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EXTERNAL COST INCURRED AND AVOIDED IN A DIRECT AIR CAPTURE HYDROGEN TECHNOLOGY

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DECLARATION OF DISSERTATION FOR THE MASTER THESIS

I declare that the work in this dissertation titled "External cost Incurred and avoided in a Direct Air Capture via Hydrogen Technology" has been researched and written by me through the guidance of my supervisor of my internship university RWTH Aachen in Germany and the supervisor of the given University certificate, Cheikh Anta Diop, Senegal. The information derived from this master thesis has been duly acknowledged in the text with the list of references given. I am entitled to a full right and thereby assume a full responsibility deriving from this dissertation.

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SATEMENT OF AUTHORSHIP

I Anthony N. Kanteh herewith assure that I wrote this master thesis independently in consultation with my supervisors for guidance, and that the thesis has fully been submitted for approval. I have included every part of this thesis as require for sourcing. A quillbot was used during this research as an artificial intelligent in chapter Two to enhanced an indirect quotation and for proper grammer checkup throughout this master thesis research. For comparing my thesis with current data, I approved that it can be stored in any relevant database for future comparison.

Signed: ______________________

Anthony N. Kanteh
Author

Date: September 13, 2023

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ABSTRACT

External cost is any consequence of an industrial or commercial activity which effects other party without the party being compensated for such activity, be it the producer or consumer and it is therefore not reflected in the market prices. These activities include physical damage to the natural, environment, impact on recreation, societal and health. External cost effects are not included in the market prices of the activities since the polluter does not bear the costs associated with them.

Here we find that quantifying the damage of external cost is the significant factor of this research work. In this paper, we identified all significant external cost derived from Direct Air Capture via hydrogen technology through the use of Impact Pathway Analysis (IPA) methodology being established by the EU community external cost of electricity generation (externE). The source of all the external cost incurring cost incurring from the production of methanol (MeOH) and hydrogen are the electrolyser, methanol reactor, photovoltaic system (PV) and the Direct Air Capture Technology itself.

Form the chosen methodology, we applied the dose or exposure response function (atmospheric model) to provide the impacts effects of external cost of air pollution. Moreover, we assumed the production of 50,000kg of methanol and hydrogen per year from this paper. We applied external cost rates to quantify the damages incurred. After applying these cost rates, the external cost incurred per 1kg of production from each of the component in this research can be identified as PV (€/kg 0.1457), DAC (€/kg 0.0048), Electrolyser (€/kg 0.1305) and Methanol reactor (€/kg 51.2859). Finally, to minimize this external cost, there is a need to recognize and prioritize all major health impacts and as well as all industries involving in such production must have a long-term consideration and must not avoid the careful management of external cost.

Key words: Methanol, DAC, Electrolyser, External cost rates, Ivory Coast

RÉSUMÉ

Le coût externe est la conséquence d'une activité industrielle ou commerciale qui affecte une autre partie sans qu'elle soit indemnisée, qu'il s'agisse du producteur ou du consommateur, et il n'est donc pas reflété dans les prix du marché. Ces activités comprennent les dommages physiques causés aux ressources naturelles, à l'environnement, à l'impact sur les loisirs, à la société et à la santé. Les effets sur les coûts externes ne sont pas inclus dans les prix du marché des activités puisque le pollueur ne supporte pas les coûts qui y sont associés.

Ici, nous constatons que la quantification des dommages causés par les coûts externes est le facteur significatif de ce travail de recherche. Dans cet article, nous avons identifié tous les coûts externes importants dérivés de la capture directe de l'air via la technologie de l'hydrogène grâce à l'utilisation de la méthode d'analyse d'impact établie par la communauté de l'UE sur le coût externe de la production d'électricité (externE). La source de tous les coûts externes encourus par la production de méthanol (MeOH) et d'hydrogène sont l'électrolyseur, le réacteur au méthanol, le système photovoltaïque (PV) et la technologie de capture directe de l'air elle-même.

Selon la méthodologie choisie, nous avons appliqué la fonction dose-réponse ou exposition-réponse (modèle atmosphérique) pour fournir les effets des impacts du coût externe de la pollution atmosphérique. De plus, nous avons supposé la production de 50 000 kg de méthanol et d'hydrogène par an dans cet article. Nous avons appliqué des taux de coûts externes pour quantifier les dommages subis. Après application de ces taux, le coût externe encouru par kilogramme de production est évalué à 0,1457 €/kg pour le photovoltaïque, 0.0048 €/kg pour le DAC, 0.1305 €/kg pour l'Electrolyseur et 51,2859 €/kg pour le réacteur au méthanol. Enfin, pour minimiser ce coût externe, il est nécessaire de reconnaître et de prioriser tous les impacts majeurs sur la santé ainsi que sur les industries impliquées dans une telle production qui doivent avoir une considération à long terme et ne doivent pas éviter la gestion prudente des coûts externe.

Mots clés : Méthanol, DAC, Electrolyseur, coût externe, Cote d'Ivoire

CHAPTER 1: INTRODUCTION

1.1 Background and significance of the research

Direct air capture (DAC) via hydrogen technology is a promising approach to reduce carbon dioxide emissions from the atmosphere by using hydrogen as an energy carrier. (Haertel et al., 2021) This new technology can have external costs incurred (CO2 emissions during hydrogen production, impact on energy use and the effects on biodiversity, etc.) (IEA, 2022) and avoided (reducing CO2 emissions, reducing dependence on fossil fuels, improving air quality, creating jobs and economic development, etc.) which are important to consider. In this context, it is important to note that the external costs and benefits of direct air capture by hydrogen technology largely depend on the material from which it is used, including the energy source used to produce hydrogen. Policy makers may utilize external cost of air pollution model to connect emissions and concentrations, making them effective tools. Additionally, the model may be used to draw conclusions about concentrations where there is no data due to the fact that observations are frequently in a scattered location. Model may easily be applied to predict exposure and health impacts when combined with population data. The calculation of external costs associated with polluters' emissions is crucial for decision-making in the right framework. (Molina, 2010)

From the Paris agreement, governments have committed to a target of reducing the climate change which is due to the increase of global warming in this contemporary society. The temperature continues to rise because of consequence of anthropogenic activities leading to satisfy' life. In order to meet this demand, the threshold set by the global community is two degrees Celsius as a tolerable level of warming, which by economists' standards is considered as an externality on the ecosystems (Shukla et al., 2022)

Obviously, staying below 2 degrees means transitioning from the source of fossil fuel technologies to a clean energy using the Direct Air capture along with the electrolysis technology as the alternative solution with use Impact Pathway Analysis as the methodology selected for this paper.

The Impact Pathway Analysis (IPA) is a methodological tool assessment bottom-up approach in which environmental benefits and costs are estimated by following the pathway from source of emissions via quality changes of air, soil to physical impacts before expressed in monetary benefits and cost. This approach was established by two famous professors, Prof. Dr. Rainer Friedrich and Prof. Dr. Peter Bickel (Friedrich & Bickel, 2001). Like in our case of evaluating the external cost incurred from the processing of Hydrogen and Methanol via the DAC technology. The IPA method has been used on many projects to evaluate external cost incurred from electricity generation from different sources of technology especially from the ExternE Externalities of Energy vol.6 Wind and hydro project conducted by (EU, 1995)

Furthermore, there is no recognized framework for determining which emissions should be taken into account when calculating external costs. The subjects of many studies are only around Global warming and economic externalities today (Rezai et al., 2012). However, pollution of air is a significant factor influencing human health, social and environment. Particles like (PM2.5, SO2, CO, NOX, C02, Noise and N_2O) which are typically the only air pollutants that are essentially taken into account in this research based upon external cost rates. These difficulties haven't been thoroughly studied before (P. L. Baumgärtner, 2010)

Many scientific research works have shown Hydrogen and Methanol production via electrolysis from the carbon capture for large utilization and evaluated through the use of life cycle assessment (Rosental et al., 2020) although showing limit external cost evaluation. Additionally, the external rate incurring in the DAC is significant factor in multiple ways of understating how external cost of emission and concentration are to be accounted for.

1.2. Research Objectives

The external cost of producing Hydrogen and Methanol has not been significantly addressed and quantified the damages incurred through the Direct Air Capture. The main objective of his work is to identify externalities through direct air capture. It relies on the production pathways for hydrogen and methanol to allow a realistic assumption for the external cost of production using the impact trajectory analysis (IPA) method which is a bottom-up methodological assessment approach in which environmental benefits and costs are estimated by tracking the source of emissions through changes in air quality, the physical impacts on the ground before expressed in monetary benefits and costs. In this paper, the master thesis attempt to address the research questions:

1) What is the current state of the DAC technology in relation to the production process of Hydrogen and Methanol? In this review, the master thesis will give the overview of the DAC process of air capture and energy use with respect to the technical readiness level.

2) What are the externalities incurred in the production of Hydrogen and Methanol with the DAC technology? In this context, the thesis will focus on providing the basic externalities incurring in the production process and give an assume external cost of production.

3) What is the impact of externalities incurred in the production of Hydrogen and Methanol? Moreover, the thesis will determine the general impacts of inputs and outputs with an assume quantification during the production with help of IPA.

4) What are the measures use to minimize the damage/internalize externalities?

These research questions are so significant to scientists, investors and world leaders who are proposing increase in investment in the production of Hydrogen and Methanol for the fight against climate change for business model and its flexibility.

The term "flexibility" describes the effectiveness of an energy system under continuous operation, with significant changes in energy production and consumption but still preserving the system's spatial and temporal stability (Vigna et al., 2018) The Green Hydrogen has the general potential to accelerate the transition towards sustainable energy business models with zero emissions (Thibualt L'Huby, 2020)

1.3 Scope of research Study

External cost is any consequence of an industrial or commercial activity which effects other party without the party being compensated for such activity, be it the producer or consumer and it is therefore not reflected in the market prices(F. Baumgärtner & Letmathe, 2020a). These activities include physical damage to the natural, environment, impact on recreation, as well as amenity. External cost effects are not included in the market prices of the activities since the polluter does not bear the costs associated with them. $N0_X$ for example causes damage to human health that imposes external cost. This impact on health makes people suffer damage to health which is not taking into account by the polluter During the past few years, a number of techniques for calculating external costs have been created, including the willingness-to-pay approach, avoidance costs, and damage costs studied by (F. Baumgärtner & Letmathe, 2020a) but for this paper it focuses on identifying the external cost incurred during the production of Green Hydrogen and Methanol from the DAC and thereby providing measures to minimize these damages as alternative valuation leading to the decrease of cost drivers of external cost.

The external cost assessment in this paper is based on the IPA method as early stated. This method is use to identify, estimate and calculate the externalities incurred through the direct air capture during the production of Hydrogen and Methanol to be use as fuels in arid zones and other parts of the world. In energy production, externality can be expressed through an adder. An adder is the unit of externality cost. Where in f(X+Y) and Xm€ per KWh or Kwp is the production cost and Y is the externality adder. (Pearce, 2001).

The research work takes into account the production pathways for H2 and MeOH in order to enable a realistic assumption for external cost of production and to understand how advancements in technology may alter environmental performance indicators through its current state of production.

The state of the DAC however is still in the early stage of development and have not yet reached a high significant commercial point (Ozkan et al., 2022) especially for the hydrogen and methanol production and the assume external cost rates are still under investigation by different countries. The valuation of external cost has high advantage; however, the externalities can be combined into a single cost category for determination (A. R. I. Rabl & Spadaro, 2005). The research on external cost considered here will account on relevant health impacts, economic and social impacts that effect the production. We considered that PV, solid electrolyser and methanol reactor account for the high system damage during the production of Hydrogen and Methanol as fuels. We assumed 50,000kg MeOH and hydrogen production per year.

CHAPTER 2: LITERATURE REVIEW

2.1. Overview of Direct Air Capture the Technology

For our literature review study case, we follow the content analysis-based review approach (Seuring & Gold, 2012) using the supply chain management system. In all, external cost measurement that offers a comprehensive understanding on valuation of monetary units and to compare different policies regarding external cost from the DAC Tech. There are several research and development on pilot projects that are focused on improving the efficiency and scalability of the DAC technology through the capturing and splitting of water and carbon molecules efficiently and sustainably over time, as well as developing the cost-effective and durable electrodes that can withstand the operating conditions of the DAC process. A total of sixty-four (64) articles and journals were very significant as references for calculating the external cost and impacts analysis were considered and included in the research. The predication of health impact uses the Uniform World Model (UWM) as an approach to determined health impact of air pollution (Spadaro, 2011).

Notwithstanding, the externalities considered by the research's author include the following but not limited to Particulates matter (2.5), Nitrogen oxides, Nitrates oxide, Sulphur oxides, noise and carbon emission equivalent. Furthermore, the damage cost per year varies with respect to air pollutants based upon the result considered in the research and its monetary valuation. In our research, we considered and set up our system into four components from the implementation of producing hydrogen and methanol through the direct air capture using solar as energy source to power the system.

The four major divided components include the direct air capture technology system, solar PV system, methanol reactor system and the electrolysis processing system. The combination of these systems helps in improving the problem of climate change and thereby providing energy access in arid zone countries.

Direct air capture is a technology that removes carbon dioxide from the atmosphere to mitigate climate change and at the same time provide sustainable energy especially in arid zones (Mcqueen, 2021). Presently there are about 19 DAC power plants operating worldwide and their current status are still in an infant stage of development activities (Ozkan et al., 2022)

2.1.1 Current state of DAC

The current DAC in operation capture close to 1 $MtCO_2$/ year (Energy Agency, 2022). Today in review, many DACs are improving the capturing capacity and increasing in every part of the world to enable each extract C02 from the atmosphere. The DACs of today have major pillars that focus on the following: The capturing technology, electrical and energy demand, cost, the environmental impact and political factor from set of governments. To have a unique DAC build-up, every sector needs to be at an equilibrium with each other. Figure 1. Shows five keys current status of the direct air capture technology by pillars.

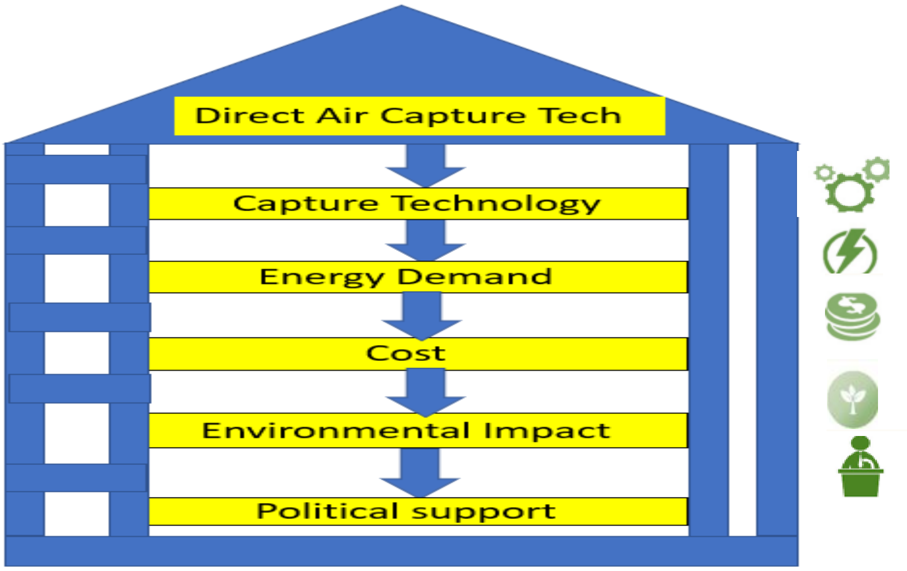

Figure 1: Five pillars of DAC Technology.

Each sector has vital role to the current existent of the technology however, as an author of this paper, I would like to encourage policymakers to support this technology to easily transition in meeting the Paris Agreement and the dependent on fossil fuels especially with the recent Russian – Ukrainian war.

The major role of any policymaker in energy transition is to support, coordinate and implements government's strategies and promote smooth cooperation for bilateral trading. Moreover, all political actors must comprehensively beware of energy transition and the interplay with institutions in the world. This transition to a new level of technology in order to mitigate climate change will subsequently involve a greater decision taking by the political actors of every nation.

These decisions will however play a vital role in climate transition and improve the livelihood of communities. To have an environment to be sustainable by latest 2050 means that fossil carbon must totally be transformed to renewable as one of the ways to accelerates and mitigate external cost and internalize it in debt. Expanding and changing industrial capacity internationally will need intensive international cooperation back-up with social policies that will be enabling in all nations, and the tackling of international justice and equity (UN, 2021) Additionally, bigger expenditures are required to achieve a fair transition, including in education and training for workers, research and innovation, and financial incentives to create supply chains using eco-friendly methods that safeguard cultures and ecosystems.

2.1.2. Principles DAC

The fundamental principles of DAC and its goal is to capture CO2 from the air. This is achieved through some chemical reactions that are connected with CO2 molecules removing from the air. Adsorption is the primary tool use by the system to process or capture CO2 along with the air contactor. Increase in the contact area helps maximize the efficiency of CO2 capture while desorption is the release of CO2 capture by the DAC.

The principle guides the design and operation of direct air capture systems, offering a comprising approach to address the challenges posed by rising externalities from CO2 and providing energy efficiency (Veronica Cortes & Caryn Laska, 2020). Obtaining fuels like (hydrogen and methanol) from CO2 is something that is arguable today however it is a more promising alternative for the entire world and for decarbonisation. Larger facilities have potential to produce 50000kgMeOH H2 and above using 70000kgCO2 capture our case study.

2.1.3. Components and Research Modelling

our research, we divided the entire system into four basic parts or model to enable capture humidity to produce Hydrogen and Methanol. During this process, we will identify all external cost incurring from each system and possible measure to take. The four basic components and schematic diagram is shown below.

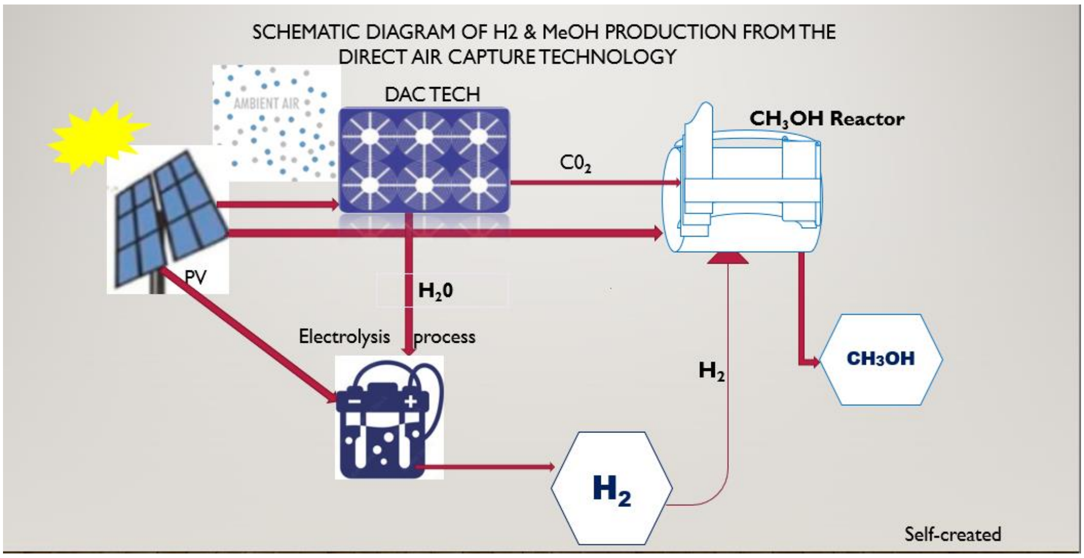

Figure 2: Schematic diagram of DAC-H2 & MeOH Tech

1.1.3.1. PV component and its basic information

The solar cell is an electronic system setup to converts light into DC electricity using the PV effect. This transformation process needs materials that can absorbed solar light and attract electron to a maximum level to allow the flow of the DC current. The flow material for absorption is known as silicon. A top and bottom metallic grid gathers dispersed charger carriers and connects the cell to the load that makes the up solar cells. To reduce light reflection from the cell, a small layer of anti-reflective coating is applied to the top surface of the cell which allow a glass layer above the cells to serves as the shield from the surroundings (Sharmin, 2014). In our research adopted the monocrystalline solar panels because of its efficiency. The Table 1. shows a summarized difference for adopting the monocrystalline panel.

Table 1: Summary of PV

Factor	Monocrystalline	Polycrystalline
Silicon material	One pure silicon crystal	Many silicon materials use
Cost	More expensive	Less expensive
Appearance	Panels have black hue	Panels have blue hue
Efficiency	More efficient	Less efficient
Lifespan	25-40 years	20-35 years
Temperature coefficient	Lower temperature coefficient, making them more efficient in heat	High temperature coefficient, making them less efficient

Source: Google scholar (https://www.ecowatch.com/solar/monocrystalline-vs-polycrystalline)

The monocrystalline solar panels are characterized by their black cell with silicon rounded edges that make their conversion to have more efficiency then the polycrystalline. The temperature coefficient indicates how much solar panels are affected in reality although every panel goes through the same testing producers and standard.

If the testing and is noted that a panel has high temperature coefficient meant that the panel losses more productivity when they are heated-up for example (polycrystalline seeing from table 1). From the basic information provided on the system and from the assumption table, the system setup is assumed to generate electricity of 223.8512434Kw per year to support the energy requirement by the other system. The justification of the PV generation time is that, it will only work for six hours per day based upon the average sunshine radiation given from the location.

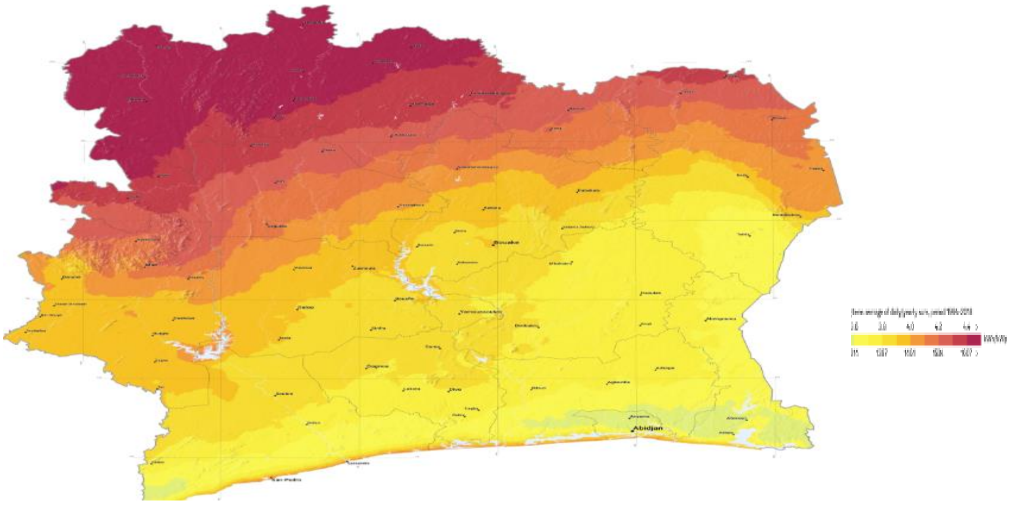

Figure 3: Sun radiation in Abidjan

Table 2: Abidjan sunshine hours

Abidjan - Sunshine hours		
Month	**Average**	**Total**
January	6	185
February	7.5	210
March	7.5	225
April	7	210
May	6	190
June	4	115
July	3.5	115
August	4	120
September	4.5	140
October	6.5	200
November	7.5	225
December	6.5	210
Year	5.9	2150

The hot season in Abidjan lasts for 5.9 months from November 22 to May 13, with an average daily high temperature above 87°F. The hottest month of potential generation of the year in Abidjan is April with an average high of 88°F an average low of 78°F.The cool season is July 3 to September 19, with an average daily high temperature below 82°F and while the coldest month of the year in Abidjan is August with an average low of 73Fand high of 81°F.

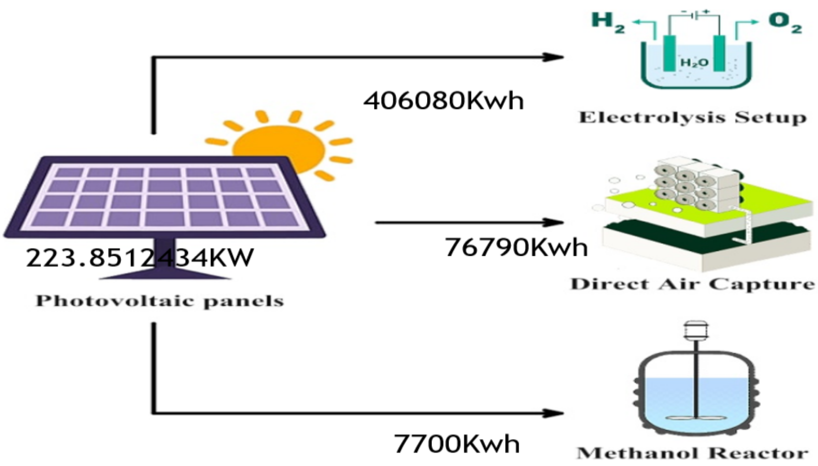

Figure 4: Energy supply model

2.1.3.2. SDAC Technology component

This component is designed in a special way to help remove C02 from the atmosphere to meet the Paris Agreement. Our research adopted the solid DAC because, the Co2 molecules interact with sorbent materials to release, stored or use to under a considerable ambient temperature condition. Solid DAC fans pull air into contactor and the filters the CO2 blended. After filtration process, the CO2 being saturated then allow the system to be turn off to release the captured CO2 from the filter The released CO2 is then removed from the unit to start another regeneration process. This process is however depended on the kind of filter installed on the system (Veronica Cortes & Caryn Laska, 2020). The below is the configuration of the solid DAC system

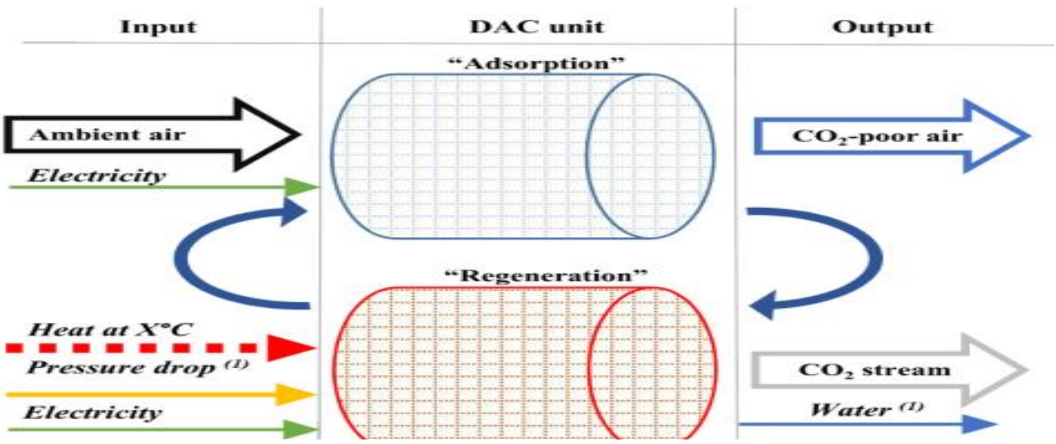

Figure 5: Solid DAC-Technology

In short, all the processes really involve the absorption and desorption through pressure of 80-100 degree Celsius (Energy Agency, 2022) as compare to the liquid DAC that captures the C02 and react chemically to form a compound. However, both of these technologies are still under Scientific investigation(McQueen et al., 2021) from our assumption, the energy requires to function the DAC is 76790Kwh

2.1.3.3. Electrolyser component:

The third com ponent is the electrolysis process. This process receives the separated water from the DAC and react with the oxygen to produce Hydrogen. For the case study, we adopted the proton exchange membrane (PEM) which has been in existing for over sixty years and was developed by the General Electric. The PEM has a several general benefits in including a broad working temperature range of (20-80°C), low gas permeability and a high current density etc. The efficiency of the PEM water electrolyser is between 62% - 82%(Wang et al., 2022)

2.1.3.4. Methanol reactor component:

Lastly is the methanol reactor component. In this component, the excess hydrogen produce from the electrolysis process is send to the methanol reactor and with the C02 that is also send from the DAC interact through chemical means to produce Methanol as the final product from the system. It has an efficiency range of 50% - 100%. The chemical conversion of $CO2$ into methanol by $CO2$ hydrogenation is a significant representative among of $CO2$ transformations that presents the difficult chances for sustainable development.

These are chemical produce from methanol as a raw material. Formaldehyde, methyl tert-butyl ether (MTBE), acetic acid (Ei-zeftawy & Ali, 1995). These chemicals are the fundamental chemical building blocks for many everyday products. Additionally, methanol may be used as a fuel for vehicles, a hydrogen carrier for fuel cells, to treat wastewater, and to generate energy. Thus, it serves as a superb fuel and a crucial component in the beginning of significant industrial processes. Methanol has also been recommended as a substitute for chemical energy carriers in recent years. Typically, methanol may be used in industrial applications (Leonzio, 2018) Figure 5. depicts the components and the following processes of identifying the external cost incurring in the system DAC via Hydrogen and methanol production.

2.1.4. State of the art

Direct air capture has been considered as one of the technologies for removing C02 from the atmosphere to meet climate policy standard. The technology focuses on the implementation of Hydrogen and Methanol production via PV energy source. Despite of these changes in invention, the technology faces series of external cost challenges during the processing of hydrogen and methanol like the noise, N2O, N0X and carbon footprints from the operation (Block, 2022). These pollutants being considered as a major external cost leading to health impact that causes damage to humans and environments. The humidity capture is being decomposed into C02 for further processing into another fuel.

Moreover, the external cost of the state of art has been significant but remains an ongoing area of research. In this research represents the state of the art in understanding and incorporating external cost include Integrated assessment models (Rogelj et al., 2018). Here we widely considered the quantification and evaluation of external cost of various economic activities. It is important to note that the research in the field of external cost is dynamic and evolving. Ongoing studies continue to refine methodologies, update data and incorporate new factors into the assessment of external costs. Most of the documents reviewed on the direct air capture technology only considered the Life Cycle Assessment (LCA) taking the context of environmental and social impacts without considering the external cost rates that would account for monetary values. In some research, external cost was considered based upon the accident or effect of air pollution (Gerlach, 2012)

2.1.5. External cost rates

External cost rates refer to the monetary values assigned to the external costs associated with a particular activity or industry. These external cost rates are estimates and are used to quantify the social, health and environmental impacts that are not reflected in market prices. It is important to note that external cost rates can vary depending on various factors such as geographical location, specific industry practices, and the methodologies used for calculation. To calculate the monetary evaluation of cost damage incurred from the production of Hydrogen and Methanol via direct air capture from the research, we make significant use of the external cost rate calculated for different EU countries that involved the monetization impact assessment of an environment per given units of pollutants.

For our research, we make use of these external cost rates that has been research by (F. Baumgärtner & Letmathe, 2020b). In meeting the target of this master thesis, we follow the path of the New sustainable Energy Developments in the world as a way forward to analyzing the external cost strategy approach.

This strategy was to account for crop losses, biodiversity loss, and human health in terms of mortality and morbidity. As it is true that crop losses are quantifiable and the loss of biodiversity may be halted with significant effort, human life cannot be replaced so we therefore based on the willingness-to-pay or willingness-to-accept methods are used to calculate the monetary value of external cost using the given external rates and damage in €/year. In this paper we present to you to follow up with (Jasinski, 2015)

The harm that greenhouse gases produce is widely acknowledged. However, there is debate regarding how to value the external costs of greenhouse gases and the way how to mitigate. In this research we assumed the external cost rates used have less than 100m heights. The final determination of external cost rates involves complex analysis and often requires the expertise of economists, environmental scientists and policymakers.

2.1.5.1. Determinations of external cost rates estimate

There are different ways use to determine external cost rates. The below are the approaches used in this research.

2.1.5.1.1 Cost approach

The approach attempts to quantify the monetary value of the damages caused by a specific activity or industry. It involves assessing a monetary value to these damages. E.g; the cost of healthcare expenses incurred due to air pollution. (Westerdahl et al., 2011).

2.1.5.1.2. Marginal abatement cost

It estimates the cost of reducing or avoiding one unit of pollution. It provides a measure of the economic value associated with the external costs that could be mitigated by implementing specific pollution control measures or adopting cleaner technologies. It’s worth nothing that external cost rates can be subjective to the ongoing debate.

Different studies and organization may provide different estimates based on varying methodologies and assumption. Furthermore, external cost rates can change over time as new research emerges technologies evolve, and societal values and priorities shift. Finally, external cost provides a means to quantify and account for the hidden costs associated with economic activities, allowing for a more comprehensive evaluation of the true social environmental, and economic impacts. (Dechezleprêtre et al., 2020)

Table 3: External cost rates

Pollutants	**Units of external cost**	**External cost rates**	**Source**
C02	€2016/t	102.70	(Baumgärtner & Letmathe, 2020b)
N20	€2016/t	27215.95	(Baumgärtner & Letmathe, 2020b)
SO2	€2016/t	17,732	(Baumgärtner & Letmathe, 2020b)
C0	€2016/t	733.02	(Baumgärtner & Letmathe, 2020b)
NOISE	€2016/kmBEV	0.00517	(Baumgärtner & Letmathe, 2020b)
PM2.5	€2016/t	69,000	(Baumgärtner & Letmathe, 2020b)
NOX	€2016/t	21,203	(Baumgärtner & Letmathe, 2020b)
CH4	€2016/t	2875	(Baumgärtner & Letmathe, 2020b)
NMVOC	€2016/t	1066	(Baumgärtner & Letmathe, 2020b)

CHAPTER 3: METHODOLOGY AND MATERIALS

3.1. Choice of external cost methodology

Human actions harm people, ecosystems, and materials, as well as pose threats to them. For instance, when generating energy, a power plant may produce pollutants that travel through the atmosphere and pose a risk to human health when ingested. Ecosystems may be disturbed following deposition. The manager of the power plant has little motivation to consider this damage while making choices. He must adhere to the emission limits set by environmental regulations, but he is not required to prevent additional minor risks and damages. Thus, the harms that result are external consequences, meaning that the person or entity creating the impacts does not take them into consideration.

It is advantageous to translate the external cost impacts into expenses in order to examine and compare them with each other. Similar to this, external cost estimates are helpful for conducting technology assessments in order to identify a technology's key weaknesses and strengths as well as to evaluate the overall performance and applicability of a technology; for instance, this would help to clarify whether and where the technology would need further improvement as well as whether funding additional research or subsidizing it would be appropriate. For future, the average marginal external costs for typical technologies at diverse places would be required as not always specific technologies (Bickel, 2005).

3.2. Data collection

The approach used in this research to evaluate external cost is built upon the NEEDS using the IPA as the methodology(Neumann, 1990). This study uses a qualitative and descriptive desktop approach for the data collection for the master thesis study designed. The research data collection was carried out using the secondary data informations without going to the site. This mean that, we make use of assume public data from researching from the Internet and making use of my institute library, the university of RWTHAachen Germany 2023. For further information and facts from literature reviews, we make use of journals, books, websites, and articles from International Renewable Energy Agency (IRENA) and International Energy Agency (IEA) etc. The data collection from these sources were credible which help build data integrity and a robust for estimating external cost damage per pollutant and monetize that outcome that makes it reliant on a good foundation. Our major assumptions in this chapter are summarized and calculated using the straightforward approach adopted by ExternE in 2008 by the EU applying the IPA from the uniform world model (UWM) to determine the monetization derived from the impact of external cost of pollutants. The atmospheric modelling for damage of each component was considered in our qualitative discussion established by the World Health Organization(IRENA, 2012). We assumed the PV generation to be 6hrs per day without any battery storage. Table 2. Indicates the data assumptions and calculation.

3.2.1. Key assumptions of data

Table four provides basic information such as the assumptions, calculations and sources for this research. The table gives the capacities of each technology considered in this research. Solar energy can be converted with the use of photovoltaics technology system when coupled with Direct Air Capture system (Hinkley et al., 2016).

In this research assumptions, we assumed the production of 50,000kg of methanol and hydrogen to be use in arid zones by for electrification and the consumption by vehicles as well as to be use in industries for production. Firstly, we calculated the capacity of the system with its assumption (50,000kg) to obtain the require energy. We finally make use of the emissions of each pollutant from each system by using straightforward calculations to determine the damages incurred from each system. in kg per year. From the damage provided based upon the assumptions, we multiply the damage incurred by the external cost rates to account for the monetary value for each component.

Table 4: Research assumptions

Data assumptions and calculation	Require energy	Source
Data assumptions and calculations		
1KgMeOH = 9kgH_20		(Schemme et al., 2020)
1kgMeOH = 0.192kgH_2		(Schemme et al., 2020)
1KgMeOH = 1.4kgC02		(Schemme et al., 2020)
Capacity of technologies		
DAC = 1.097Kwh/kgCO2		(Jiang et al., 2023)
SOEC = 42.3KwhH2		(Gerloff, 2021)
Methanol reactor = 0.154KwhMeOH		(Schemme et al., 2020)
WE ASSUMED 50,000KG OF HYDROGEN AND METHANOL PRODUCTION PER YEAR		
Calculations:		
50000kg MeOH * 1.4KgC02 = 70000KgC02/yr (DAC capture capacity)		
50000KgMeOH*0.192KgH_2 = 96000KgH2/yr (H_2 needed to produce MeOH)		

From these data given, we calculate the require energy needed by the technologies (DAC, SOEC and MeOH Reactor) and after, we sum to give us the total energy generation in KW for the PV System		
DAC = 1.09kwh/kg*70000kgC02=	67790Kwh/yr	
SOEC = 42.3kwh/kg*9600kgH_2 =	406080kwh/yr	
MeOH reactor = 0.154kwh/kg*50000kgMeOH =	7700kwh/yr	

3.2.2. Final assumptions of data

From table 4, the calculations and assumptions we obtained results in table 5 as guidelines use for the research. In this table is summarized as final assumptions use to determine the impact effects of external cost and avoidance and the monetary valuations of each component.

Table 5: Final assumptions

Components of Tech	C02 and H2 requirements	Energy required by the system (KWH)	Capacity generation (KW)
PV			223.8512434KW/yr
DAC:			
C02 needed	70000kgC02		
Electricity needed		76790kwh/yr	
H2 production:			
Electricity needed		406080kwh/yr	
Amount of $H_2$0 needed	450,000kgvH20(Neglected) no environmental impact		
MeOH production			
Amount of H_2	9600kgH_2		
Electricity need		7700Kwh/yr	
Total energy		490570kwh/yr	
*Atmospheric models: sources of receptor matrices calculated straightforward			

*Global warming: The physical impacts according IPCC temperature depletion (1.5C)
*Health impacts: ERF for all health impacts in a straight line
*Monetary valuation: This is the cost of all impacts from external cost damage incurred.
*Economic and social impacts

3.3. Data analysis using IPA method

The methodology used in this research is the Impact Pathway Analysis which helps to identify the impact of externalities and calculate the damage cost incurred from the production of Hydrogen and methanol via the DAC technology and to provide mitigation producer (A. Rabl & Spadaro, 2016). The impact pathways approach in this research seeks to estimate the effects of pollutants from the changes in emission through impact on outcomes that society values and compare it to the damage cost. It consists of four stages:

3.3.1. Emission source

The first step is to identify all the main sources of external cost incurring from the given technology and its components. From the case study; PV power plant, DAC, Electrolysis process and methanol reactor

3.3.2. Dispersion (Atmospheric modelling)

The second step is the spread of pollution around the source and to estimate how the changes in emissions of air pollutants resulting from the system considered in the research and change in concentrations. In order to convert emissions from diverse sources into concentration, we estimated the total of 20km2 land area of Abidjan, Ivory Coast with an assumed population of 5,516,000 with the growth rate of 3.01% in 2022 (Google scholar) using the sample size of 100,000 as for the case study.

The spread of emissions in the atmosphere through vertical or horizontal means from its sources is considered as dispersion and the shape where it is approximately trace is known as plume. The spreading of plume is based upon the meteorological condition like for example; (the velocity of wind in the air).

The features of turbulence and therefore the dispersion of pollutants are influenced by the temperature variation with the altitude. Incident solar radiation, the predominant wind speed, and the proportion of cloud cover all influence the temperature in the atmosphere. Atmospheric conditions can be categorized as either class A, which is highly unstable, class B, which is moderately unstable, class C, which is somewhat unstable, class D, which is neutral, class E, which is slightly stable, or class F, which is fairly stable. For instance, very unstable situations (class A) will result from very low wind speeds (i.e., <2 m/s) and extremely intense incoming solar energy (Molina, 2010). There has been more research to provide a clarification proof of the classification of different stability of atmospheric level. (Nicholas P. Cheremisinoff, 2002) The primary greenhouse gases like the CO2 and N_2O remain in the atmosphere for a sufficient amount of time to mix uniformly over the world. Both local and regional effects are considerable for the majority of other air pollutants, especially PM2.5, NOx, and SO_2, for which atmospheric dispersion is large over distances of hundreds to thousands of kilometers.

Therefore, to account for all substantial damages, a combination of local and regional dispersion models is required. For the immediate vicinity (50 km from the source). Some micropollutants, such as harmful metals and persistent organic pollutants, influence us through food and drink, whereas the inhalation dose is the only factor for the conventional air pollutants (PM, NOx, SO2) (PM, NOx, SO2). For the movement of these contaminants through the food chain, a rather straightforward model has been created. These estimates generally show that the dose received through ingesting can be around two orders of magnitude more than the dose received through inhalation. However, the amount of these micro pollutants released by electric power technologies is so negligible that it only has a minimal impact on the cost of overall damage (Spadaro, 2005)

3.3.3. Modelling of Components

The research adopted the atmospheric modelling based upon the IPA bottom-up approach. Atmospheric modelling is a systematic and mathematical tool apply to simulates and predict the function or behaviour of the atmosphere. (Seigneur & Dennis, 2011). The current state of the atmospheric model is used to calculate the concentration of outdoor air pollution. The model is designed to determine the effect of climate change, quality of air management etc. Moreover, the model has many impacts such as the environmental impact, greenhouse gas emission impact from industries. We therefore applied the atmospheric model for each component of the system from table 6 - 9. The emissions of each pollutant in G/KWH were multiplied by the energy required to operate each component. The conversion factor of grams to kilograms per year was applied by multiplying the emission results by (0.001kg) to obtain the final results of external costs damage incurred.

Table 6: Atmospheric model of PV

POLLUTANTS	EMISSION G/KWH	**Sources**	ENERGY G/KW	KW*0.001KG	EXTERNAL COST DAMAGE (KG/YR)

CO2	98	(IAEA, 1997)	490570	48075860	48075.86
N0X	0.18	(IAEA, 1997)	490570	88302.6	88.3026
S02	0.2	(IAEA, 1997)	490570	98114	98.114
PM2.5	0.18	(Farzaneh et al., 2022)	490570	88302.6	88.3026
C0	0.14	(Farzaneh et al., 2022)	490570	68679.8	68.6798
CH4	0.11	(Farzaneh et al., 2022)	490570	53962.7	53.9627
N_20	0.02	(Farzaneh et al., 2022)	490570	9811.4	9.8114

Table 7:Atmospheric model of DAC

Pollutants	Emission g/kwh	**Sources**	Energy generated g/kwh	Kwh*0.001Kg	External cost damage (Kg/yr)
C02	30	(IEA, 2022)	76790	2303700	2303.7
Noise	13100	(IEA, 2022)	76790	1005949000	1005949

Table 8: Atmospheric model of H2 production

Pollutants	Emission in kg	**Sources**	Require energy (kwh/g)	Unit: kwh/g (0.001)	External cost damage (kg/yr)
C02	50	(Turbine, 2023)	406080	20304000	20304
N0X	0.175	(Turbine, 2023)	406080	71064	71.064
N_20	0.265	(Turbine, 2023)	406080	107611.2	107.6112
CH4	0.004	(Turbine, 2023)	406080	1624.32	1.62432

Table 9: Atmospheric model of methanol production

Pollutants	Emission in kg	**Sources**	Require energy (kwh/g)	Unit: kwh/g (0.001)	External cost damage (kg/yr)
NMV0Cs	0.1798	(Kajaste et al., 2018)	7700	1384.46	1.38446

C02	0.5	(Alsayegh et al., 2020)	7700	3850	3.85
N0X	9282	(Kajaste et al., 2018)	7700	71471400	71471.4
N_20	4795	(Kajaste et al., 2018)	7700	36921500	36921.5
CH4	1384	(Kajaste et al., 2018)	7700	10656800	10656.8
C0	2372	(Kajaste et al., 2018)	7700	18264400	18264.4

(Formula 1: Straightforward: emission*energy require*0.001kg = damage)

The Exposure Response Function is a subset of the modelling. It is the extent to which the pollution at risk is exposed. This step takes into account the dose-response function considering the impacts effects of pollutants. We applied the atmospheric dispersion modelling using the Uniform World Exposure model to determine the ambient air pollution impacts. The impacts of these exposures lead to premature deaths, sickness, crop lost etc.

The exposure-response function (ERF) links the physical effects of pollution on a receptor (such as a population) to the exposure that causes those effects (such as an increase in hospitalizations). A harm can only be measured if the associated ERF is known. These processes are known to have the most significant effects on crops, construction materials, and human health. The primary and secondary air pollutants, such as nitrates and sulfates, are among the most significant pollutants. The concentration pollutants used from the emission sources includes the following: (PM2.5, Noise, $S0_2$, $N0_X$, C02, CO, N_20) and the assumption base is from literature review. The calculation of the impacts (damage in physical units) from this exposure, using exposure-response functions (ERF) e. g. cases of asthma due to increase in nitrogen oxides during a given period of illness.

3.3.4. Monetary Cost

A monetary assessment of these effects, such as multiplying by the price of asthma attack. The effects and expenses are totaled across all potential receptors. A multidisciplinary system analysis is used in the endeavour, including engineers, dispersion modellers, and economists, ecologists, and epidemiologists The result of the IPA is the damage cost per kg of emitted pollutant. The main objective of monetary value is to account for all costs, both market and nonmarket, damages are valued financially. For instance, the value of an asthma episode must account for the willingness-to-pay (WTP) to forego further suffering in addition to the expense of medical care and lost productivity. If a non-market goods (goods in which people consumed but are not traded like admiration, respect and authority etc) WTP has been accurately calculated, it is equivalent to a price that is consistent with prices paid for market items.

For calculating non-market costs, economists have created a number of tools like the contingent valuation (CV) being one of the most well-known tools. Asking people how much they would be ready to spend on a specific commodity if they could purchase it. The fundamental concept behind a CV numerous studies have been conducted (Cameron et al., 1989)

It turns out that non-market commodities, particularly the valuing of death, dominates the damage costs of air pollution leading to external cost. The so-called "value of statistical life" VSL is the single most crucial characteristic. People who believe economists attempt to gauge the worth of life typically react negatively to this phrase. Life has an unbounded worth; to save a person in danger, no effort is spared. The "willingness to pay to avoid an anonymous premature death" is really what VSL is. The phrase "value of prevented fatality" (VPF) is preferable.

For deaths that typically result in a significant reduction in life expectancy (LE), such as those caused by cancer and accidents, VPF is appropriate to be accounted for (A. Rabl & Spadaro, 2016). Moreover, monetizing impact is the most challenging phase of a life cycle exposure. The scientific and economic literature have, however, well-developed procedures for quantifying and assigning a monetary value to the environmental damages; several of these methodologies go back more than 45 years.

The process of impact assessment requires the integration of a wide range of knowledge, including, among other fields, engineering, material sciences, climatology and biological sciences, ecology, sociology, and economics. The Impact Pathways Methodology is a widely accepted, uniform approach to this process. With this approach, the analyst tracks the movement of a pollutant or environmental load from the source of emission to the impact it has on the receptors in question, assigning a final score (A. Rabl & Spadaro, 2016)

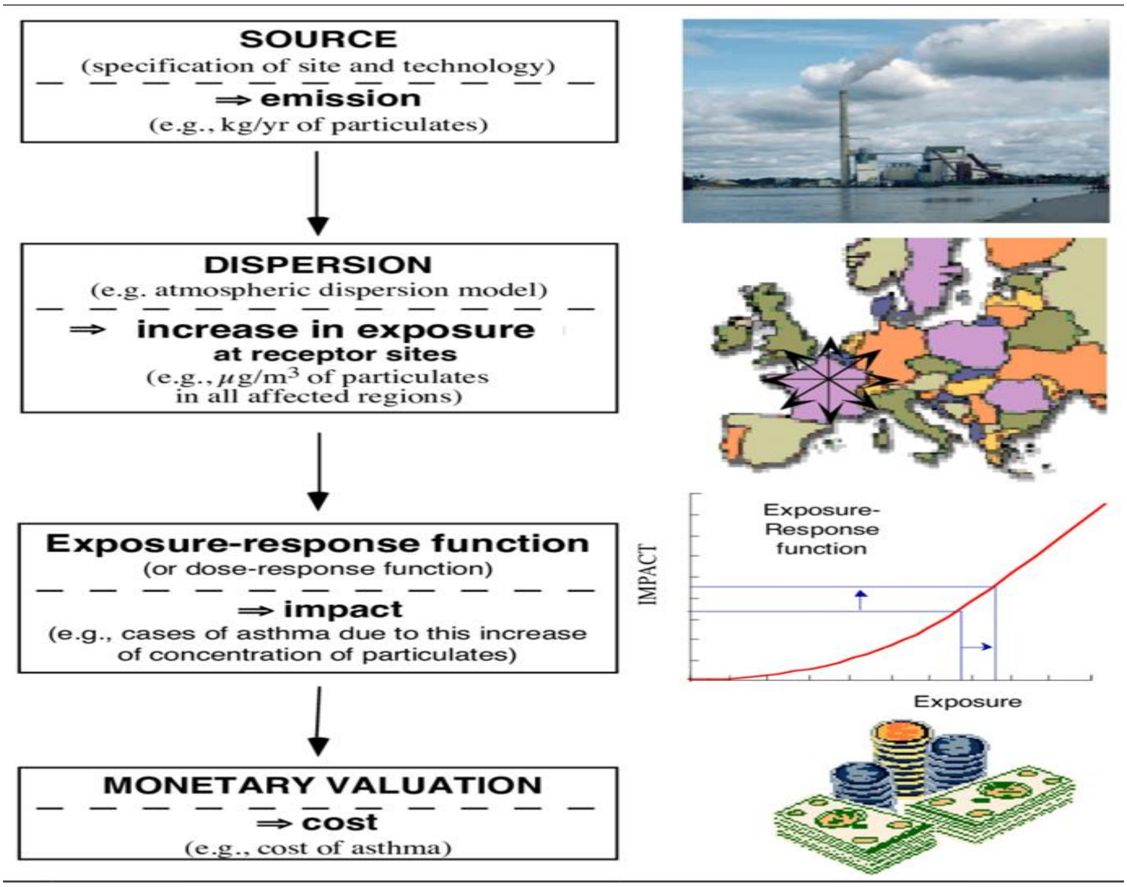

Figure 6: Impact Pathway Analysis (IPA)

3.4. Health Impact

Financially speaking, the expenses of damage are mostly driven by the health effects. The most significant expense is the mortality and morbidity caused by C02, which is computed using the using the atmospheric modelling of external cost to determine the reduction in life expectancy per exposure and to demonstrates the main contaminants and their effects on health. Primary pollutants are those that are released into the air directly by the installed technology and secondary pollutants are those that are produced in the environment as a result of the chemical transformation of some primary pollutants (Pope et al., 2020b)

Today in general view, discussions on health by experts have been emerging that air pollution cause by industries at current state of temperature is mainly connected with so many health difficulties like the respiratory diseases and mortality. However, the method of analyzing the problem is not well understood by epidemiologists due to a lot of exposures and its impact. The majority of recent investigations have pointed to tiny particles as the main offender. While SO2 may also have a substantial direct influence on health, the evidence for NOx has a direct effect with a strong effect. The likelihood of duplicate counting when aggregating the costs of damage across pollutants is not completely eliminated due to the size of the uncertainties (A. Rabl & Spadaro, 2000). The dose-response functions for the common air pollutants (particulate matters, NOx, SO2, and CO2) are often based on concentrations in ambient air, therefore the designations ER function are also employed. We discuss acute and chronic CR functions based on the epidemiological strategy utilized to identify a CR function. To conduct a time series analysis of a population, the most popular and straightforward method is to find brief associations (over a few days) between air pollution and a health end-point of the selected functions. Observations of people or communities exposed to various degrees of pollution are necessary for end-points that don't manifest for a longer period of time. Few studies have determined the dose-response functions for chronic impacts, which are hardly challenging to define with confidence (Pope et al., 2020b). Here, we assume that the Uniform World Model is the source of all dose-response curves for the effects of air pollution on health. This is evidenced by the fact that multiples research throughout a wide range of pollution locations of the world have discovered fairly comparable CR function slopes without any support for no-effect thresholds. Furthermore, in various investigations, a whole dose-response function for one of the common air contaminants has been attempted to be mapped. Table 8. shows a list of impact of pollutants as discussed.

Table 10: Pollutants and impacts

Pollutants	Impacts
Particulates matters (2.5,10)	Chronic mortality, Acute mortality, Morbidity (hospital admission. Heart failure, cough, lower respiratory symptoms etc)
SO2	Asthma, mortality, cardio pulmonary morbidity, hospitalization, restricted work by doctor
NOX	Chronic mortality, Asthma (children), Respiratory hospital admission, Asthma(adults)
NOISE	Lower hearing ability, heart attack (mortality)
CO2	Mortality, respiratory hospital admission, cardiovascular morbidity
N20	Respiratory hospital admission, Diabetes, lung cancer, asthma attack (chronic bronchitis)
NMVOCs	Diabetes, lung cancer, asthma attack (chronic bronchitis)

External cost from air pollution with respect to health impact also represents two processes through chemicals that affect the human health; the intake and uptake associated with inhalation. Some of these pollutants NOX, CO_2, CO, SO_2 and PM have heavy metals that affect the respiratory system and direct association of air pollution and lunch cancer risk and risk mortality that has demonstrated many epidemiological researches, particularly with people who are already living with cancer diseases.

The PM is one of the common pollutants that increase the risk of effective respiratory symptoms. The second process is by chemical that goes through human body by up-take producer which involve the absorption of skin. In industrialized countries, it is often reported as the most frequent way of exposure. The public and regulatory authorities are very concerned about the mounting evidence that a variety of substances, including medications and environmental toxins, might target the immune system and potentially have harmful consequences on the host's health. PM and CO_2 include coverage for a second for outdoor air pollutants. It is believed that oxidative stress-induced genotoxicity is a key link in the development of cancer (Serafini et al., 2022)

A one third of premature deaths are thought to be brought on by air pollution every year in come from the working of larger industries producing chemicals like methanol from steam that a high external cost from its production. (Juginović et al., 2021)

Prenatal exposure to air pollution can have an impact on a child's growth during infancy and childhood, mostly via impairing organogenesis. (Mulenga et al., 2018)The interval from utero through the first few years of life is crucial for the immune system's development. If exposed to environmental pollution early in life, the immune system's development may be affected. As a result, the impacts of this period's exposure to harmful contaminants may result in a higher risk of allergies in later life. PM exposure during pregnancy can result in immune system development in babies that is delayed (Mulenga et al., 2018). According to the WHO, air pollution is the modification of the atmospheric properties by any chemical, physical, or biological factor in either the interior or outdoor environment (Manisalidis et al., 2020).The main diseases associated with outdoor air pollution, including PM, CO, O_3, NO_2, and SO_2, include PM, CO, O_3, NO_2, and SO_2. In this review, we provided a figure (6) shows the key adverse results about how air pollutants affect the immunological and neurological systems while also looking at how they work. It is important to emphasize that in this situation, human beings are exposed to combinations of air pollutants rather than just one type of pollutant. Therefore, it is important to research how numerous chemicals affect human bad health

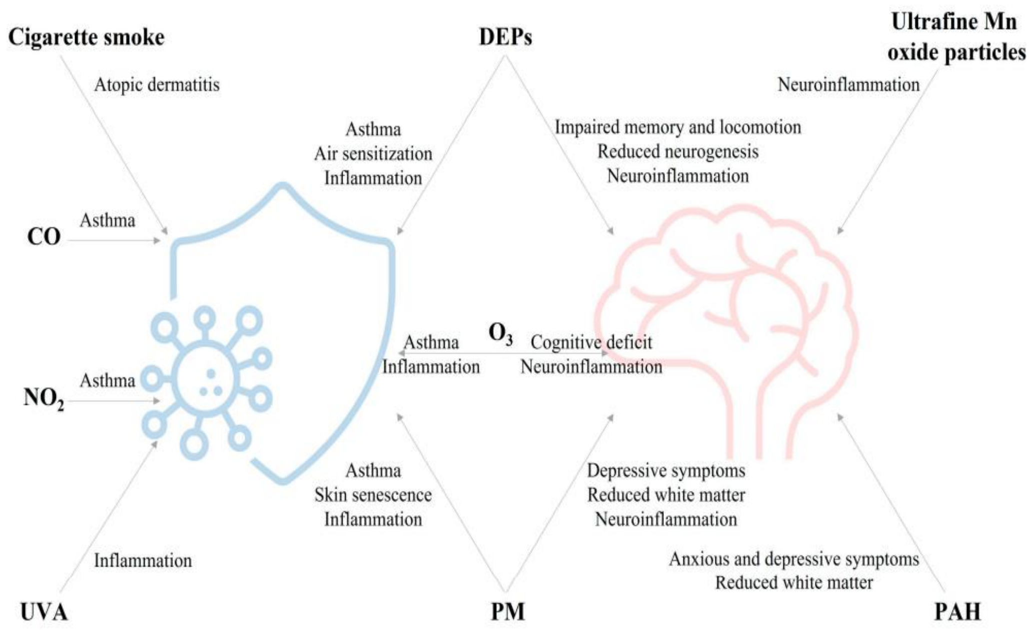

Figure 7: Adverse effects of air pollution

outcomes involving from industries activity

3.5. Climate change

In real word, it is challenging to calculate the cost of climate change due to the numerous diverse repercussions (outcomes) that must be taken into consideration across all nations in the world. In addition, one needs to forecast how these effects and costs will change in the far future because they will manifest in coming decades and centuries. The valuation of mortality in developing nations, where the majority of the effects would manifest themselves, and the selection of the discount rate for intergenerational costs raise contentious ethical questions in addition to the scientific difficulties. Many articles have published the estimate damage cost per ton of C02 (Shukla et al., 2022). Climate change is the long-term temperature condition and its weather patterns. These changes are due to the increase in temperature.

Effects and causes of external cost of climate change

There are many greenhouse gases that cause the change in climate due to activities of human like the CO2 and methane. These air pollution from factory heating or production of special chemicals or fuels. Climate research scientists have shown that human is responsible for the all-global warming this day. Of the last four decades (UN report - 2011-2020) was reported to have had the warmest climate record previous. Intense droughts, water scarcity, destructive fires, rising sea levels, flooding, melting polar ice, catastrophic storms, and a decline in biodiversity are now some of the effects of climate change today (UN, 2023)

External cost plays a key role in climate change because, it can affect our health, ability to grow food, housing safety and work due to the emissions from pollutants which are not being accounted for by polluters of power plant owner. Some countries are already vulnerable to the impact of climate change especially most developing countries. Condition like rise in sea level leading to intrusion into communities making them to relocate.

To avoid external and protect the climate, thousands of scientists and government agencies on climate change need to review and come up with some basic ways of curtailing the increase in global temperature to at least 1.5°C according to the Paris Agreement (Rogelj et al., 2018). This would help humanity avoid the worst climate change effects and maintain a habitable environment. However, presently strategists have predicted a 2.8°C rise in temperature by the end of the century if not curtailed (UN, 2023). About half of most of the greenhouse gas emissions worldwide in 2022 report are produced by these top countries: China, The United States of America, India, European Union, The Russian Federation and Brazil. (Crippa et al., 2022)

Both animals on land and in the ocean are at risk from climate change. As the temperatures rise, these hazards rise as well. The rate of extinction in the planet is 1,000 times higher now than it has ever been in recorded human history, and this is exacerbated by climate change. (Gullino et al., 2022). Within the next several decades, one million species face extinction. Threats from climate change include exotic pests and illnesses, forest fires, and harsh weather (Gullino et al., 2022). Others won't be able to move and live, but some species will. Global hunger and poor nutrition are on the rise for a variety of causes, including climate change and an increase in extreme weather occurrences. Crops, animals, and fisheries might all be lost or become less effective (Gullino et al., 2022).

Marine resources that provide food for billions of people are at danger as a result of the ocean's increasing acidity. Food sources from herding, hunting, and fishing have been hampered in several Arctic locations due to changes in the snow and ice cover. Heat stress can reduce available water and grazing areas, which can lower crop output and have an impact on cattle.

Climate change increases the factors of that put and keep people in a complete vicious cycle of poverty. Flooding may sweep away clustered and slum communities. Heat can also make it very difficult to work in outdoor places like job sites. Water scarcity may affect crops growth Over the past decade (2010 – 2019), weather-related evens displaced an estimated of 23.1 million people on average each year leaving many more vulnerable. Most refugees come from countries that are mostly vulnerable and least ready to adopt to the impacts of climate (Gullino et al., 2022).

3.6. Social Impact Of external cost

Social interactions or behaviour between two or more group of people are defined as those in which one individual has an impact on the other, especially within the same species (O'Connell & Hofmann, 2011). Exposure to environmental stress is a key life stage that can affect illness which can be influence later on, as stated in the developmental origins of adult disease hypothesis. In addition to possible changes, social behaviour during development might also be impacted by exposures in later life. Experimental research has started to support the effects of air pollution on outcomes linked to social behaviour throughout development and in adulthood based on epidemiological data. This experimental research has only used rodent model systems thus far; the results are briefly outlined here (Moosa et al., 2017)

Ambient air pollution is pervasive, affects people of all ages and from all geographical areas, but it also frequently involves unequal exposure, which exacerbates socioeconomic and racial-ethnic disparities. Its significant impact on public health is caused in part by urbanization and international industrial activity. There is growing evidence that long-term exposure to ambient air pollution affects human neural function and social-neurobehavioral outcomes, including autism spectrum disorder, bipolar disorder, and depression (Nachman & Parker, 2012). It is well known that long-term exposure to ambient air pollution increases the risk of morbidity and mortality from cardiovascular and respiratory diseases (Weitekamp & Hofmann, 2021)

However, because air pollution is such a complex combination, effects on social behaviour may result from exposure through pathways other than endocrine disruption, such as oxidative stress, neuroinflammation, and even direct neuronal injury. These effects may arise from exposure in adult animals or from exposure during development, which may disturb brain development and thus influence adult social behaviour (Ibanez et al., 2019). Sources of anthropogenic and natural air pollution coexist. The social impact of air pollution includes the but not limited to migration displacement, educational disruption and cultural damage (Google scholar). According to how they are controlled, the U.S. EPA divides air pollutants into two main categories: criterion air pollutants and air toxics. There are six criterion of air pollutants that are widely distributed throughout the United States, which might theoretically pose a threat to human health or welfare. These include lead, nitrogen dioxide, sulfur dioxide, ozone, and particle pollution (W.H.O, 2014). The National Ambient Air Quality Standards are established, reviewed, and revised in accordance with the Clean Air Act of 1963 for each criterion air pollutant. The Clean Air Act was amended in 1990, identifying 189 air toxics, often known as hazardous air pollutants, and defining a procedure for controlling these pollutants' emissions (McCarthy et al., 2014). Pollutants known as "air toxics" are dangerous, irreversible, or disabling reversible health effects, such as cancer and other grave health consequences. Following the delisting of two pollutants, there are presently 187 air toxics recognized under the Clean Air Act, such as metal compounds, polycyclic organic matter. (Weitekamp & Hofmann, 2021). Air pollution is still a major problem worldwide even though levels of several air pollutants have declined in the United States as a result of regulations under the Clean Air Act. In 2016, 91% of the world's population resided in regions where the World Health Organization's air quality standards were surpassed (W.H.O, 2014).

3.6.1. Developmental exposures

A range of developmental problems known as autism spectrum disorders (developmental disability caused by differences in brain) affect social interactions and communication throughout adolescence and adulthood. Their genesis is influenced by both hereditary and environmental factors. Numerous recent meta-analyses and systematic reviews have evaluated the epidemiological data supporting the link between air pollution exposure and autistic spectrum disorders (Sealey et al., 2016).

Each of these reviews identified a link between prenatal exposure (when the woman is pregnant and takes in drugs or alcohols, it brings change in the body and the brain of her baby causing a long-term effects) to fine particulate matter and diagnoses of autism spectrum disorders, while highlighting limitations in the available evidence (Sealey et al., 2016). According to a number of epidemiological studies, short-term variations in air pollution exposure can have an impact on people's behaviour. For instance, elevated fine levels Ozone and particle matter were linked to higher rates of violent crime but non-violent crime, suggesting that they may have an impact on aggressive behaviour.

Additionally, a recent systematic review and meta-analysis from Harvard six cities cohort studies (Pope et al., 2020) found that short-term exposure to nitrogen dioxide was positively associated with depression (which includes social withdrawal and isolation), but not with ozone, sulfur dioxide, or particulate matter. A different meta-analysis discovered a link between depression and long-term (>6 months) exposure to fine particulate matter. Both assessments highlight the gaps in the evidence and recommend additional high-quality research to determine the effects of air pollution on mental health (Weitekamp & Hofmann, 2021). In our research, we found that chronic exposure to air leads to increase in vulnerability and premature death as far insecurity and increase in criminality (Patel et al., 2021)

3.6. 2. Evolutionarily conserved neural circuits

The perception and assessment of sensory signals is the first step in the display of social behaviour, which is then integrated with internal physiological condition which calls for several levels of coordinated brain cell activity (Reichert, 2009). The first way that electrochemical signals are transmitted between neurons is through neural networks. Gene regulatory networks, a group of regulatory connections between genes expressed inside brain cells, are another area of activity.

Following an excessive amount of data linking certain behavioural reactions and specific gene expression patterns in the brain, the idea of gene regulatory networks was proposed. Given the addition of the social network component to information processing, gene regulatory networks are probably unique for social behaviour (Sinha et al., 2020). Some regions of the brain that leads to the degeneration as a result of impact of air pollution.

Table 11: Region of the brain and basic functions **(Weitekamp & Hofmann, 2021)**

Cerebral cortex	CS	integration decision-making
Lateral septum	LS	emotional learning, social affiliation
Ventral pallidum	VP	emotional learning, parental care
Medial amygdala	meAMY	aggression, social recognition, motivation
Striatum	Str	compulsive behaviour
Hippocampus	HIP	spatial learning
Anterior hypothalamus	AH	aggression, reproduction, parental care

CHAPTER 4: RESULTS AND SENSITIVITY ANALYSIS

Table 12-15 show the results in monetary valuations obtained from the damage incurred from the production of 50,000kg of MeOH and H2 per year. In each table we account for the monetary valuation by multiplying the result we obtain from the damage incurred by the external cost rates. We maintained the straightforward calculations method from table 12–15 in order to determine which pollutant will have a high external cost impact during the production.

Table 12: Monetary value of PV

Pollutants	External cost rate(€/t)	External cost damage (Kg/yr)	Monetary valuation (€/yr)
CO2	102.7	48075.86	4937.390822
N0X	21203	88.3026	1872.280028
$S0_2$	17.732	98.114	1.739757448
C0	733.02	68.6798	50.343667
CH4	2875.65	53.9627	155.1778383
N_20	27215.65	9.8114	267.0236284

Table 13: Monetary value of DAC

Pollutants	External cost rate(€/t)	External cost damage (Kg/yr)	Monetary valuation (€/yr)
CO2	102.7	2303.7	236.58999
Noise	0.00517	1005949	5.20075633

Table 14: Monetary value for H2 production

Pollutants	External cost rate(€/t)	External cost damage (Kg/yr)	Monetary valuation(€/yr)
C02	20304	102.7	2085.2208
N0X	71.064	21203	1506.769992
N_20	107.6112	27215.95	2928.741039
CH4	1.62432	2875.65	4.670975808

Table 15: Monetary value for methanol production

Pollutants	External cost rate(€/t)	External cost damage (Kg/yr)	Monetary valuation(€/yr)
NMV0Cs	1066	1.38446	1.47583436
C02	102.7	3.85	0.395395
N0X	21203	71471.4	1515408.094
N_20	27215.95	36921.5	1004853.698
CH4	2875.65	10656.8	30645.22692
C0	733.02	18264.4	13388.17049

Formula:(External cost rates*Damage incurred) = monetary valuation

4.1. Main Results

The implementation of our chosen methodology presented in this paper leads to the quantification of external cost due to both air pollution, climate change, health impacts, social impact and monetary valuation for the designed technology. Regarding air pollution as externalities, the DAC component has just two externalities considered for the level of emission (noise and C02) from our results. These pollutants (noise, C02) become relevant only during the operation of the DAC while capturing about 70,000kgC02/yr which needed for the production. In our main results, we modelled each component of the system to obtain the damage of pollutants incurring during the generation of energy supply and the production of Hydrogen and Methanol in kilogram per year via the DAC technology deigned.

The modelling of component was done using the straightforward calculations my multiplying the emissions of pollutants with the require energy of the system component to obtained the damage incurred in kg/yr. We considered the conversion for external cost rates given in (€/t) and our damage result in (kg/yr). We therefore converted the unit of tons to kilogram by multiplication taking into account (0.001kg) conversion factor. Furthermore, we maintain the straightforward calculation to determine the quantitative monetary valuation of each system by multiplying the external cost rates of the pollutants by the damage incurred through the system to have the valuations of damage in monetary units for each component as external cost.

The external cost rates of these pollutants were considered based upon the magnitude of impacts exposure research done by(F. Baumgärtner & Letmathe, 2020a). The evaluation quantification result covers various types of impacts. Health impacts which include mortality, acute and chronic health effects from pollutants emitted due to its magnitude. Major pollutants with high-external cost drive from our results are the CO2, NOx and N_2O. With respect to percentage allocation, CO2 constitutes 50% of the overall results making it alone as the key and leading external cost driver for the designed system.

The results also indicate that health impacts dominate from the damages quantified from the study because it plays a major role in evaluation of the ecosystem in particular the mortality due to primary and secondary particulate matters which are highly toxic when emitted. Ones these health impacts and other environmental damages are taken into account and assigned a monetary value, then an estimate is obtained from the external costs which are not accounted for. It is therefore important to underline that external cost represents a significant portion of the total production cost of each component designed herein. The table shows the main results of external cost and the main cost drivers incurred from the production of hydrogen and methanol in kilogram per year.

Table 16: External cost and drivers

	PV System	DAC System	Electrolyser (H2)	Methanol Reactor
External cost per year(€/yr)	7283.955741	241.7907463	6525.402806	2564297.061
External cost per 1kg(€/kg)	0.1457	0.0048	0.1305	51.2859
Pollutants with major risk	CO2	CO2	N_20	$NO_{X,}$

4.2. Sensitivity analysis

The sensitivity analysis firstly shows how target variables changes with respect to changes in input variables. There are many ways to assess the external cost damage and its monetary values of GHG emissions and the accompanying global warming leading to health impact. The cost estimates for these two factors are questionable today in the world due to the uncertainty. The external cost of hydrogen and methanol were calculated based on the external cost rates of these pollutants (PM2.5, $N0_X$, $S0_2$, N_20, C02, Noise NMVOCs, CO) from the overall. In our sensitivity analysis, we conducted different analyses to show the risk impacts of external cost of production from each component and the external cost drivers of the technology. In the scenario cases, we assume a ten percent increase in production of specific pollutants that incurred a high external cost per year.

This assumption of the ten percent is to determine which pollutant will have a high risk if there is an increase in the production. Our increment was based upon any pollutant which external cost incurred from one thousand Euros per year to the maximum external cost incurred from the research per year (€/yr) will fit in the selection criteria for the sensitivity analysis. In our second scenario case, we assume a twenty percent increase in the production to determine the same effects on the cost drive for the technology.

Table 17: Sensitivity analysis of PV

Pollutants	Baseline	Scenario A (+10% CO2)	Scenario A (+10% NOX)
CO2	4937.390822	5431.129904	4937.390822
NOX	1872.280028	1872.280028	2059.508031
SO2	1.739757448	1.739757448	1.739757448
CO	50.343667	50.343667	50.343667
CH4	155.1778383	155.1778383	155.1778383
N20	267.0236284	267.0236284	267.0236284
Total (€/yr)	7283.955741	7777.694823	7471.183744
Major risk of pollutant		0.06778	0.02570
		6.78%	2.57%
External cost incurred of 1kgMeOH/H2(€/kg)	0.1457	0.1556	0.1494
		Scenario B +20% CO2	Scenario B +20% NOX
CO2	4937.390822	5924.868986	4937.390822
NOX	1872.280028	1872.280028	2246.736033
SO2	1.739757448	1.739757448	1.739757448
CO	50.343667	50.343667	50.343667
CH4	155.1778383	155.1778383	155.1778383
N20	267.0236284	267.0236284	267.0236284
Total (€/yr)	7283.955741	8271.433905	7658.411746
Major risk of Share		0.1356	0.0514
Risk Share in %		13.56%	5.14%
External cost incurred1kgMeOH/H2(€/kg)		0.1654	0.1532

From our first sensitivity analysis taking from PV system, we selected CO2 and NOX based on the standard selected by the research. We increase the generation of electricity by 10% for (CO2, NOX) and the result shown was fairly changed from CO2 increase. Now in case two, we increase the same selected pollutants by 20%. Considering the two results from critical analysis, increase in the generation electricity will have an impact on the expansion with CO2 as the major risk in our production as compare to NO_X. The graph further explains that CO2 from all indication is a high-cost driver from PV system.

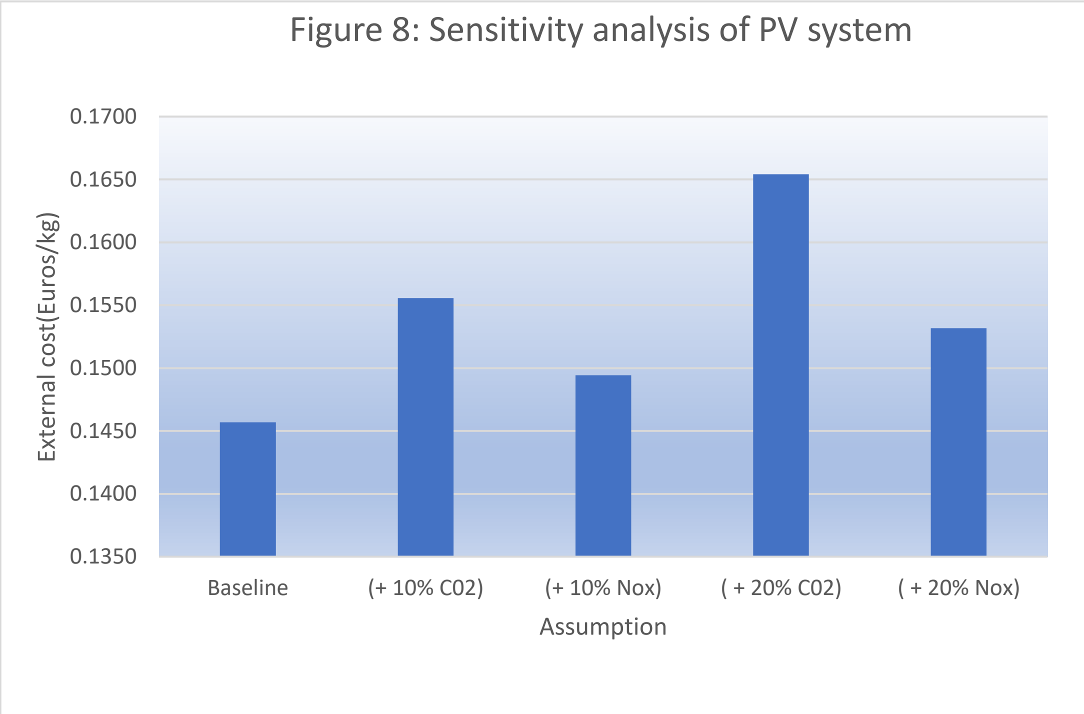

Table 18: Sensitivity analysis of DAC

Pollutants	**Monetary valuation**	**Scenario A (+10% CO2)**	**Scenario A (+10% Noise)**
CO2	236.58999	260.248989	236.58999
Noise	5.20075633	5.20075633	5.720831963
Total(€/yr)	241.7907463	265.4497453	242.310822
Major risk of pollutants		0.097849067	0.002150933
Risk share in %		9.78%	0.22%
External cost incurred (€/kg)	0.0048	0.0053	0.0048
		Scenario B (+20%CO2)	Scenario B (+20%Noise)
CO2	236.58999	283.907988	236.58999
Noise	5.20075633	5.20075633	6.240907596
Total(€/yr)	241.7907463	289.1087443	242.8308976
Major risk of pollutants		0.195698135	0.004301865
Risk share in %		19.57%	0.43%
External cost incurred from CO2 capture (€/kg)	0.0048	0.0058	0.0049

The second sensitivity analysis was done from the DAC technology. In our analysis, we selected all the two major pollutants as they play a major role in capturing the humidity for the production of hydrogen and methanol. The role of the noise comes from the DAC as the fans rotate. It produces noise considered as externality. For the sensitivity analysis, we did not follow the selection producer for the DAC technology because we needed to compare two major risks factor within the DAC since they are the only two pollutants.

Our critical analysis review show that CO2 contribute a major risk factor of 9.78% if increase by 10% and in scenario B, we increase the both pollutants by 20%. The result shows a significant amount of CO2 increase of 19.57% as compare to the Noise being produced by the fans of the DAC of 0.43%. From the graphical indication below, CO2 is the main external cost driver for the DAC operation increasing from 10% to 20% share, the external cost incurred for C02 also increased from (0.0053€/kg to 0.0058€/kg) cents.

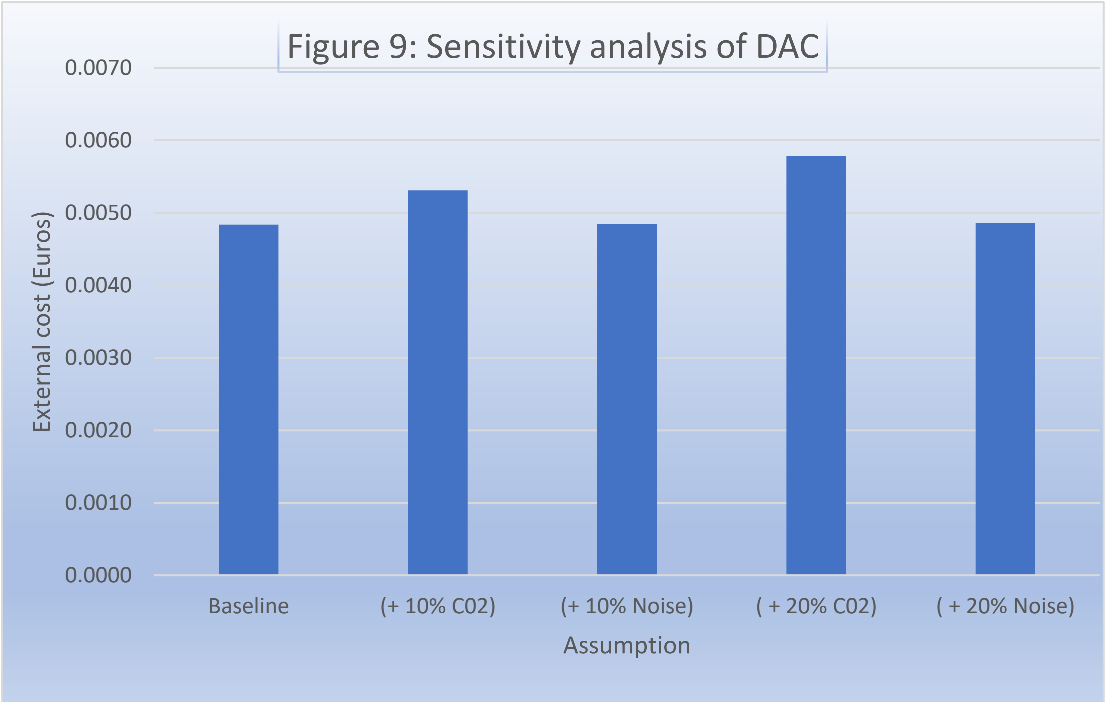

Figure 9: Sensitivity analysis of DAC

Table 19: Sensitivity analysis of H2 production

Pollutants	**Monetary valuation**	**Scenario A (+10%CO2)**	**Scenario A (+10% NOx)**	**Scenario A (+10% $N_2$0)**
C02	2085.2208	2293.74288	2085.2208	2085.2208
N0X	1506.769992	1506.769992	1657.446991	1506.76999
$N_2$0	2928.741039	2928.741039	2928.741039	3221.61514
CH4	4.670975808	4.670975808	4.670975808	4.67097581
Total(€/yr)	6525.402806	6733.924886	6676.079806	6818.27691
Major risk of pollutant		0.031955434	0.023090835	0.04488215
Major risk of pollutant in %		3.20%	2.32%	4.49%
External cost incurred of 1kgH2(€/kg)	0.1305	0.1347	0.1335	0.1364
		Scenario B (+20%CO2)	Scenario B (+20% NOx)	Scenario B (+20% $N_2$0)
C02	2085.2208	2502.26496	2085.2208	2085.2208
N0X	1506.769992	1506.769992	1808.12399	1506.76999
$N_2$0	2928.741039	2928.741039	2928.741039	3514.48925
CH4	4.670975808	4.670975808	4.670975808	4.67097581
Total(€/yr)	6525.402806	6942.446966	6826.756805	7111.15101
Major risk of pollutant		0.063910868	0.04618167	0.089764
Major risk of pollutant in %		6.39%	4.62%	8.98%
External cost incurred of 1kgH2(€/kg)	0.130508056	0.138848939	0.136535136	0.14222302

In our third sensitivity analysis for the electrolyser, $N_2$0 was considered as the major pollutants due to the high-cost of percentage share it shows when producing hydrogen. We assumed increase of 10% and 20%. In our 10% increase for $N_2$0, the result show 4.49% share. However, taking the next case scenario B, we increase the production by 20% which shows a double result of 8.98% as compare to scenario A.

From this critical review, increase in the production of 20% will yield N_2O as a major risk factor in the production leading to an increase of external cost of production from (0.1364€/kg – 0.1422€/kg). Figure 10, clearly provide more details from the assumption of (10% and 20%).

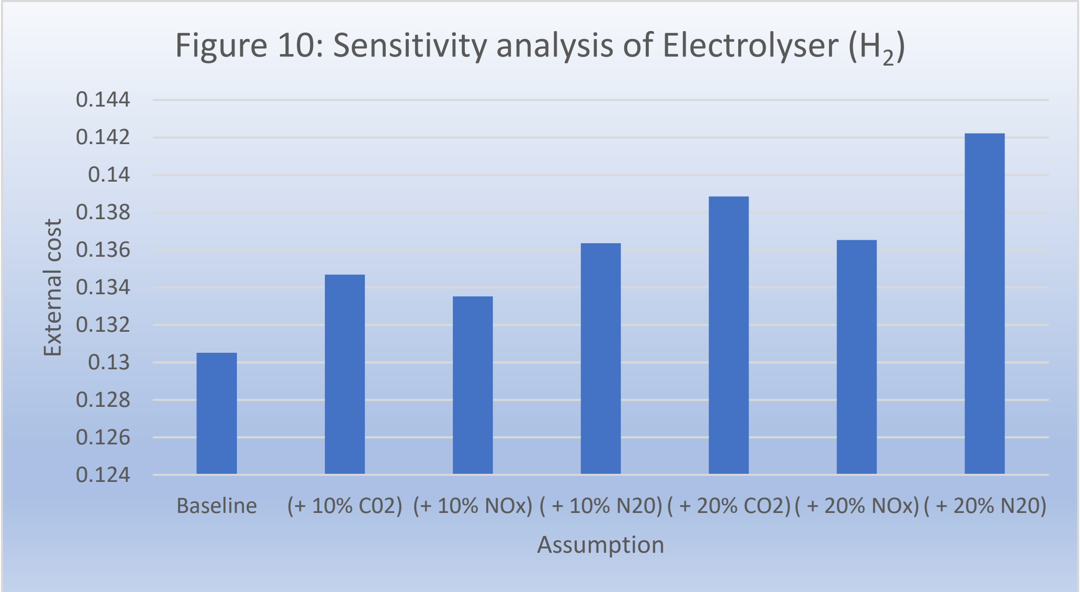

Figure 10: Sensitivity analysis of Electrolyser

Table 20:

Sensitivity ana of methanol production

Pollutants	**Monetary valuation**	**Scenario A (+10% NO_X)**	**Scenario A (+10% N_2O)**	**Scenario A (+10% CH_4)**	**Scenario A (+10% CO)**
NMV0Cs		1.47583436	1.47583436	1.475834	1.475834
C02	0.395395	0.395395	0.395395	0.395395	0.395395
N0X	1515408.094	1666948.904	1515408.09	1515408	1515408
N_20	1004853.698	1004853.698	1105339.07	1004854	1004854
CH4	30645.22692	30645.22692	30645.2269	33709.75	30645.23
C0	13388.17049	13388.17049	13388.1705	13388.17	14726.99
Total (€/yr)	2564297.061	2715837.87	2664782.43	2567362	2565636
Major risk of pollutant		0.059096433	0.03918632	0.001195	0.000522
Major risk of pollutant in %		5.91%	3.92%	0.12%	0.05%
External cost incurred 1kgMeOH(€/kg)	51.2859	54.3168	53.2956	51.3472	51.3127
Pollutants	Monetary valuation	Scenario A (+20% NO_X)	Scenario A (+20% N_2O)	Scenario A (+20% CH_4)	Scenario A (+20% CO)

NMV0Cs	1.47583436	1.47583436	1.47583436	1.475834	1.475834
C02	0.395395	0.395395	0.395395	0.395395	0.395395
N0X	1515408.094	1818489.713	1515408.09	1515408	1515408
$N_2$0	1004853.698	1004853.698	1205824.44	1004854	1004854
CH4	30645.22692	30645.22692	30645.2269	36774.27	30645.23
C0	13388.17049	13388.17049	13388.1705	13388.17	16065.8
Total (€/yr)	2564297.061	2867378.68	2765267.8	2570426	2566975
Major risk of pollutant		0.118192866	0.07837264	0.00239	0.001044
Major risk of pollutant in %		11.82%	7.84%	0.24%	0.10%
External cost incurred 1kgMeOH(€/kg)	51.28594122	57.34757359	55.305356	51.40852	51.33949

From the fourth and last sensitivity analysis, we selected four major pollutants out of six. We maintain our selection criteria for all pollutants from the methanol reactor. Our critical analysis shows that an increase of 10% in the production of methanol will lead to an increase of external cost of each selected pollutant with NOx constituting 5.91% share as a major risk factor from the methanol production thus the change is relatively fair. From scenario B, we considered 20% also to determine the external cost impact.

The results from these reviews show that NOx increase from 5.91% to 11.82% which increase the external cost of production and environmental impact as well. We can therefore conclude that NOx is the high-cost driver from producing methanol. Figure 11 provide the level of variation between NOx, CO, CH4 and N_2O thus NOx serving as the major risk factor from the overall.

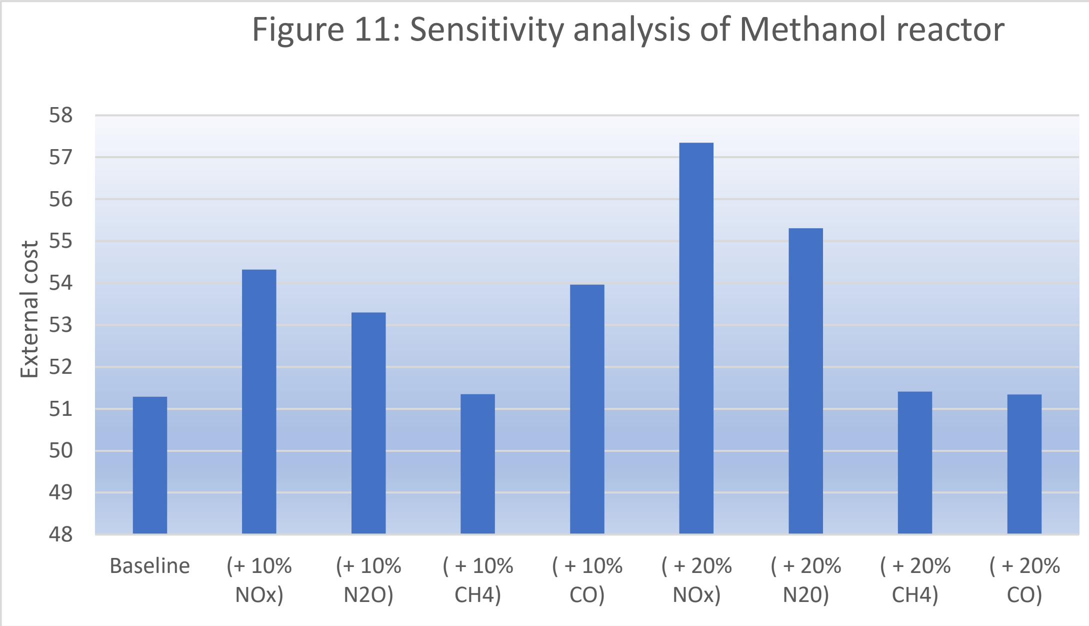

Figure 11: Sensitivity analysis of methanol reactor

CHAPTER 5: DISCUSSIONS AND INTERPRETATIONS

5.1. Calculations of external costs

The calculation of each component under the assumption that all production and damages are located in Abidjan, Cote d'Ivoire. From table 5. we assumed the total amount of water needed to produce 50.000KgMeOH is 450,000Kg volume of H_20 considering 1kgMeOH is $9kgH_20$ although this quantity of water however is not considered due to a non-environmental exposures and health damage that might lead to high impacts. From the first scenario case of 10% increase in electricity generation it determines relatively fair change in PV and applying the 20% in production leads to a high significant change from 6.78% share to 13.56%.

From the overall system designed, we can conclude that a 10% increase does not lead to a high impact on the system. But considering a 20% increase in the production will lead to a significant impact. This mean that, increase of 20% will have a greater impact on the system that will lead to incurring high external cost. Moreover, this high cost might bring government or administrative decision taking to a closure of the operating industry due to breach of international standard operating protocols set-up. The consequences of such decision will bring about loss of job by employees of the industry.

Nevertheless, the other pollutants mentioned are relevant to the research from the overall analysis. In our discussion, we have identified key external cost drivers that are significant and thereby influencing external cost incurred. These high-cost drivers are reported base on the variation of emissions which were quantified in monetary values for each component. These externalities (C02, NO_X, N_2O) are the most constituting cost drivers from the production. These influential cost drivers accounted for in this research are based on the level of technology use. Today as the world continues to integrate technology from a developing and learning scale to a well-developed and commercial level, these cost drivers will subsequently decrease as the efficiency of the technology improves.

5.2. Internalizing/mitigation of external cost

Internalization involves the process of incorporating or accounting for market decision through pricing or regulatory interventions. In short, internalizing is achieved by charging polluters of industry for example the damage costs by pollution generated during the generation of energy. These externalities generated can be regulated through government agencies, self-regulation for safety management, taxes, subsidies and cost minimization (Gupta & Prakash, 1993)

Many studies have discussed the concept of internalizing external cost which is not new in economics discission. This external cost concept was developed by Arthur Cecil Pigou (1877-

1959), who wrote and published the book Economics of Welfare in 1920.This concepted was added by Alfred Marshall(Ramalho & Santos, 2021). The goal to internalize External cost is to ensure that the costs and benefits of activity are reflected in the prices paid by the participants, rather than being imposed on third parties who are not part of the transactions. In this study we adopt the below measures to mitigate the external cost and impacts.

5.2.1. Sustainable technology

Internalizing external cost can necessitate new industrial machinery. This would need the use of new technologies during the processes of manufacture, distribution, and disposal. By investing in a more sustainable power plant. Cost of utilizing the technology will reduce. This is a reference to the technology's efficiency (input-output ratio). Which technology has lower operating costs for the same level of performance? The technology used has an impact on institutional architecture. The technology designed is within the institutional choice like the Dry-Hy project using the DAC setup design to produce hydrogen and methanol.

5.2.2. Pollution control regulations

This refers to the rules or measures put in a standard place by environmental agencies with international measures and governments to mitigate and manage the harmful effects of pollution on the environment and public health. These controls are important to limit the release of pollutions into the water, air, soil as well as to ensure industries and individual adopt good practices that reduces their environmental impact. Moreover, the effective pollution control and regulations are essential for protecting the environment and human health. These regulations are often considered as new scientific findings and emerge and as societies become more aware of crucial for a sustainable and a better future. The controls must be in according with carbon pricing. It is a tax on carbon emissions or cap and trade system that allows firms to buy and sell permits for emissions with the goal of reducing GHGs.

5.2.3. Cost of management

For the technology designed to be operational, it requires commitment of internal management setup to continue the modification and maintained cost of resource through monitoring and enforcing every regulation which may be done by applying government regulations and safety management measures during production.

Internalizing external cost helps to create a more efficient and equitable allocation of resources by ensuring that the costs and benefits of economic activities are reflected in the prices paid by the participants imposed on the third party.

5.3. Limitations of the research

The research methodology has a number of uncertainties and constraints that need to be addressed in order to make the model more robust. In our search, one major limitation of this master thesis work was the lack of gathering a comprehensive comparative available data source to identify the external cost of producing hydrogen and methanol. Secondly, the research didn't consider battery storage due to the selected operational hours chosen. The external cost rate and the emissions of pollutants considered in this research were not taking from the selected country of research due to unavailability of data.

5.4. Contributions to the research

The contributions of this master thesis are the development of a comprehensive assessment model to identify the external cost through the Direct air capture via hydrogen technology. In this model, we were able to identified major pollutants incurred and calculated its external cost in monetary values. We can however say that after our critical assessment of the model, we can present this model to be adopted for countries in Sahel regions especially with an extreme climate condition to provide energy access as well.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

From the research work, we can draw three implications for conclusion.

6.1.1. The first is the methodological producer:

we show that applying damage factors to the physical impact due to exposure is relevant to those standards of mitigation for the application of the emissions leading to external costs damage factors as a result of findings that provides decision makers with additional information. For applying appropriate damage factors to air pollutants, we need to take into account the place and the height of emissions to obtain possible detailed estimation of externalities. This result allows decision makers to manage an aspect to understand how external costs incurred and to compare with economical performances of products and with potential economical tools for their promotion (e.g., Improve technology through giving subsides)

6.1.2. The second is the application of methodology:

The case study of our research, external cost incurred from the production of Hydrogen and methanol via direct air capture technology using PV for energy supply. This unique technology speaks of more potential if we compare it with any fossil fuel power generation like a coal power plant because it will show a lower external cost as compare to the coal power plant.
Moreover, we can say that the external cost of producing Hydrogen and Methanol have not been significantly addressed and quantified the damages incurred through the Direct Air Capture. Thus, identifying externalities through the direct air capture (DAC) is the focus of this paper. However, we identified external cost rate as one of the mediums used in our research to calculate the impact of damage incurred on health (like the chronic mortality and morbidity), society and environment in monetary units.

The technology under consideration also seeks not to only provide energy access in arid zone but to also solve the problems of climate change as per the Paris agreement of reducing the increase of temperature to a minimum level of 1.5°C

6.1 3. The third is the technology:

We have reviewed the state-of-the-art of the DAC across the commercial and research sectors, seeking to provide clear research challenges in the science, engineering, economics, and socio-political domains. The development and deployment of DAC will continue to provide research challenges as the technology has not been significantly developed by many organizations. While we continued to improve the materials of DAC technology, it is important to particularly understand the integration with the energy system, their evolving costs, and their sustainability from a wider frame of reference, a focus on new materials and processes for DAC will provide new opportunities, and the development of DAC at the same time will raise challenges in the socio-political domain also.

To conclude, we discuss high-level of challenges that researchers could address soon to improve our understanding of DAC, unlock new levels of efficiency and sustainability, and increase societal acceptance. Massive adaptation and mitigation efforts will be needed in response to climate change. The modifications to social norms and behavioural patterns, structural and physical adaptability, will enhance a wide range of clean energy producing technologies, as well as GHG emission reduction technologies.
Understanding the complexity, interdependencies, speed, and scale will continue to be of the utmost significance as the need for interaction between these adaptation and mitigation factors. We can say that the DAC is still in its infancy level. Finally, our quantification of external cost was based on series of assumptions from the designed model of the technology which explains how externalities incurred in the model and monetized from the result provided. In spite of numerous limitations of the research, the valuation of external cost allows the integration of environmental impact and the externalities determination and consideration.

6.2. Recommendations to the research:

The recommendation of this master thesis is to take into account the external cost incurring from the production of hydrogen and methanol which is deeply rooted in market failures, this master thesis seeks to promote sustainable development of the technology and improve the quality of efficiency as it provides measures to mitigate all external cost incurred from the production. Materials used to develop the technology must critically be reviewed with respect to the following:

6.2.1. Distributional concerns:

External cost often has unequal distributional impact, affecting certain communities or specific groupings. E.g., the energy production facilities emitting pollutants that may be located near marginalized communities leading to disproportionate health and environmental burdens. Recognizing external costs helps highlight these distributional concerns and promote fair outcomes by ensuring that all costs are properly allocated and accounted for.

6.2.2. Recognize and prioritize health impacts:

It is better realizing the quality of individual health and the safety of communities.

6.2.3. Have a long- term economic consideration:

Ignoring external cost managers in production facilities can have long- term economic consequences. Environmental damage, resource depletion, and health impacts can impose substantial cost on future generations.

6.2.4. Promote friendly policies:

Encourage policies that promote energy efficiency. This mean that new technologies will be develop to increase energy access.

6.2.5. Increase public awareness and education:

Raising awareness about externalities will lead to an increase of more demand for sustainable technologies.

6.2.6. Research and innovation:

Investing in the research and development of clean technologies and sustainable practices can lead to the creation of more efficient and less pollution alternatives.

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