmental impacts on ecosystems and biodiversity, including:

a. Global warming: Assesses the contribution to climate change through greenhouse gas emissions.
b. Depletion of stratospheric ozone: Evaluates the release of substances that deplete the protective ozone layer, such as chlorofluorocarbons (CFCs).
c. Acidification: Measures the release of acidic compounds that can disrupt ecosystems and corrode infrastructure.
d. Eutrophication: Examines nutrient enrichment in water bodies, leading to algal blooms and oxygen depletion.
e. Photo-oxidant formation: Considers the formation of ground-level ozone and other photochemical pollutants.
f. Ecotoxicological impacts: Assesses the potential harm to ecosystems and wildlife from exposure to pollutants.
g. Habitat alterations and impacts on biodiversity: Considers changes to natural habitats and loss of biodiversity resulting from land use changes and pollution.

Interpretation

The Interpretation phase in LCA involves analysing and presenting the results from the other three phases. The goal of the Interpretation phase is to draw conclusions, identify impacts and determine areas for potential environmental improvement (Baumann & Tillman, 2004). This phase involves two types of analysis. The first focuses on examining the results to identify significant environmental impacts, highlighting which lifecycle stages or processes contribute most to the overall impact. This step helps to pinpoint key areas that could benefit from changes or improvements, offering practical insights into where to direct sustainability efforts. The second type of analysis assesses the robustness of the findings to ensure confidence in the results. This includes evaluating the consistency and reliability of the data, checking methodological choices for accuracy, and confirming that the study is complete and aligned with its defined scope (Baumann & Tillman, 2004).

Articles

There is a wide range of literature regarding the GHG emissions, as assessed by LCA, in renewable energy sources and specifically in wind (wind turbines) and solar (photovoltaics) technologies. Within each of these two technologies, varying levels of GHG emissions are observed, influenced by a range of variables such as the different types of materials for the equipment, power capacity, geographical location and time horizon for wind and solar power projects, respectively (Hertwich et al., 2014).

Research shows that clean technologies (as wind and solar) do not imply zero GHG emissions, but rather significantly lower levels compared to conventional technologies. For instance, when comparing the GHG emissions intensity of wind and solar technologies to those of natural gas technology, which emits significantly less compared to other fossil fuels, the GHG emissions intensity from natural gas are still approximately ten times higher (Nugent & Sovacool, 2014).

GHG emissions at Wind Power Projects

Following the search process, four relevant articles were selected based on two criteria: measuring GHG emissions intensity using the CO2-eq./kWh indicator and employing a "cradle to grave" approach. These articles provide LCA analyses of four distinct wind power projects. The basic characteristics of the wind power projects are presented in this section and the tables with the GHG emissions intensity (CO2-eq./kWh) and the GHG emissions contribution of each life cycle are presented in the Results sector (table 1 and table 2).

1) Ardente et al. (2008) conducted an LCA of an Italian wind farm located in South Italy (Sicily), covering a total area of 4.5 km^2. The wind farm is comprised of 11 turbines, each with a nominal power of 660 kW, resulting in a total power capacity of 7.26 MW. The system boundaries included only the wind farm, without the equipment for its electrical interconnection (central substation, cables, trenches), as well as the energy inputs and emissions outputs for five (5) phases of the wind farm's life cycle. Manufacturing, Construction, Operation and Maintenance, Transportation and Future wind power plant disposal.
2) An LCA study was carried out by Li et al. (2021) on an onshore wind farm in North China, comprising twenty 2 MW wind turbines with a total power capacity of 40 MW. The following figure 2 shows the system boundaries and the life cycle phases. The system boundaries included both the wind farm and the infrastructure for electrical interconnection, such as the local transformers, the medium voltage panels, the central substation, cables and trenches. System boundaries also considered the energy inputs and emissions outputs associated with the life cycle of wind power, which is divided into five distinct phases. Manufacturing, Transportation, Construction and Installation, Operation and End of Life (EoL).

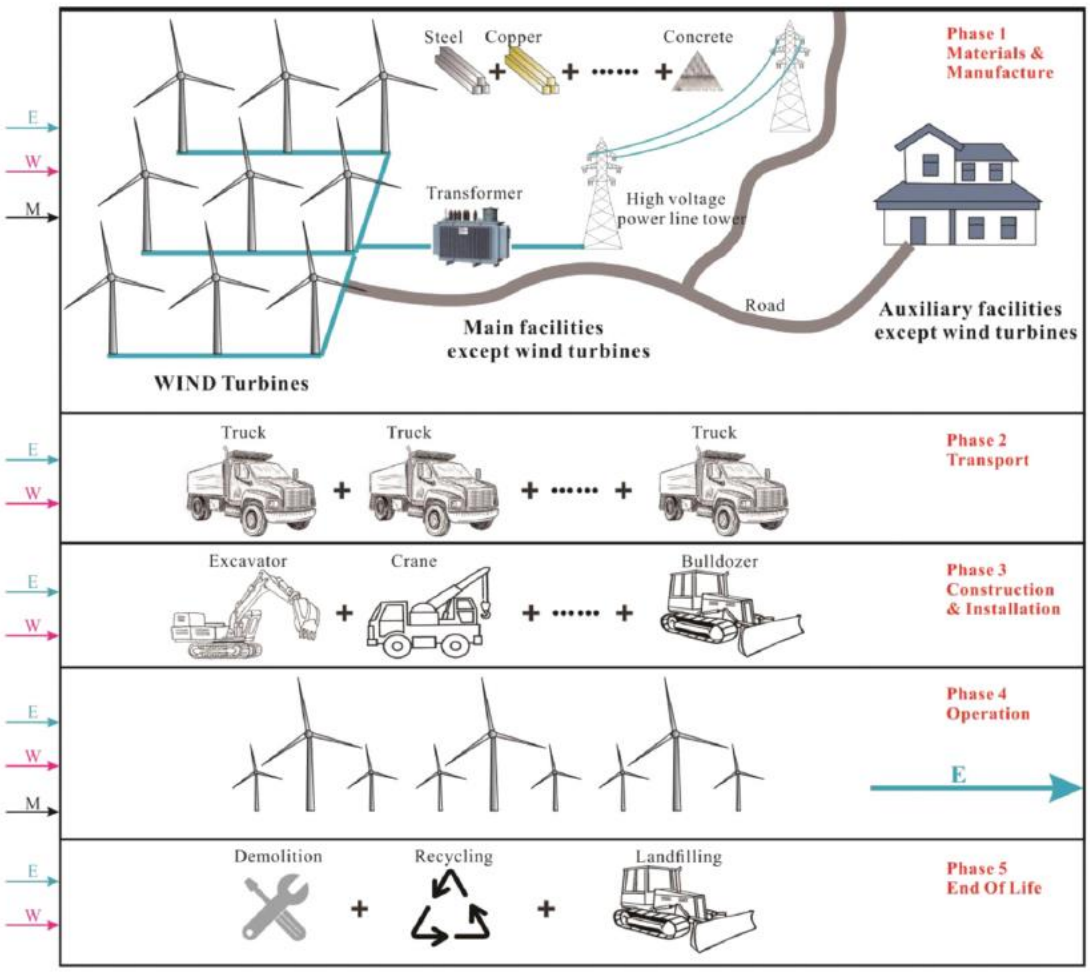

Fig. 2. System boundaries and life cycle phases of a wind farm in North China (Li et al., 2021)

3) Oebels & Pacca (2013) processed an LCA study for a hypothetical wind farm located in the coastal area, of the Northeast of Brazil, on the State of Ceara, with 14 wind turbines of 1.5 MW each, totalling a power capacity of 21MW. The wind speed and capacity factor of the wind farm were estimated using available data from valid sources. The following figure 3 shows the system boundaries and the life cycle phases. The system boundary is defined at the substation of the wind park, encompassing the cables and losses between the transformer and the substation. However, the assessment excludes the substation itself. Four phases were assumed for the wind farm's life cycle, excluding the EoL phase, as it would have been based on vague assumptions. Material processing-Manufacturing, Construction, Operation and Transportation.

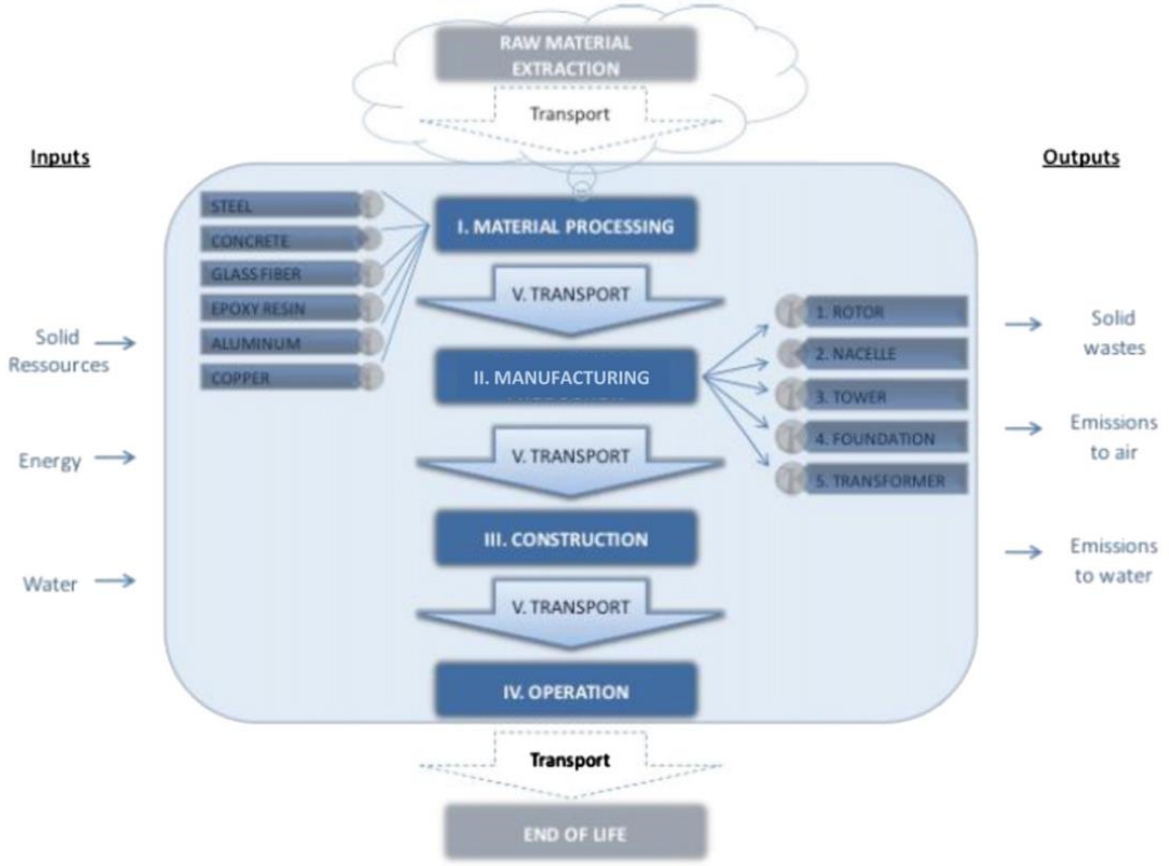

Fig. 3. Flowchart of a hypothetical wind farm in Northen Brazil (Oebels & Pacca, 2013)

4) Rajaei & Tinjum (2013) evaluated through LCA, the wind farm Glacier Hills Wind Park, located in the towns of Randolph and Scott in Columbia County at the State of Wisconsin. This wind farm has a generating capacity of 162 MW, comprising 90 wind turbines with a rating of 1.8 MW each. The system boundaries encompassed not only the wind farm but also the equipment for its electrical interconnection up to the point of connection to the transmission system. This included local transformers, the central substation, cables, and trenches. The wind farm's lifecycle was divided into four activities. Material Production, Transportation, Earthwork and Construction and Transmission System.

GHG emissions at Solar Power Projects

Following the search process, four relevant articles were selected based on two criteria: measuring GHG emissions intensity using the CO_2-eq./kWh indicator and employing a "cradle to grave" approach. These articles provide LCA analyses of four distinct solar power projects. The basic characteristics of the solar power projects are presented in this section, while table 1 and table 2 with the GHG emissions intensity

(CO2-eq./kWh) and the GHG emissions contribution of each life cycle are presented in the Results sector.

1. In a study led by Constantino et al. (2018) an LCA was conducted to evaluate a set of 10 photovoltaic (PV) plants, installed in NE Brazil, with a total installed power capacity of 1.1MW_p. The technology of PV modules was multi-Si type, manufactured in China. The system boundaries of the study were defined to include the combination of photovoltaic module manufacturing, balance of system (BOS) materials, and photovoltaic energy production. Direct emissions stemming from the manufacturing process of the PV modules, as well as emissions originating from the energy generation process required for manufacturing, were accounted for. Additionally, data pertaining to transport and the recycling process were incorporated, although the results of these two components were presented separately from the others. The LCA "cradle to grave" approach included five phases, for the project life cycle. Manufacturing, Transportation, Installation, Operation & Maintenance, Final decommissioning/Recycling.
2. The authors Corona et al. (2016) performed an LCA of a commercial high concentration photovoltaic power plant (HCPV) located 20km south of Casablanca, in Morocco. The installed power capacity of the plant was 1.008MW. PV modules were manufactured in Spain, then transported by ship to Casablanca and finally distributed to the HCPV plant by road. System boundaries include the PV modules, trackers, inverters, cables, building and the following five phases. Material Extraction and Manufacturing (E&M), Transportation, Construction, Operation and Maintenance (O&M), Dismantling and Disposal (D&D).
3. An LCA study was carried out by García-Valverde et al. (2009) for a 4.2 kWp stand-alone photovoltaic system (SAPV) at the University of Murcia (south-east of Spain). It consists of 40 mono-crystalline silicon modules (24 V, 106 W_p) mounted on a building rooftop with galvanized steel supporting structures. The following figure 4 shows the system boundaries and the life cycle phases. The system boundaries included the equipment for the SAPV system and the energy inputs and GHG emission outputs for the following three phases. Construction, Operation and Decommissioning phase.

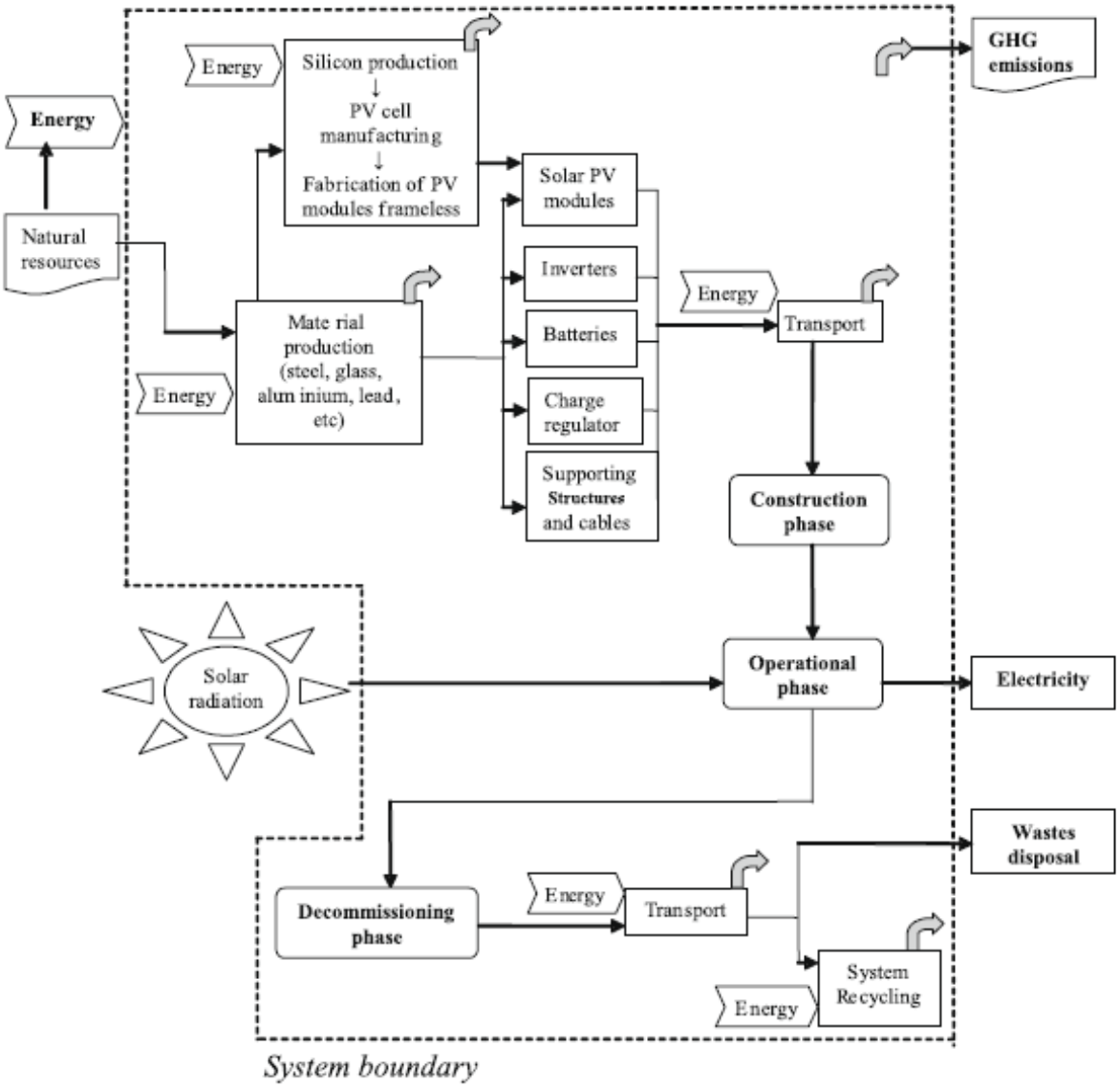

Fig. 4. System boundaries of a photovoltaic system at south-east Spain (García-Valverde et al., 2009)

4. Rahman et al. (2019) conducted an LCA study for a 3.6 kW_p stand-alone solar PV system, with poly-crystalline PV modules, intended to supply electricity to St. Martin's Island, a small island in the northeastern part of the Bay of Bengal, at Bangladesh. The following figure 5 shows the system boundaries and the life cycle phases. The system boundaries included the equipment for the PV system until the control room and the energy inputs and GHG emission outputs for the following four phases (the decommissioning phase was excluded within of the system boundaries). Manufacturing, Transportation, Construction and Operational phase.

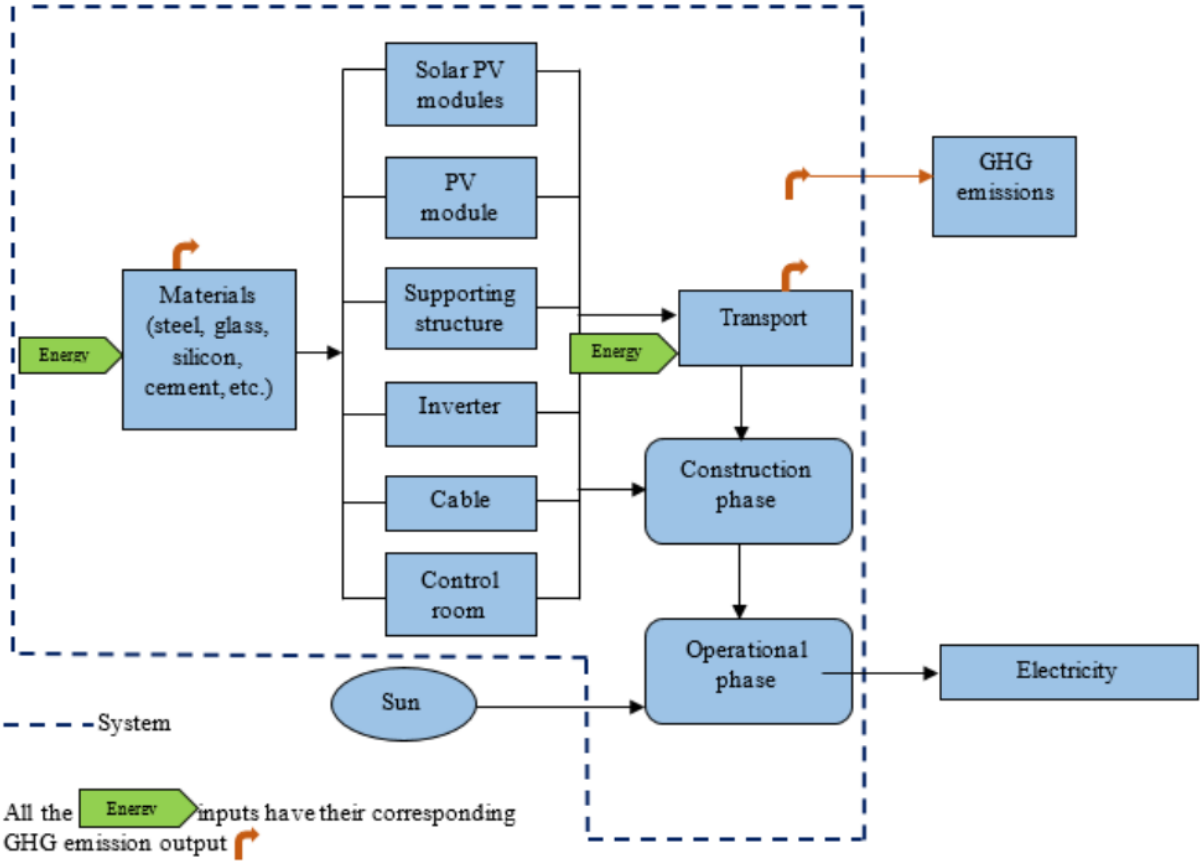

Fig. 5. System boundaries of a solar PV system at Bangladesh (Rahman et al., 2019)

Method

To address the two research questions, the qualitative method was chosen as the research approach. The first research question focuses on understanding the dominant factors influencing climate change and global warming impact of wind and solar power projects. This process requires gathering data from articles running LCA on wind and solar power projects. Because the key point is to select the relevant data from the pool of the LCA articles' information and content, a qualitative analysis method was chosen and specifically a mixture of content analysis and thematic analysis (Bryman, 2012).

Content analysis is used to analyse the content of communication by coding and interpreting textual, visual, or audio data to identify patterns, themes, or biases. This method is flexible, applicable to diverse data types, and can efficiently handle and examine large volumes of information and complex data, which was the reason for its choice (Bryman, 2012).

Thematic analysis is used for identifying, analysing, and reporting patterns (themes) within data. It involves examining the data to pinpoint recurring topics, ideas, and meanings, which are then organized into themes that capture the essence of the data. This approach is valuable because it provides a flexible and accessible way to gain deep insights into complex qualitative data, allowing researchers to interpret and present findings in a structured manner (Bryman, 2012).

The second research question tries to analyse the effectiveness of an educational program aiming to empower learners to make sustainable decisions regarding wind and solar power projects. Questionnaires were selected as the measurement tool, as the standardization of questions enhances comparability, while the structured nature of responses also facilitates straightforward and accurate data analysis. The analysis of the questionnaires' data employs a qualitative method, as the responses consist of answers to critical and knowledge-based questions and do not include numerical data (Bryman, 2012).

Data Collection

The Data Collection method was organized in two distinct stages corresponding to the two research questions. The first stage involved gathering data for three major categories: LCA methodology in wind and solar power projects, and post-humanist ecology. The second stage focused on gathering data for the educational program.

For the first stage of Data Collection regarding LCA in wind and solar power projects, research articles for individual power projects served as the primary data source, supplemented by some reviews. The method of Data Collection's first stage was structured into the following ten steps:

1. Initially, literature from the beginning of the master's program focused on post-humanist ecology concepts was consulted,
2. Subsequently, recommended literature from supervisors was utilized, primarily covering LCA, ESD, transformative learning, post-humanistic theories and Social Research Methodology concepts.
3. A thorough search was conducted through Scopus Database and Web of Science Database to gather literature articles specifically addressing LCA in wind and solar power projects.
4. Correspondingly, a search was conducted through Scopus Database and Web of Science Database to gather literature articles specifically addressing post-humanist ecology.
5. The gathered literature was categorized into the three aforementioned major categories.
6. The theoretical framework of post-humanist ecology was structured as the background and philosophical lens of the thesis based on post-humanist ecology literature.
7. Research articles from both LCA categories were analysed with the aim of identifying potential patterns of similarities and differences between the two technologies.
8. Following the comparison between the two technologies, the master thesis proceeded to identify the environmental impacts – GHG intensity emissions, according to LCA. This involved determining the identity of the environmental impacts, the phases at which these impacts occur and investigating their root causes for both technologies.
9. Complementary to the investigation of research articles, reviews in LCA for both technologies served as a benchmark, in order to check if the reported GHG intensity emissions' values of the specific studies comply with the reviews' values.
10. Lastly, environmental impacts were analysed under the post-humanist ecology perspective, and those with the greatest environmental impact were classified as the predominant environmental impacts.

For the second stage of Data Collection, the research method administering two questionnaires, one used at the beginning of the educational program and the other upon its completion. The method encompassed the following steps:

1. Data on students' roles and background.
2. Data on students' initial knowledge levels were collected using the first questionnaire.

3. The second questionnaire gathered data on the learning outcomes of the program, as well as feedback from students.

Search Process

The research method is developed according to the following structure. Initially, data was collected regarding the existing literature about theoretical frameworks and the two research questions. Subsequently, the data are chosen as the scientific background for designing the educational program. The data were collected through the following procedure.

A search was performed through the Scopus Database and Web of Science Database, with the aim of finding articles referring to LCA method in wind and solar energy projects and articles related to post-humanist ecology.

In addition, Google Scholar was used to find articles providing specific definitions needed for the thesis, such as the definition of the three dimensions of sustainability.

Lastly, recommended books and articles during the different courses of the master program, suggestions from the master thesis' supervisors, as well as literature (books and articles) from my own knowledge and prior learning, were utilized. These sources are referred to in the following paragraph named "Further literature".

Regarding the search in Scopus and Web of Science and in order to expand the initial pool of articles, the following list of keywords was formed: "life cycle assessment", "wind", "wind energy", "wind farm*", "solar", "solar energy", "solar farm*", "PV", "photovoltaic" "post-humanis*", "ecolog*", "manufacturing", "construction", "operation".

The results of each Database's search are following:

Scopus Database

A search was performed using the keywords "life cycle assessment", "wind", "wind energy", "wind farm*", "solar", "solar energy", "solar farm*", "PV", "photovoltaic" with the filter of article title, which means it searched the keywords only in the title, resulting in 270 articles. Following the criteria's choice of limited to Energy subject area, English language and limited to "life cycle assessment" keywords the articles were narrowed down to 132. After they were sorted by the highest citation ranking, the abstracts of those 132 articles were read and finally the following 7 most relevant articles were selected:

- Article 1: Constantino et al. (2018).

- Article 2: Li et al. (2021).
- Article 3: García-Valverde et al. (2009).
- Article 4: Oebels & Pacca (2013).
- Article 5: Pehl et al. (2017).
- Article 6: Peng et al. (2013).
- Article 7: Rahman et al. (2019)
- Article 8: Rajaei & Tinjum (2013).

The keywords “life cycle assessment”, “manufacturing”, “construction”, “operation”, were searched with the filter of article title, abstract, keywords which means it searched the keywords at title, abstract and author keywords and 25 articles were found. Following the criteria’s choice of limited to English language the articles were narrowed down to 22. After they were sorted by the highest citation ranking, the abstracts of those 22 articles were read and finally the following 2 most relevant articles were chosen:

- Article 9: Ardente et al. (2008)
- Article 10: Rabaia et al. (2021).

The keywords “post-humanis*”, “ecolog*” were searched with the filter of article title, which means it searched the keywords only at title and 28 articles were found. Following the criteria’s choice of limited to English language the articles were narrowed down to 26. After they were sorted by highest citation ranking, the abstracts of those 26 articles were read and finally the following 2 most relevant articles were chosen:

- Article 11: Aretoulakis (2014).
- Article 12: Wei & Kewen (2010).

Lastly, the keywords “educational intervention”, “sustainability”, were searched with the filter of article title and 10 articles were found. The abstracts of those 10 articles were read and the following 2 most relevant articles were chosen:

- Article 13: Richardson et al. (2017).
- Article 14: Samant et al. (2016).

Web of Science Database

A search was conducted using the keywords “life cycle assessment”, “wind”, “wind energy”, “wind farm*”, “solar”, “solar energy”, “solar farm*”, “PV”, “photovoltaic” with the filter of title, which means

it searched the keywords only at title and 196 articles were found, which then were sorted by highest citation ranking. Following the criteria's choice of document types, the articles were narrowed down to 182. The titles of those 182 articles were scanned, and the ones which were referring to specific detailed material analysis for the two technologies were discarded. Finally, the abstracts of the most relevant ones were read, and the following 2 relevant articles were chosen:

- Article 15: Corona et al. (2016)
- Article 16: Hertwich et al. (2014).

The keywords "life cycle assessment", "manufacturing", "construction", "operation", were searched with the filter of topic, which means it searched the keywords at title, abstract and author keywords and 29 articles were foun, which then were sorted by highest citation ranking. The abstracts of those 29 articles were read and finally the 4 following most relevant articles were selected, which were already chosen during the search process on Scopus Database, namely:

- Article 2, Article 6, Article 7, Article 8,

The keywords "post-humanis*", "ecolog*", were searched with the filter of title, because a narrow focus on theory of post-humanist ecology was prioritized and 16 articles were found, which then were sorted by highest citation ranking. The abstracts of those 16 articles were read, but no relevant article was found.

Lastly, the keywords "educational intervention", "sustainability", were searched with the filter of article title and 9 articles were found. The abstracts of those 9 articles were read and the following 2 most relevant articles were chosen, which were already selected during the search process on Scopus Database, namely:

- Article 13, Article 14

Google Scholar

The keywords "life cycle assessment in a nutshell", were searched with the filter of date from 2023 and 485 articles were found. The titles of those 485 articles were scanned and finally the following 1 most relevant article was chosen:

- Article 17: Mudersbach et al. (2023)

The keywords “life cycle assessment”, “greenhouse gas emissions”, “PV”, “wind”, “meta-survey”, were searched and 65 articles were found. The titles of those 65 articles were read and finally the following 1 most relevant article was selected:

- Article 18: Nugent & Sovacool (2014)

Further Literature

In addition to the articles identified through the Scopus Database, Web of Science Database and Google Scholar, further literature was utilized to support the thesis. This additional literature included books and articles introduced during master’s program courses, those recommended by supervisors and literature already familiar to me. These references provided insights into the following themes and concepts:

LCA: In the domain of LCA, Baumann and Tillman (2004) provided a cornerstone reference. Widely recognized and cited internationally, their work offers comprehensive guidance on the principles and applications of LCA, preparing students for practical implementation of the methodology.

Social Research Methodology: Bryman (2012) served as an indispensable resource for social research methodology. This book is known for its methodological rigor and is valuable to equip researchers with tools for designing, collecting, and analysing data while adhering to high academic standards.

Biology & Post-humanistic Ecology: Explorations of post-humanistic ecology and biology were enriched by foundational works such as Bekoff (2004), which bridges biology and philosophy to examine ethical behaviour in non-human animals and the shared moral dimensions across species. Haraway (2016) and Kopnina (2019) contributed valuable insights into post-humanist frameworks, while Weldemariam (2019), Weldemariam (2022) and Wilson and Edwin Jeevaraj (2023) explored fostering care and responsibility toward non-human entities, addressing the ethical challenges of the Anthropocene era.

Transformative Learning: In the context of transformative learning, Mezirow (2000) and Wals (2012) highlighted the transformative potential of education in promoting sustainability. These works emphasize critical thinking and the role of education as a tool for challenging unsustainable norms and fostering democratic values.

Renewable Energy: Jelley (2020) documented the fundamental principles, benefits and challenges associated with renewable energy sources.

Research Ethics: BERA (2018) was selected because it provides the principles and the guidelines for the research ethics, particularly in educational research.

Sustainability: Purvis et al. (2018) offered a comprehensive viewpoint of the "three pillars" concept of sustainability—environmental, social, and economic dimensions.

Questionnaires

To assess the effectiveness of the educational program and evaluate its learning outcomes for the participants, two questionnaires are administered at different stages. Both questionnaires are attached to the sector "**Appendix 1 – Questionnaires**".

The first questionnaire is distributed before the beginning of the educational program, to gather data on participants' initial knowledge. It consists of fifteen questions in total, separated into three main parts. The first part includes ten questions which indicate the familiarity of the participants with the main concepts which are going to be discussed in the educational, namely sustainability, LCA and life cycle phases, GHG emissions and GHG emissions intensity, global warming potential. The second part encompasses three task questions where the participants need to rank the lifecycle phases in the correct order. Lastly the third part consists of two questions answered with yes or no, referring to their general understanding of sustainability.

The second questionnaire is administered at the end of the educational program, to gather data on participants' knowledge after the completion of the educational program. It consists of fifteen questions again, organized in four parts. The first part contains four multiple choice questions related to the LCA methodology and GHG emissions intensity. The second part is the same as the first questionnaire's second part and includes the same three task questions where the participants need to rank the lifecycle phases in the correct order. The third part encompasses four questions with four definitions, for which the participants should give their level of understanding. Lastly the fourth part entails four open-ended questions. The first two questions require critical thinking and utilizing the learned knowledge in order for the participants to come up with a justified answer, while the next two questions ask for the participants feedback on the educational program.

Both questionnaires' answers are analysed qualitatively, to assess the knowledge level before and after the educational program. Comparing the results of the two questionnaires, an assessment could be conducted regarding the learning outcomes and the impact of the educational program on participants' gained knowledge and skills. Lastly, the feedback gathered from the second questionnaire provides suggestions for potential improvement.

Data Analysis

The qualitative analysis process, for the first research question, primarily revolves around data reduction, an aspect that enhances the understanding of the collected data effectively. In the case of this master thesis, data reduction involves condensing the wealth of information obtained from the studies into manageable formats. This condensation is critical for interpreting the material and extracting key findings related to GHG emissions intensity and associated factors (Bryman, 2012).

A qualitative approach using content analysis and thematic analysis was employed to extract and analyse information from eight relevant studies focusing on the environmental impact of wind and solar power projects. The process facilitated the organization and documentation of data, related to GHG emissions intensity including variables such as installed capacity, country of origin, functional unit, lifespan and contributions of various phases to emissions intensity (Bryman, 2012).

Once the data extraction phase was complete, the collected information was carefully reviewed and synthesized to identify common themes, patterns, and trends across the studies. This involved categorizing and coding the data to uncover relationships and insights related to the environmental impact of wind and solar farms.

The data analysis for the second stage, involving the educational program, contains the analysis of participants data. First of all, all the participants are working in the same renewable energy company, which builds wind and solar power projects in order to produce and sell electrical energy. Moreover, it should be noted that initially, twenty-three (23) individuals volunteered to participate in the program and completed the first questionnaire but eventually sixteen (16) of them attended the program.

The sixteen (16) participants roles who attended the program are:

- 12 engineers from whom
    - 2 directors, one in construction and one in operation & maintenance department
    - 5 electrical engineers, one in licensing, two in construction, one in operation & maintenance and one in technical & procurement department
    - 2 civil engineers, one in construction and one in technical & procurement department
    - 3 mechanical engineers, one in licensing, one in construction and one in operation & maintenance department
- 2 financial officers
- 1 geologist

- 1 secretary

The seven (7) participants roles who didn't attend the program, while they filled in the first questionnaire are:

- 4 engineers from whom
  - 2 electrical engineers, one in operation & maintenance and one in technical & procurement department
  - 1 civil engineer, in licensing department
  - 1 mechanical engineer in construction department
- 2 lawyers
- 1 financial officer

Furthermore, the data analysis encompasses two questionnaires aiming to evaluate participants' knowledge levels, adapting program content and assessing overall effectiveness. Initially, responses from the first questionnaire are descriptively analysed, organizing and tabulating data to identify trends in participants' familiarity with fundamental concepts, GHG emissions, lifecycle phases, sustainability and post-humanism ecology perspectives (Bryman, 2012).

Subsequently, a comparison of pre- and post-questionnaire responses allows for an assessment of knowledge improvement post-program. Thematic analysis of open-ended questions provides qualitative insights into participants' feedback and suggestions for program enhancement. Additionally, the data analysis of the second questionnaire answers provides an analysis of participants' knowledge utilization and their performance to apply learned concepts in real-world contexts in their daily working routine in wind and solar power projects (Bryman, 2012).

Research Ethics

Throughout this master thesis, various ethical considerations are taken into account to establish a transparent process during data collection and that the analysis is fair. Ethical responsibility extends to all participants involved in this study, including teachers, learners and educational researchers, ensuring that their contributions are respected and aligned with ethical principles and practices (BERA, 2018).

Intellectual property rights were strictly respected, with a commitment to acknowledging and citing proprietary information, data, or findings according to legal and ethical standards. Participant names were referenced only with explicit consent, ensuring confidentiality for any potentially identifying information (BERA, 2018).

Ethically, this study prioritizes transparency in reporting findings, respecting the autonomy of participants, and acknowledging power dynamics inherent in the research context. For this reason, all the participants were fully informed about the purpose of the study, the structure of the educational program and how their responses would be used, before they were engaged in the research. So, their participation was a result of a free and informed decision (BERA, 2018).

In line with the responsibilities towards participants, informed consent was obtained from all individuals before they completed the questionnaires or participated in discussions. They were explicitly informed of their right to withdraw from the study at any time without providing a reason and without any consequences in any way. To preserve the participants' privacy, both questionnaires were anonymous and no personal information was included in them, or in the study. Furthermore, as I conducted the research within the company I am employed, I took extra care to minimize any potential power relations by reassuring that participation was entirely voluntary and independent of any work-related consequences (BERA, 2018).

Educational Program

This method's section presents the educational program, which plays a major role in this study, as it is the key component of the two research questions. It provides an overview of the participants involved, the design of the program, its implementation and the methods used for data collection, which are described in detail in the following subsections.

To be noted that both questionnaires and lecture presentation of the educational program are attached at Appendices, Appendix 1 – Questionnaires and Appendix 2 – Lecture Presentation, respectively.

Participants

As the instructor, I implemented the specialized educational program outlined in the master's thesis for my colleagues. This target audience comprises individuals involved in wind and solar energy projects, including top-level executives and on-site workers. Most of my colleagues are engineers specializing in electrical, mechanical, or civil engineering. Additionally, in my department there are also other professionals from other fields. Financial officers, secretaries, and lawyers. The engineers are divided into four major teams, based on projects' phases and needs, covering both wind and solar farms. The first team works on the development of the projects, which includes the licensing phase and the primary design. The second team manages the construction. The third team handles the maintenance and operation phase of the projects. Finally, the fourth team, known as the technical and procurement team,

provides technical support, conducts studies, designs drawings, selects equipment, and manages procurement processes. The other professions play supporting roles for the projects.

All engineers possess extensive expertise for both wind and solar power projects. They are able to understand in depth the concepts of LCA, environmental impacts and sustainability principles. The other professions have an elementary knowledge of both technologies.

Program Design

The educational program comprises two primary components: a core framework, which remains constant, and a customizable sector that adjusts its content based on the knowledge level of the participants. The core framework is built on the two theoretical frameworks (transformative learning and post-humanistic ecology), along with simplified interpretations of the first research question's results at a basic level, obtained through the LCA methodology. Conversely, the customizable sector offers additional details and information adjusted to the varying knowledge levels of the target audience. Incorporating this idea, the following scheme was developed as the plan for the educational program.

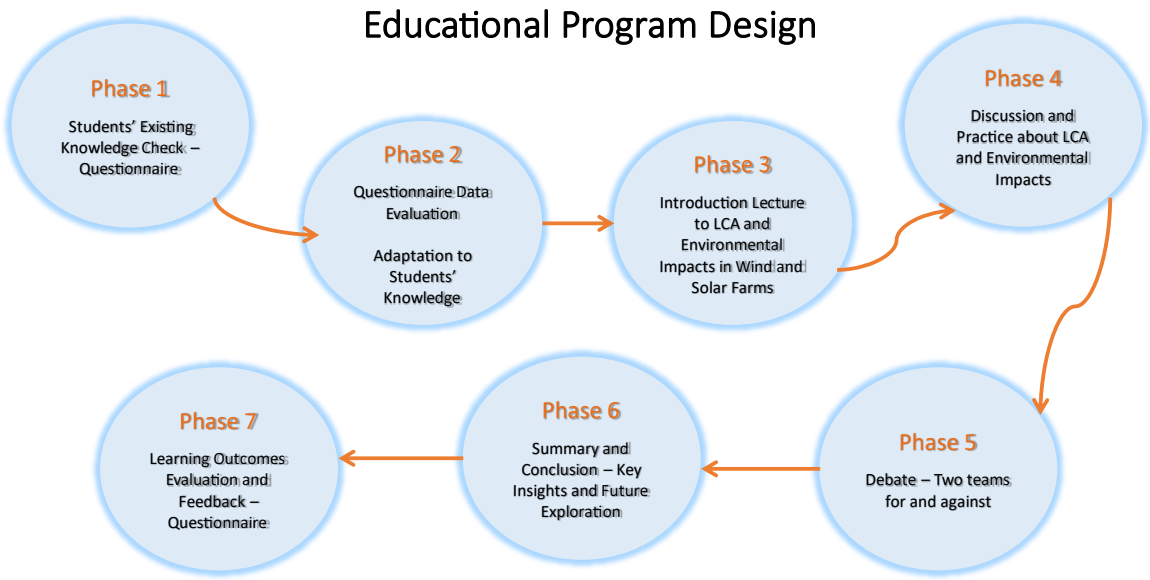

Figure 6. Educational Program Design and Phases

The educational program consists of seven distinct parts (figure 6). Initially, an assessment phase involves administering a questionnaire tailored to gauge participants' existing knowledge (phase 1 and 2). The aim of the questionnaire is to check the existing knowledge of the colleagues. This knowledge

level assessment of the participants has a double scope. First to adapt the customizable sector to their knowledge needs and second to have a knowledge benchmark in order to analyse the educational program effectiveness after its completion.

Then in phase 3 the teaching process begins with an introductory presentation delivered orally by the instructor (myself). The presentation covers the sustainability concept and the LCA methodology, along with the identification of environmental impacts related to the GHG emissions intensity of wind and solar energy projects. This presentation, incorporating lectures and PowerPoint slides, lasts for 90 minutes and a 15-minute break for coffee and snack follows.

Subsequently, phase 4 of the educational program entails a discussion session. Participants, including both learners and the teacher, collaboratively navigate through existing knowledge concerning environmental impacts in wind and solar energy projects. Additionally, they explore potential future pathways for enhancing the overall sustainability of each project, as well as methods for knowledge utilization in their practical life. In this session, the teacher's role is to guide and support the discussion, encouraging critical thinking, perspective transformation and knowledge exploration, aligning with the emancipatory perspective principles and transformative learning (Wals, 2012). This discussion session lasts for 60 minutes. A 45-minute break for lunch follows.

A debate segment follows, at phase 5, where participants form two groups, each representing a different perspective. One group advocate for prioritizing the environmental dimension from a post-humanist ecology standpoint, while the other group promotes an integrated perspective that considers all three dimensions of sustainability, emphasizing a humanist viewpoint. Each group selects three participants to represent their team and serve as speakers. Each speaker is given 10 minutes to present their position. This format facilitates argument presentation and engaging discussions. The debate segment is followed by a 15-minute break for coffee and snacks.

As the program approaches its conclusion, at phase 6 a summary session is conducted. Here, a volunteer from the target audience summarizes the analysis of discussions, highlighting the opinions, viewpoints and questions raised during the debate. Key insights and areas for further exploration are provided to participants by the teacher, alongside potential avenues for future research to advance knowledge in the field. This part is estimated to last around 30 minutes.

Finally, at stage 7 the participants are invited to fill in the second questionnaire. The scope of this questionnaire has two dimensions. Firstly, assessing the post-educational program knowledge level of the participants and comparing it with their pre-educational program knowledge level will provide an

evaluation regarding the gained knowledge and the effectiveness of the learning outcomes. This evaluation process identifies areas for refinement and improvement, guiding future versions of the program. Secondly, the participants through the second questionnaire are able to provide constructive feedback and suggestions for improvement.

The primary learning outcome of the educational program is to educate the learners about the existence of environmental impacts on wind and solar power projects, their origin and their effect on sustainability and provide ideas for more sustainable practices. Moreover, the learning outcomes encompass an interactive experience of transformative learning and an enhanced understanding of LCA methodological structure. Through participation in discussions and debates on sustainability topics, the learners develop critical thinking skills, question their belief system, expand their worldview and improve their ability to analyse various perspectives on environmental issues, including post-humanistic and humanistic viewpoints. Additionally, participants raise their awareness of the entanglement of human and non-human entities in ecosystems, strengthening their capacity to contribute to sustainability efforts in professional contexts, such as wind and solar power projects. They also cultivate empathy, care, and responsibility towards the environment and non-human entities, engaging in reflective practices to identify areas for personal and professional growth in sustainability efforts.

Lastly, knowledge utilization is a critical learning outcome in the educational program, empowering students to apply their understanding of environmental impacts, sustainability, methodological tools and theoretical frameworks to real-world contexts, particularly within wind and solar power projects. In practical terms, participants utilize their knowledge to propose and implement more sustainable practices within wind and solar energy projects. This may involve advocating for the adoption of eco-friendly technologies, optimizing resource management strategies, or designing systems that minimize ecological disturbances.

Program Implementation

Following the design outlined in the previous section, the educational program was implemented by me within my company, an independent power producer (IPP) that develops and constructs wind and solar energy projects for its own portfolio. All participants in the educational program were my colleagues from the same company. Initially, twenty-three (23) colleagues volunteered to participate in the program and completed the first questionnaire. However, due to scheduling conflicts, seven (7) were unable to attend, leaving a final group of sixteen (16) participants who engaged in both the program and the second questionnaire. Among these participants, twelve (12) are engineers from various levels within the

organization, including two (2) directors. The remaining participants include two (2) financial officers, one (1) geologist, and one (1) secretary.

As mentioned in the previous section, the educational program was designed based on seven distinct phases. The first one of them (first questionnaire) was conducted on 19th of July, the second (first questionnaire analysis) was conducted on 20th of July and the rest five phases were conducted on 26th of July. As not all the volunteers who took the first questionnaire on 19th of July were able to participate on 26th of July there was a difference in the number of participants on the first two phases and the rest of them.

Data Collection

The data of the educational program for this study are collected through the administration of two questionnaires, the first before the beginning of the program and the second after its completion. The first questionnaire comprises 15 closed-ended questions divided into three categories. The first category assesses students' familiarity with fundamental concepts from literature, like sustainability and its primary approach with the three pillars, LCA, environmental impacts on wind and solar farms and the climate change and global warming metric of GHG emissions intensity. The second and third categories evaluate students' understanding of greenhouse gas emissions from electricity technologies, the various phases of wind and solar power projects and their perspective on sustainability issues.

Finally, with the second questionnaire, participants are invited to present their knowledge gains and to provide anonymous written feedback. The second questionnaire contains 15 questions: 11 closed-ended and 4 open-ended questions, divided into four categories. The first category assesses the taught knowledge, while the second and third categories mirror those from the first questionnaire, evaluating participants' understanding of greenhouse gas emissions from electricity technologies and various phases of wind and solar power projects. The fourth category includes 2 questions aimed at promoting critical thinking of the taught knowledge, along with 2 questions requesting direct feedback and suggestions for improving the educational program.

Results – LCA implementation in Educational Program

Results section includes two main parts. The first part presents the first research question's results from the literature research analysis of the eight (8) articles, four (4) in wind and four (4) in solar technology, under the context of LCA method for global warming and climate change impact, using the metric of GHG emissions intensity, CO_2-eq./kWh (Peng et al., 2013). The second part of results section presents the second question's results of the educational program implementation.

LCA Results

Regarding the first part, the results show that GHG emissions intensity is considerably higher in solar technology compared to wind technology. In addition, they show that among the five different life cycle phases of a wind and solar energy project, the Manufacturing phase accounts for the highest GHG emissions intensity, while the Decommissioning phase has the lowest. The other three phases (Construction, Operation and Maintenance, and Transportation) fall in between, with their GHG emissions intensity values varying and changing order from project to project.

The gathered data from the eight (8) articles, are organized and presented in the following two tables. The table 1 is the more analytical and is structured into two main columns representing the respective technologies (wind and solar), with four sub-columns dedicated to each power project discussed in the articles. The table's data include installed capacity, country of power project installation, the functional unit of the life cycle assessment (LCA) set at 1 kWh for all projects, and the project lifespan, typically 20 years except for Constantino et al. (2018), which spans 25 years.

Subsequently with green colour the table highlights the critical aspect of GHG emissions intensity for each project. It delineates how GHG emissions intensity is distributed across the five main phases of both wind and solar power projects, detailing GHG emissions intensity, GHG emissions, or total energy requirements. Where data was not available, or a phase was excluded the cell of the table is coloured grey.

Table 1. Data from wind and solar farms' articles

Technology	**Wind**	**Solar**

Article	Ardente et al. (2008)	Li et al. (2021)	Oebels & Pacca (2013)	Rajaei & Tinjum (2013)	Constantino et al. (2018)	Corona et al. (2016)	García-Valverde et al. (2009)	Rahman et al. (2019)
Installed Capacity (W)	7,260.0	40,000.0	21,000.0	162,000.0	1,100.0	1,008.0	4.2	3.6
Country	Italy	China	Brazil	USA	Brazil	Morocco	Spain	Bangladesh
Functional Unit	1kWh	1kWh	1kWh	1kWh	1kWh	1kWh	1kWh	1kWh
Lifespan (years)	20	20	20	20	25	20	20	20
GHG emissions intensity (gCO2-eq./kWh)	8.80 - 18.50	16.40 - 28.20	7.10	16.90	81.70	53.30	131.00	173.42
Manufacturing Phase	56% of total energy requirement	101.6% to 106.5% of total CO2-eq. emissions	Majority of CO2-eq./kWh	Major contributor CO2-eq./kWh	84% of total CO2-eq. emissions	82 gCO2-eq./kWh	Included in Construction	Major contributor of total GHG emissions intensity
Transportation Phase	6.4% of total energy requirement	1.7% to 2.8% of total CO2-eq. emissions	Second contributor of CO2-eq./kWh	Third contributor of CO2-eq./kWh	Non specified	Non specified	Excluded	1.46 gCO2-eq./kWh Third contributor
Construction Phase	29.9% of total energy requirement	0% of total CO2-eq. emissions	Less than 1% contribution of CO2-eq./kWh together	Second contributor of CO2-eq./kWh	Included in Manufa-cturing	Non specified	1.7% of embodied CO2	Second contributor of total GHG emissions intensity
Operation & Maintenance Phase	6% of total energy requirement	7.8% to 13.3% of total CO2-eq. emissions		Fourth contributor of CO2-eq./kWh	Non specified	11gCO2-eq./kWh	Small proportion of embodied CO2	No GHG emissions intensity
Decommisioning Phase	1.7% of total energy requirement	-22.7% to -12.3% of total CO2-eq. emissions	Excluded	Excluded	Non specified	Negative gCO2-eq./kWh	3.67% of embodied CO2	Excluded

As Table 1 contains extensive data, presenting a challenge for readers to navigate, a condensed summary follows in Table 2. This table retains all the key information for using them in the educational program

framework, focusing on installed capacity, country of project installation, GHG emissions intensity, and the hierarchical order of life cycle phases based on GHG emissions intensity, listed from highest to lowest. For ease of reading, the phases are abbreviated as follows: Manufacturing (Man), Construction (Con), Transportation (Tran), Operation and Maintenance (O&M), and Decommissioning (Dec).

Table 2 makes it easy to detect the GHG emissions intensity values for each project and technology, allowing for a comparison between the two technologies. It also clearly indicates which phases have the highest impact on climate change and global warming, according to their hierarchical order based on GHG emissions intensity. To highlight the important data, both lines are coloured green.

Table 2. Important key data for educational program application

Technology	**Wind**				**Solar**			
Article	Ardente et al. (2008)	Li et al. (2021)	Oebels & Pacca (2013)	Rajaei & Tinjum (2013)	Constantino et al. (2018)	Corona et al. (2016)	García-Valverde et al. (2009)	Rahman et al. (2019)
Installed Capacity (kW)	7,260.0	40,000.0	21,000.0	162,000.0	1,100.0	1,008.0	4.2	3.6
Country	Italy	China	Brazil	USA	Brazil	Morocco	Spain	Bangladesh
GHG emissions intensity (gCO2-eq./kWh)	8.80 - 18.50	16.40 - 28.20	7.10	16.90	81.70	53.30	131.00	173.42
Phases	1.Man 2.Con 3.Tran 4.O&M 5.Dec	1.Man 2.O&M 3.Tran 4.Con 5.Dec	1.Man 2.Tran 3+4.Con +O&M	1.Man 2.Con 3.Tran 4.O&M	1.Man 2.Con	1.Man 2.O&M 3.Dec	1.Man 2.Dec 3.Con	1.Man 2.Con 3.Tran 4.O&M

Educational Program Implementation Results

The results are presented in alignment with the seven distinct phases of the educational program design:

1. Phase 1. Student's existing knowledge check – Questionnaire: The first questionnaire was administered to assess participants' existing knowledge on key concepts related to sustainability,

LCA and GHG emissions, and renewable energy technologies. The questionnaire was anonymous, and the 23 initial volunteers completed and submitted it.

2. Phase 2. Questionnaire Data Evaluation - Adaptation to Students' Knowledge: The first questionnaire was analysed qualitatively and revealed the following findings about the participants' existing knowledge. Overall, participants demonstrated a moderate level of familiarity with sustainability concepts, with many (18 out of 23) displaying high familiarity of the three dimensions of sustainability (environmental, social, and economic) and the relationship between climate change and GHG emissions. However, knowledge gaps were noted in more technical areas such as LCA, GHG emissions intensity, and the environmental impacts of renewable energy technologies. Only a small number of participants answered that they are significant and above familiar with LCA (8 out of 23) and only a few ranked correctly the LCA phases and the electricity technologies based on GHG emissions intensity (6 out of 23). Furthermore, while the participants' knowledge of GHG emissions and their connection to global warming and climate change was stronger, they were less aware about specific metrics such as Global Warming Potential (GWP) and GHG emissions intensity. Based on these findings, the educational content was adapted to include more detailed explanations of LCA, GHG emissions metrics, and their significance in wind and solar energy.
3. Phase 3. Introduction Lecture to LCA and Environmental Impacts in Wind and Solar Farms: During the lecture, the 16 participants seemed motivated and expressed interest in the topic, particularly as they learned about the practical applications of LCA methodology and its utility in assessing the climate change and global warming impacts of wind and solar energy technologies, focusing on the metric of GHG emissions intensity. They participated actively in exercises and tasks which needed the application of the LCA methodology, and they were asking related questions, expressing their curiosity and engagement with the subject. Some participants were already familiar with the basic principles of LCA, while others started from scratch. Despite the different knowledge levels, the lecture was successful in keeping all of them motivated as the knowledge level was progressively rising, keeping all of them, or almost all of them, on track. The participants seemed to clarify in their mind the various stages of wind and solar power projects and the way GHG emissions intensity is distributed throughout the different phases of their life cycle. Furthermore, the lecture emphasized the importance of LCA as a methodological tool for identifying potential environmental impacts and possible strategies for their mitigation in wind and solar energy projects. Lastly, this phase prepared the participants for the upcoming interactive discussion and debate sections, where participants would delve

deeper into sustainability topics and apply their newly acquired knowledge in more practical and critical contexts.

4. Phase 4. Discussion and Practice about LCA and Environmental Impacts: Following the introduction lecture, the discussion phase started with practical examples and case studies of some of the company's power projects, both in solar and wind technology. The focus of the discussion was to identify the environmental impacts in these projects and propose strategies to mitigate them. The participants were actively engaged in the discussion, bringing their professional experiences, each one in the context of their roles. Others from the standpoint of project planning, others form development side, procurement, construction, operation and maintenance. During the discussion, participants gave their opinion regarding the value of LCA as a decision-making tool in their professional work. Some participants recognized the need to integrate LCA methodology at the early stages of project planning, while others pinpointed the challenges of incorporating LCA into fast-paced, real-world projects, arguing that in real world the company's policy prioritizes the quick and financial optimal execution of the project over its sustainability dimensions. Despite these challenges, many participants acknowledged that using LCA as part of a broader sustainability strategy could lead to more knowledge-based, sustainable decision-making across all stages of wind and solar power projects. The participants were enthusiastic with the discussion flow and led it beyond the merely technical issues, trying to explore the broader implications of sustainability in renewable energy. They discussed how other environmental factors, such as biodiversity, water use and ecosystem impact, as well as social and economic factors, like the indigenous people's rights, the influence on the local societies and economies should be considered, in order to provide a more holistic view of a project's sustainability. Subsequently, the discussion focus shifted to the role of engineers, project managers, directors and other professionals and how they can collaborate and coordinate together in order to address the environmental impacts and sustainability issues in wind and solar energy projects. By the end of this session, it was evident that the discussion phase raised the participants' awareness of the complexities of sustainability and especially of its environmental dimension, in wind and solar energy projects. The interactive nature of the session fostered a collaborative learning experience, enabling participants to reform their thinking and develop new strategies for addressing environmental concerns in their work.
5. Phase 5. Debate – Two teams for and against: During this phase, participants were randomly divided into two equally numbered groups of eight participants, with each one of the groups to support a distinct perspective on sustainability. One group advocated prioritizing the environmental dimension from a post-humanistic ecological standpoint, emphasizing the

importance of minimizing ecological harm and protecting non-human entities. They effectively used LCA data and GHG emissions intensity metric to substantiate their arguments, highlighting environmental protection as a primary consideration. In contrast, the second group promoted an integrated sustainability perspective, balancing environmental, social and economic dimensions. This group presented a holistic argument, emphasizing the interconnectedness and interdependence of the three sustainability pillars which lead to a dynamic equilibrium and inevitable trade-offs among them. They argued that any change in one dimension affects the other two, and it is not possible to separate them and optimize only one dimension. Moreover, they asserted that while environmental sustainability is vital, addressing social and economic factors is essential for ensuring the feasibility and long-term success of renewable energy projects. Participants demonstrated a solid grasp of the theoretical frameworks and methods discussed in earlier phases and were able to apply these ideas to the debate. However, this section revealed that many participants found it challenging to weigh the perplexed function impact among the environmental, social and economic dimension of sustainability. While they could examine the direct and obvious impact of a decision, they faced difficulties in assessing the indirect effects of it in the three dimensions of sustainability and the possible trade-offs. The debate format facilitated lively discussions and allowed participants to examine both sides of the sustainability arguments. While most participants managed their time effectively, a few experienced stress levels, due to time constraints. In addition, they showed willingness to question their own assumptions about sustainability and to consider the implications of different approaches for both the environment and society. Overall, the debate phase significantly enhanced participants' ability to critically analyse sustainability issues in the context of wind and solar energy projects. It also highlighted the complexities and trade-offs involved in prioritizing different sustainability dimensions.

6. Summary and Conclusion – Key Insights and Future Exploration: In this session, a volunteer from the participants summarized the key points of the educational program. It seemed that participants were able to apply the theoretical knowledge of LCA and GHG emissions intensity in their professional roles, at wind and solar energy projects. The value of LCA was highlighted as a methodological tool for assessing environmental impacts. Subsequently, following the volunteer's summary, the teacher (myself) outlined some areas for further exploration, specifically a deeper analysis of LCA phases, strategies for reducing GHG emissions intensity in wind and solar power plants and the possible perspectives and approaches of post-humanistic ecology in renewable energy decision-making.

7. Learning Outcomes Evaluation and Feedback – Questionnaire: At this phase, the second questionnaire was given to the participants aiming to evaluate the learning outcomes and gather feedback on the effectiveness of the educational program. This questionnaire was designed to assess the gained knowledge, the participants' ability to apply new information in their professional contexts and their suggestions for further improvement of the educational program. The results from the second questionnaire analysis, indicated significant improvements in participants' awareness of the key concepts covered throughout the program. Participants demonstrated a high-level understanding of the LCA methodology and its contribution in assessing the environmental impacts of wind and solar energy projects. All participants were able to correctly rank the LCA phases, based on the GHG emissions intensity metric, for wind and solar energy technologies, which reflected a significant improvement from their initial knowledge level. Most of the participants (14 out of 16) showed excellent understanding of LCA phases and processes. Except the knowledge-based questions, the questionnaire included questions which demanded to apply critical thinking and combine different learned concepts in order to provide a comprehensive answer. The participants were able to justify their answer by showing the ability to think critically and out of the box. They also proposed strategies and ideas, supported by facts and evidence, to mitigate the GHG emissions intensity of wind and solar power projects. The feedback on the educational program was rather positive and constructive. The participants appreciated the interactive nature of the discussion and debate sections as well as the opportunity to engage with their peers in this type of learning environment. They valued positively the use of case studies, practical examples, and real-world applications in bringing the gap between theory and practice. All the participants provided ideas of constructive feedback and areas for improvement. Some of them suggested that they would like more in-depth coverage of topics, such as more methods of assessing environmental impacts, except LCA and methods which can assess efficiently social and economic impact also in renewable energy projects. A few participants suggested incorporating hands-on activities, such as workshops or group projects, to further reinforce the application of learned concepts. From a post-humanistic ecology perspective, participants appeared to enhance their awareness of ecological issues and adopt a more environmentally conscious mindset. However, they continued to balance this with a practical, anthropocentric approach which prioritized the overall benefits of the company and found equilibrium among the three dimensions of sustainability. The given feedback will be used to improve future versions of the educational program, ensuring that it continues to meet the needs of the target audiences and further empowers participants to make more sustainable and knowledge-based decisions in their daily work.

Discussion

This discussion section refers to the three main points of this master thesis, which are the global warming and climate change impact on wind and solar energy projects, the educational program to empower participants in knowledge-based sustainable decisions and the analysis of the program from a post-humanistic ecology perspective. Subsequently it examines the challenges and the opportunities of this study.

Addressing Climate Change Impacts in Wind and Solar Projects

The results from the first research question reveal two significant patterns in the LCA of wind and solar power projects. The first pattern is that wind energy emerges as a cleaner alternative compared to solar energy in terms of GHG emissions intensity. From a sustainability standpoint, this suggests that stakeholders in the renewable energy sector may want to favour wind energy projects over solar energy projects, at least until solar technology can achieve comparable GHG emission intensity levels (Nugent & Sovacool, 2014).

The second pattern is that the Manufacturing phase is identified as the primary contributor to GHG emissions in both technologies. This phase encompasses the production of critical components such as wind turbine blades, towers, solar photovoltaic panels and inverters, all of which require substantial energy inputs and materials that have significant GHG emissions intensity footprints. Addressing GHG emissions at this stage in a drastic way, could reduce significantly the overall GHG emissions intensity of wind and solar energy projects (Hertwich et al., 2014).

To mitigate the environmental impact of the Manufacturing phase, one potential strategy could be the consideration of GHG emissions during the development and procurement phases. Specifically, the procurement department of the wind and solar energy companies in alignment with the companies' management, could prioritize equipment that is manufactured with lower GHG emissions intensity, which involve assessing the carbon footprint of suppliers and choosing those that adhere to sustainable production practices. Additionally, other supplementary strategies like incorporating recycling and reusing materials, investing in energy-efficient manufacturing technologies, and selecting renewable energy-powered production facilities could further lower emissions associated with equipment manufacturing (Wei & Kewen, 2010).

However, it is crucial to recognize that focusing exclusively on the Manufacturing phase will not be sufficient to achieve a comprehensive and optimal sustainability strategy. All stages of the project

lifecycle, including transportation, construction, operation and decommissioning, must be considered for a holistic approach to sustainability (Oebels & Pacca, 2013). For example, in the transportation phase, optimizing logistics to reduce emissions from fuel consumption and selecting low-emission vehicles can contribute to emissions reduction. During operation, maintenance practices that maximize the efficiency and lifespan of energy projects can minimize emissions over time. Finally, addressing emissions during the decommissioning phase by employing sustainable disposal methods, repurposing components or recycling equipment can assist in reducing further a wind or solar power project's environmental impact (Mudersbach et al., 2023).

Implementation of the Educational Program – Empowering Decision Making

The educational program addressed the idea that sustainability is a super set of elements under similar concepts and values and organized in three main dimensions, environmental, social and economic (Purvis et al., 2018). As it is impossible to analyse the whole superset of elements in once, this educational program focused specifically on the environmental impacts of climate change and global warming in wind and solar power projects, through the application of the LCA method. During the learning process, participants demonstrated innovation and critical thinking, particularly when the limitations of the LCA method were reached (Baumann & Tillman, 2004).

The program set two key objectives for analysis using the LCA method across four studies in wind technology and four studies in solar technology. The first objective was to assess the metric of GHG emissions intensity, while the second was to rank the five lifecycle phases of each project based on their contributions to GHG emissions intensity. However, some studies, such as Constantine et al. (2018), did not provide data for all lifecycle phases. This incomplete data presented a challenge, as a comprehensive evaluation could not be performed without making certain assumptions.

To address this challenge, I proposed the hypothesis to compare and rank only the mentioned and available data. Any guess for estimating the missing data was avoided and there was analysis and comparison among only the known data, even if in that way, some pieces of the whole puzzle were missing. This approach allowed participants to navigate the limitations of the LCA method while fostering critical thinking and problem-solving skills in accordance with transformative learning (Wals, 2012). By applying assumptions strategically, they were able to integrate their theoretical understanding with practical knowledge, enhancing their ability to adapt the LCA methodology to real-world scenarios.

Based on the results, the educational program appears to be a valuable introduction to the application of the LCA methodology in assessing global warming and climate change impact in wind and solar power

projects. Its design, which includes both a fixed and an adaptable component, provides the opportunity to suit the participants' knowledge and experience and provide them with the proper level of information to keep them motivated. Also, the interactive discussion and the debate section fosters dynamic engagement between the teacher and participants, as well as among participants themselves. This interactive format aligns with the principles of transformative learning (Mezirow, 2000), encouraging collaborative learning and critical dialogue.

The educational program equipped participants with the tools and knowledge to make informed, sustainability-focused decisions in their professional routine. By integrating theoretical insights with practical problem-solving exercises, participants gained the capacity to address real-world sustainability challenges in wind and solar energy projects. The program enabled them to evaluate lifecycle phases, identify key contributors to GHG emissions and propose strategies for mitigation.

Furthermore, the emphasis on knowledge-based decision-making aligns with the goals of sustainable development by raising awareness on environmental issues, interdependences among the three dimensions of sustainability and the need for holistic thinking. The participants were encouraged to consider trade-offs, evaluate alternative approaches and apply innovative solutions in their professional contexts. By doing so, the program reinforced the importance of aligning business decisions and projects viability with environmental sustainability goals, thereby preparing participants to act as informed and responsible contributors to the renewable energy sector.

Discussion of results through post-humanistic perspective

The prevailing concept of sustainability, as a three-dimension pattern structure, based on the environmental, social, and economic pillars, largely reflects an anthropocentric perspective. Humans are both the primary agents and beneficiaries of sustainability efforts, with decision-making frameworks designed to optimize human well-being (Purvis et al., 2018). However, the inclusion of the environmental dimension within this sustainability pattern, presents an opportunity to transition toward a post-humanistic ecology approach. This philosophy advocates for decentring human interests and recognizing the intrinsic value of all living entities, fostering an ecological consciousness that transcends human-centered priorities (Taylor, 1981). Within this context, the educational program can be promoted for its capacity to advance this shift and cultivate a more ecologically balanced and inclusive perspective among participants.

The program succeeded in sensitizing participants to the ecological implications of wind and solar projects, encouraging them to consider environmental impacts beyond human-centric benefits. By

analysing lifecycle phases through the LCA methodology, participants were exposed to the environmental impacts of wind and solar energy systems, such as material extraction, energy consumption in manufacturing and waste generation during decommissioning. This awareness aligns with post-humanistic principles by emphasizing the interconnectedness of human activities and the environment and advocating for sustainability efforts that benefit the planet as a whole, rather than exclusively serving human needs (Weldemariam, 2022).

Despite raising post-humanistic awareness, the program remained constrained by a fundamentally anthropocentric orientation. While participants were empowered to make sustainable knowledge-based decisions, they were ultimately guided by the primary drivers of wind and solar power projects: optimizing benefits for human stakeholders (Jelley, 2020). These drivers include minimizing costs, improving operational efficiency, and enhancing project feasibility, which reflect anthropocentric priorities (Wei & Kewen, 2010).

Lastly, while the GHG emissions intensity is an essential metric for assessing climate change and global warming impact, when there is exclusive reliance on it, it falls short in capturing the environmental impact from the point of non-human life. This limitation calls the need for other supplementary metrics and methodologies which are able to assess the interconnected impacts on biodiversity, natural landscapes, and ecological systems, in order to align with a post-humanistic perspective (Wilson & Edwin Jeevaraj, 2023).

Challenges and Opportunities

One of the main challenges was the limited use of literature case studies, which included only four studies on wind and four studies on solar technology, respectively. This small sample size created a limitation in the generalizability of the results. Participants got informed of these limitations, which encouraged them to critical thinking and deeper analysis of the available data. Subsequently their attention was shifted to learning the LCA methodology itself, instead of focusing solely on the results.

Another challenge was striking the right balance between theoretical instruction and practical application. While the program aimed to teach the methodological framework behind LCA, translating this method into practical exercises that participants found relevant and engaging, proved challenging. Ensuring that participants could apply their learning effectively in real-world scenarios, without feeling overwhelmed by the complexity of the methodology, required effort. Continuous adjustments were needed to maintain participant engagement.

As was previously mentioned, the challenge of navigating incomplete data added another layer of complexity to the program. Some studies did not provide information on all lifecycle phases, which necessitated that the teacher and the participants make assumptions and continue the comparison with only the known data, in order to bypass this obstacle. While this practice promoted critical thinking and the development of problem-solving skills, it also introduced potential biases into the analysis. Participants had to learn to recognize the limitations and implications of these assumptions, becoming experienced at understanding how incomplete data could influence their findings.

Moreover, since the educational program was implemented across two separate dates (phase 1 and 2 on the first day and the remaining phases on the second day), there is a risk, as observed in our case, that some participants may not attend both days. This could lead to inconsistencies in the evaluation process, as the first questionnaire, which assesses the participants' initial knowledge, would reflect the responses of those present on day 1, while the second questionnaire, which evaluates the learning outcomes, would be based on the participants present on day 2.

Lastly, maintaining consistent engagement among participants posed a challenge, especially given the varied skill levels and diverse knowledge backgrounds within the group. The program required active participation in group discussions, debate section and problem-solving exercises. For participants with limited experience or knowledge in sustainability assessments or data analysis, keeping pace with more advanced peers was difficult, which could impact the overall dynamic and collaborative nature of the learning experience.

Apart from the aforementioned challenges, the educational program presented several opportunities. One of them was that participants gained practical experience with the LCA methodology, enhancing their data analysis and critical thinking skills. Working with real data, even when incomplete, required participants to make thoughtful assumptions and effectively apply their learning to real-world scenarios.

The educational program also provided the opportunity for the learners to participate in an interactive environment which included sections with discussions, debates and collaborative problem-solving exercises. This opportunity not only deepened participants' understanding of the LCA methodology but also promoted teamwork, peer learning and confidence in presenting and defending their findings.

Additionally, the use of diverse case studies provided participants with a comparative view of GHG emissions intensity across wind and solar technologies. This opportunity broadened their understanding of the specific challenges and strengths associated with each technology.

Lastly, the program promoted the opportunity to come across the environmental impacts of wind and solar energy technologies, which raised post-humanistic ecology awareness among the participants, fostering more responsible and sustainable decision-making practices in their daily working routine.

Conclusion and Recommendations

This master thesis aimed to assess the GHG emissions intensity of wind and solar energy projects through an LCA approach, and then based on the results to design, implement and analyse through post-humanistic lens, an educational program with the goal to enhance sustainability-focused decision-making in people working in the wind and solar energy sector.

The results indicate that based on GHG emissions intensity, between wind and solar energy, wind energy is the cleaner energy source, and that among the five lifecycle phases, the Manufacturing phase is the largest contributor to GHG emissions. This conclusion is consistent with prior reviews (Nugent & Sovacool, 2014; Hertwich et al., 2014; Pehl, 2017; Rabaia, 2021).

The educational program enchased the participants' ability and knowledge to apply LCA methodology and critically evaluate sustainability issues in wind and solar energy projects. With the use of interactive discussions, debates and problem-solving activities, the program fostered critical thinking, knowledge application and collaborative learning. Despite some limitations, such as incomplete data sets and varying participant skill levels, the program successfully empowered participants to make knowledge-based decisions, supporting environmental sustainability while maintaining the viability of the wind and solar power projects.

From a post-humanistic ecology perspective, the educational program raised the learners' awareness of the ecological impacts of wind and solar projects, encouraging them to recognize the intrinsic value of all living systems (Taylor, 1981). The learners were sensitised about the entanglement between humans, animals and the environment (Weldemariam, 2022). But although the program introduced and highlighted the post-humanistic ecology perspective, learners accepted it up to a point, and after that point they maintained an anthropocentric focus on human benefits for the wind and solar power projects.

Future research is recommended to expand on the findings of this study, while overcoming its limitations, by exploring a broader range of methods, target audiences and contexts. Methodologically, future studies could incorporate both quantitative and qualitative analyses, either independently or through mixed methods, to assess the practical applications and long-term effectiveness of educational programs designed to enhance sustainability decision-making.

Future research could focus on different target groups, including policymakers, manufacturers, developers, transporters and energy regulators in the wind and solar energy sector, with the aim to explore the way how these groups engage in environmental impacts and sustainability decisions. Educational programs tailored for these target groups should focus on providing sector-specific knowledge and hands-on training for assessing environmental impacts through tools like LCA.

In addition, a primary limitation of this research was the small sample of the case studies, with only four studies for wind and four studies for solar technology, respectively. While these case studies provided useful insights, a broader range of case studies from various geographical regions and technology models would enhance the generalizability of findings. By including diversified datasets, future research could explore regional and technological differences in GHG emissions intensity, contributing to improved recommendations for the wind and solar energy sector.

Moreover, the reliance on GHG emissions intensity as the main metric, while essential, captures only a fraction of the total environmental impacts of wind and solar energy projects (Baumann & Tillman, 2004). Future studies could integrate additional indicators, such as biodiversity, ecosystem health and resource depletion, to align more closely with post-humanistic ecology principles that emphasize the intrinsic value of natural systems (Taylor, 1981). Even more research could expand and widened its aim from exclusively environmental impacts to sustainability impacts, which include also the social and economic dimension except the environmental one.

Additionally, the study revealed that while the educational program successfully encouraged a post-humanistic ecology awareness, it wasn't successful in challenging the embedded anthropocentric perspective of the participants. To encourage a shift towards environmental sustainability, research could explore strategies that include post-humanistic perspectives more thoroughly into educational frameworks and decision-making processes. This would include investigating how these philosophies could influence the evaluation of wind and solar energy projects and promote sustainability approaches that recognize the intrinsic value of all life, not just human interests (Weldemariam, 2019).

Beyond the future research recommendations, at least as important are the practical recommendations for the industry professionals, the government, the policymakers and regulators and the educational institutions.

The wind and solar industry professionals should integrate the LCA tool into their decision-making processes and promote the sustainability way of thinking and acting, especially in their working routine for the wind and solar power projects. The companies which are involved in renewable energy sector

should prioritize trainings, seminars and educational programs for their employees, in order to enchase their knowledge and abilities to understand and evaluate sustainability (through LCA or other methods and tools) and adopt sustainable practices and mindset.

Furthermore, the role of governments and regulatory authorities is very important in adopting policies and regulations that prioritize the energy power projects with lower life cycle GHG emissions, encouraging the promotion of cleaner energy technologies. Furthermore, policymakers should work towards creating publicly accessible LCA databases, ensuring that decision-makers at all levels have access to transparent, reliable and standardized sustainability data.

Educational institutions should be engaged actively into developing and implementing sustainability curricula. Educational programs, like the one assessed in this study, are valuable in empowering participants to engage with sustainability assessments but also meet challenges in balancing theoretical instruction with practical application. This challenge, as well as other educational challenges which possess difficulties for a small educational team, can be addressed by educational institutions which have the resources and the impact to design curricula that incorporate more interactive learning methods and practical data analysis workshops. Innovative tools such as virtual simulations, hands-on training with LCA software and real-world case studies could provide participants with a deeper understanding of complex project dynamics. Additionally, interdisciplinary courses combining technical, ecological, and ethical perspectives can promote a more holistic approach to sustainability education. (Wals, 2012).

Finally, a stronger partnership between academia, industry, and government agencies are essential for refining and standardizing LCA practices in the wind and solar sectors. Joint initiatives, such as knowledge-sharing platforms and collaborative research projects, can enhance data transparency and promote innovation in sustainability assessment. Encouraging dialogue between different stakeholders will help align environmental goals with economic and policy frameworks, leading to more informed and sustainable energy decisions.

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Appendices

Appendix 1 – Questionnaires

First Questionnaire – Pre Education Program

	How familiar are you with the following concepts	Familiarity Level				
		Not at all	Slightly	Moderately	Significantly	Highly
1	Sustainability encompasses three dimensions (environmental, social and economic)	☐	☐	☐	☐	☐
2	Life Cycle Assessment (LCA) is a method to assess potential environmental impacts throughout a product's life cycle	☐	☐	☐	☐	☐
3	LCA involves four main phases: goal and scope definition, inventory analysis, impact assessment and interpretation	☐	☐	☐	☐	☐
4	Cradle-to-grave is the full LCA from resource extraction, to manufacturing, usage, and maintenance, all the way through to its disposal phase	☐	☐	☐	☐	☐
5	Climate change and global warming environmental impacts are linked to Greenhouse Gas Emissions (GHG)	☐	☐	☐	☐	☐
6	Global Warming Potential (GWP) describes how much impact a gas will have on atmospheric warming over a period, compared to CO_2	☐	☐	☐	☐	☐
7	The greenhouse effect of a particular gas is typically quantified by its GWP relative to CO_2, allowing it to be expressed as a CO_2-equivalent	☐	☐	☐	☐	☐
8	GHG Intensity is the ratio of the quantity of greenhouse gases emitted per unit of electricity generated ($g_{CO2\text{-}eq.}$/kWh)	☐	☐	☐	☐	☐
9	A wind or solar power plant consists of 5 different life cycle phases. Manufacturing, Transportation, Construction, Operation & Maintenance, Decommissioning	☐	☐	☐	☐	☐

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10	Education of Sustainable Development (ESD) seeks to empower individuals to create a more sustainable future	☐	☐	☐	☐	☐

	Rank the GHG emissions intensity contribution phases (1 the most to 5 the least)	**Phases**				
		Manufacturing	Transportation	Construction	O&M	Decommissioning
11	Wind Farms	☐	☐	☐	☐	☐
12	Solar Farms	☐	☐	☐	☐	☐

	Rank the electricity technologies (1 the most to 5 the least)	**Electricity Technologies**				
		Hydropower	Fossil Fuels	Nuclear	Wind	Solar
13	According to GHG emissions intensity	☐	☐	☐	☐	☐

	Please answer with Yes or No				
14	Is the environmental impact of manufacturing solar panels outweighed by the long-term benefits of their use?	YES	☐	NO	☐
15	Is the initial investment cost of modern wind turbines justified by their overall economic and environmental benefits?	YES	☐	NO	☐

Second Questionnaire – Post Education Program

Please circle the right answer (A, B, C or D)

1 What is the primary purpose of life cycle assessment (LCA)?

A To assess the environmental impacts of a product or system throughout its life cycle

B To determine the economic feasibility of a project

C To evaluate the social benefits of a renewable energy project

D To measure the efficiency of energy production

2 What is the aim of the Interpretation phase in LCA?

A To identify and quantify the inputs and outputs

B To evaluate the significance of potential environmental impacts

C To analyze results, draw conclusions, and make recommendations

D To define the system boundaries and functional unit

3 What is the use of the functional unit in LCA?

A To determine the goal and scope definition of the study

B To quantify the environmental impacts of the product

C To normalize data and facilitate comparisons between products

D To visualize the life cycle stages of the product

4 How many times higher (approximately) is the GHG emissions intensity of natural gas compared to wind technology?

A x 5

B x 10

C x 50

D x 100

	Rank the GHG emissions contribution phases (1 the most to 5 the least)	**Phases**				
		Manufacturing	Transportation	Construction	O&M	Decommissioning
5	Wind Farms	☐	☐	☐	☐	☐
6	Solar Farms	☐	☐	☐	☐	☐

	Rank the electricity technologies (1 the most to 5 the least)	**Electricity Technologies**				
		Hydropower	Fossil Fuels	Nuclear	Wind	Solar
7	According to GHG emissions intensity	☐	☐	☐	☐	☐

	How much the program enhanced your understanding to the following	**Understanding Level**				
		Not at all	Slightly	Moderately	Significantly	Highly
8	Life Cycle Assessment (LCA)	☐	☐	☐	☐	☐

9	GHG emissions on wind and solar energy	☐	☐	☐	☐	☐
10	System boundaries of the 2 technologies	☐	☐	☐	☐	☐
11	Sustainable Development	☐	☐	☐	☐	☐

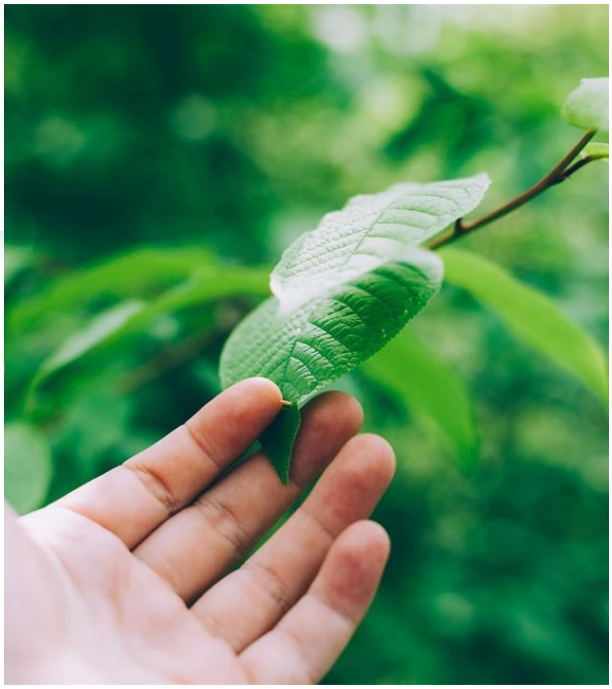
Please briefly write your answers

12	Suppose that you are responsible for minimizing the GHG emissions intensity of a 10MW solar farm. What will be your strategy to achieve it?
13	In what aspects of your daily work can the learned knowledge influence you to develop your professional work?
14	Were the concepts of the educational program explained effectively? How could they be improved?
15	Do you have any suggestions for additional topics or tools that could improve future sessions of the educational program?

Appendix 2 – Lecture Presentation

Sustainability – Three Dimensions

- What is sustainability
- Three Dimensions
- Environmental
- Economic
- Social

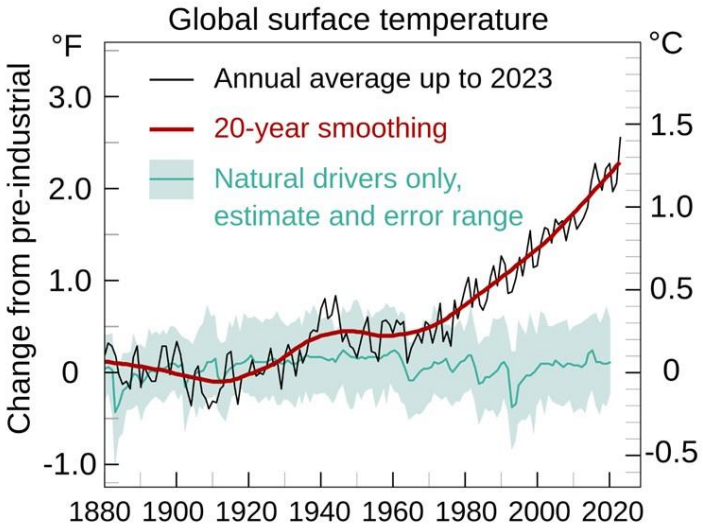


Sustainable Development Goals (2030)

Figure 1 (Wikipedia, 2015)

Climate Change – Global Warming

Figure 2 (Wikipedia, 2023)



Life Cycle Assessment (LCA)

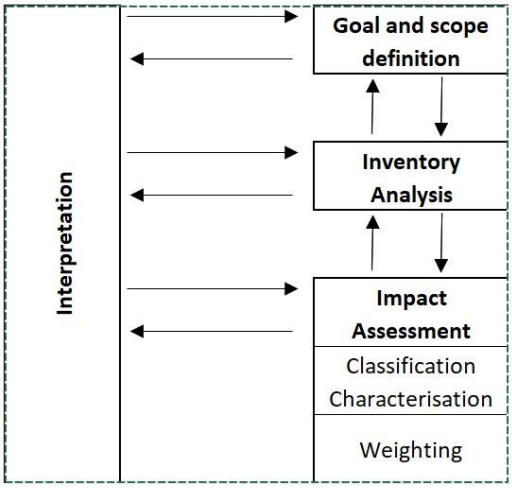
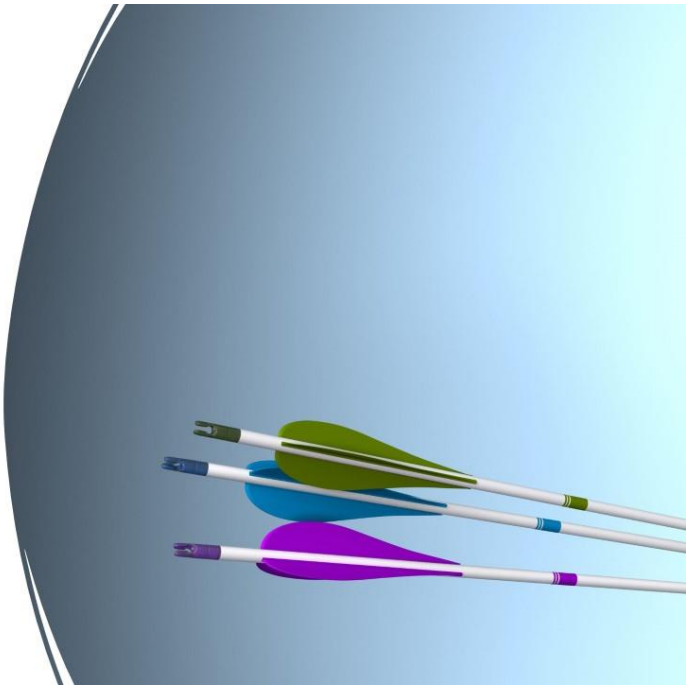


Figure 3 (Baumann & Tillman, 2004)

- What is LCA?
- Structured methodology for evaluating environmental impacts
- "cradle to grave" approach
- 4 main phases

LCA - Goal and Scope Definition

- Define context and purpose.
- Why is it done? How are the results going to be used? Who is the target audience?
- Product choice
- Define functional unit
- System boundaries



LCA – Inventory Analysis (LCI)

- Flowchart construction
- Data collection
- Calculations – resource use and pollutant emissions

LCA – Impact Assessment (LCIA)

- What is an environmental impact?
- Environmental impact categories
- Translating inventory loads in impact categories

LCA – Interpretation

- Findings of LCI or/and LCIA are combined with the defined goal and scope to reach conclusions and recommendations

ISO 14043 (2000) standard:

- 1)Identify significant issues.
- 2)Evaluate the completeness, sensitivity, and consistency of the data.
- 3)Draw conclusions and make recommendations.

Practice Task

- Design a flowchart assessing the life cycle stages of a smartphone and their environmental impact at each stage

Coffee Break

Greenhouse Gas Emissions (GHG) Intensity

- Different GHG : SO2, N2O, CH4 and Fluorinated gases
- Global Warming Potential (GWP) -> CO2 equivalent
- GHG Intensity = ratio of the quantity of greenhouse gases emitted per unit of electricity generated (gCO2-eq./kWh)

Energy sources – GHG emissions intensity

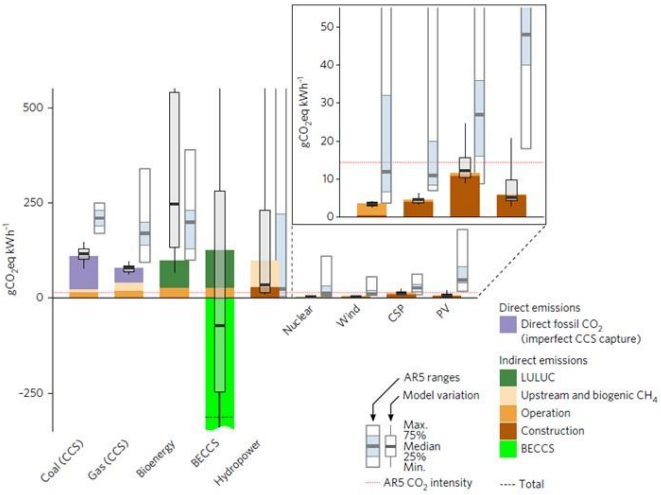


Figure 4 (Pehl et al., 2017)

Wind Farms – LCA

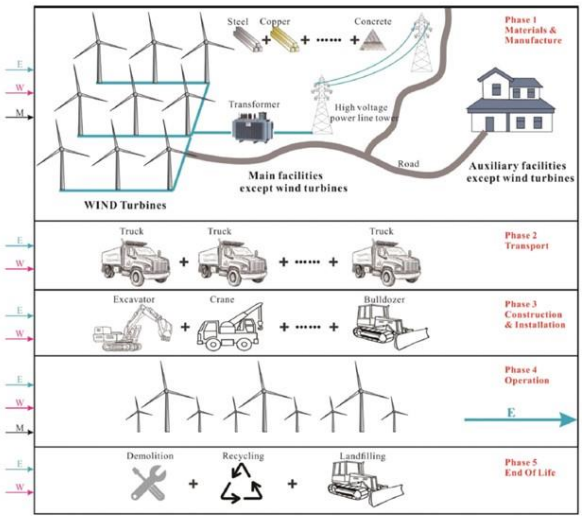


Figure 5 (Li et al., 2021)

Solar Farms – LCA

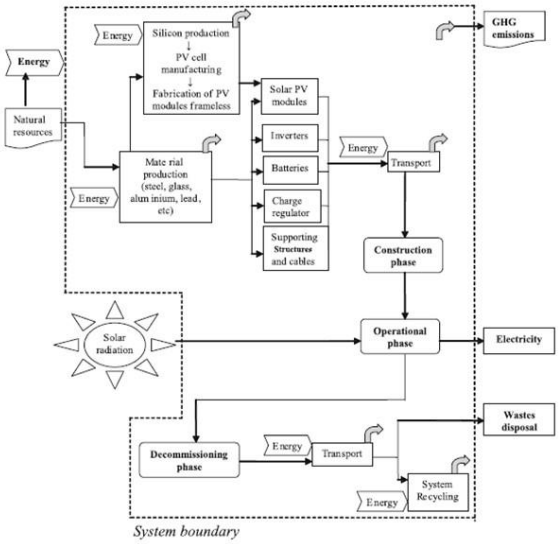


Figure 6 (García-Valverde et al., 2009)

Wind and Solar – GHG emissions intensity

Technology	Wind				Solar			
Article	Ardente et al. (2008)	Li et al. (2021)	Oebels & Pacca (2013)	Rajaei & Tinjum (2013)	Constantino et al. (2018)	Corona et al. (2016)	García-Valverde et al. (2009)	Rahman et al. (2019)
Installed Capacity (W)	7,260.0	40,000.0	21,000.0	162,000.0	1,100.0	1,008.0	4.2	3.6
Country	Italy	China	Brazil	USA	Brazil	Morocco	Spain	Bangladesh
Functional Unit	1kWh	1kWh	1kWh	1kWh	1kWh	1kWh	1kWh	1kWh
Lifespan (years)	20	20	20	20	25	20	20	20
GHG emissions intensity (gCO2-eq./kWh)	8.80 - 18.50	16.40 - 28.20	7.10	16.90	81.70	53.30	131.00	173.42
Manufacturing Phase	56% of total energy requirement	101.6% to 106.5% of total CO2-eq. emissions	Majority of CO2-eq./kWh	Major contributor CO2-eq./kWh	84% of total CO2-eq. emissions	82 gCO2-eq./kWh	Included in Construction	Major contributor of total GHG emissions intensity
Transportation Phase	6.4% of total energy requirement	1.7% to 2.8% of total CO2-eq. emissions	Second contributor of CO2-eq./kWh	Third contributor of CO2-eq./kWh	Non specified	Non specified	Excluded	1.46 gCO2-eq./kWh Third contributor
Construction Phase	29.9% of total energy requirement	0% of total CO2-eq. emissions	Less than 1% contribution of CO2-eq./kWh together	Second contributor of CO2-eq./kWh	84% of total CO2-eq. emissions	Non specified	1.7% of embodied CO2	Second contributor of total GHG emissions intensity
Operation & Maintenance Phase	6% of total energy requirement	7.8% to 13.3% of total CO2-eq. emissions		Fourth contributor of CO2-eq./kWh	Non specified	11gCO2-eq./kWh	Small proportion of embodied CO2	No GHG emissions intensity
Decommisioning Phase	1.7% of total energy requirement	-22.7% to -12.3% of total CO2-eq. emissions	Excluded	Excluded	Non specified	Negative gCO2-eq./kWh	3.67% of embodied CO2	Excluded

Wind and Solar – GHG emissions intensity

Technology	Wind				Solar			
Article	Ardente et al. (2008)	Li et al. (2021)	Oebels & Pacca (2013)	Rajaei & Tinjum (2013)	Constantino et al. (2018)	Corona et al. (2016)	García-Valverde et al. (2009)	Rahman et al. (2019)
Installed Capacity (kW)	7,260.0	40,000.0	21,000.0	162,000.0	1,100.0	1,008.0	4.2	3.6
Country	Italy	China	Brazil	USA	Brazil	Morocco	Spain	Bangladesh
GHG emissions intensity (gCO_2-eq./kWh)	8.80 - 18.50	16.40 - 28.20	7.10	16.90	81.70	53.30	131.00	173.42
Phases	1.Man 2.Con 3.Tran 4.O&M 5.Dec	1.Man 2.O&M 3.Tran 4.Con 5.Dec	1.Man 2.Tran 3+4.Con +O&M	1.Man 2.Con 3.Tran 4.O&M	1.Man 2.Con	1.Man 2.O&M 3.Dec	1.Man 2.Dec 3.Con	1.Man 2.Con 3.Tran 4.O&M

Lunch Break

Discussion

- Questions
- Thoughts
- Opinions
- How do you plan to utilize this knowledge

Coffee Break

Debate

- Theme: “Sustainability Dimensions: Environmental Priority vs. Integrated Approach”
- Pro Team : Environmental Priority
- Con Team : Integrated Approach – considering all three dimensions

Summary - Conclusion

- A Brave Volunteer to summarize and conclude

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Thank You !