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DEPARTMENT OF ELECTRICAL AND INFORMATION ENGINEERING

Development of an Economic and Environmental Decision Making Model for Optimal Solar and Wind Energy Utilization

By

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A Thesis submitted in fulfillment for the Degree of Master of Science in Electrical and Electronic Engineering in the Department of Electrical and Information Engineering of the University of Nairobi

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Declaration of Originality

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Dedication

This work is dedicated to my family and friends.

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List of Abbreviations

CIR	-	Cost Index Ratio
CFC	-	Chlorofluorocarbon
DALY	-	Disability Adjusted Life Years
DMM	-	Decision Making Model
EDMMRE	-	Environmental Decision Making Model for Renewable Energy
EEDMM	-	Economic and Environmental Decision Making Model
EIA	-	Environmental Impact Assessment
ETAP®	-	Electrical Transient Analyzer Program
E_3MG	-	Energy-Environment-Economy Model at the Global
GHG	-	Green House Gases
GTAP	-	Global Trade Analysis Project
HEDMMOU	-	Health and Ecosystem Decision Making Model for Optimal Utilization
HOMER	-	Hybrid Optimization Model for Electric Renewable
HyRef	-	Hybrid Renewable Energy Forecasting
IAEA	-	International Atomic Energy Agency
ICOI-WS	-	Initial Cost of Investment for Wind and Solar
LCA	-	Life Cycle Assessment
LCC	-	Life Cycle Costing
MOLP	-	Mixed Objective Linear Programming
NEC	-	Net Economic Contributions
NRES	-	Non-Renewable Energy Sources
OEFCCSW	-	Optimization of Emissions with Fuel Cost Constraints using Solar and Wind
OSeMOSYS	-	Open Source Energy Modeling System
PAH	-	Polycyclic Aromatic Hydrocarbon
Pta	-	Spanish Petesha
PV	-	Photovoltaic
RE	-	Renewable Energy
RES	-	Renewable Energy Sources
RET	-	Renewable Energy Technology
SIIDMMOU	-	Social Impact on Investment Decision Making Model for Optimal Utilization
SIV	-	Social Impact Value
SPEA2	-	Improved Strength Pareto Evolutionary Algorithm
TOR	-	Terms of Reference
UNEP	-	United Nations Environment Programme
VOS	-	Value of Solar
WASP	-	Wien Automatic System Planning

Abstract

Since the emergence of renewable energy, Renewable Energy Technology (RET) has been considered harmless, clean and free. On the other hand, non-renewable energy sources are perceived as the only hostile technology to the environment without focusing on the detrimental effect of Renewable Energy Sources (RES). Many people have continued to use this ‘harmless’ technology without considering the long term environmental and economic impacts. It is, therefore, important to evaluate the environmental impacts of solar and wind technologies and decide on the net environmental and economic benefit before utilization. This will ensure optimal utilization while maintaining the quality and availability of natural resources for current and future generations. For a suitable decision from the model, there is need to interrelate social, health, ecosystem, emissions and resource cost effects of solar and wind technology to the environmental and economic impacts. This will improve the judgment on whether or not to deploy the technology depending on the net benefit to the community. In light of the above, in this thesis an Economic-Environmental Decision Making Model (EEDMM) for optimal utilization of solar and wind energy is developed. The model is developed using Modified ReCiPe 1.3 and PowerSizing models and simulated based on the Improved Strength Pareto Evolutionary Algorithm (SPEA2) on MATLAB environment. Improved Strength Pareto Evolutionary Algorithm is also utilized to solve the uncertainties of solar and wind energy sources. The simulated results from this thesis demonstrates the economic and environmental impacts of solar and wind technologies, and effectively makes the decision on the viability of deploying the technology as per the Environmental Impact Assessment (EIA) regulations provided by UNEP in the 2018 – 2021 medium term strategy. The simulated results show that solar PV causes reduction in Ozone depletion by 30.15% while wind reduces it by 81.86% as compared to conventional sources. These two energies are shown to reduce climate change to global warming potential, toxification to human being, photochemical oxidation formation, formation of particulate matter and radiation due to ionization with respect to the inputs; taking the fuel costs as the constraints. In conclusion, the developed Economic and Environmental Decision Making Model (EEDMM) is useful in providing prior advice to the users on whether or not the utilization of the solar and wind is achieved. The decisions are made from the EEDMM chart.

CHAPTER 1

INTRODUCTION

1.1 Background

Conservation of natural resources necessitates a better utilization in the current world. According to Oxford dictionary, utilization can be defined as an effective and practical action of using something. Environmentally friendly and economical energy implementation of Renewable Energy (RE) employment is decided properly by selection of type of energy, which suitably utilizes the air, water, land and energy resources. Before taking action, especially concerning wind and solar energies, a detailed study of the social impacts, ecosystem, health, emissions and resource costs, with fuel costs as the constraints, should be conducted.

Adoption of renewable energy sources has increased rapidly with the perception of alleviating poverty due to notion that the energy is free, clean and harmless. In fact, in rural areas, these sources are largely used for rural development expansion. According to [1], RE accounts for about 20% of global power consumption. Over 1.3 billion people in the world live in rural areas where accessibility of electricity is minimal. In Kenya, Rural Electrification and Renewable Energy Corporation (REREC) is mandated in implementation of rural electrification projects and green energy drives. This Corporation has since led to faster and rapid spread of RET in rural areas where electricity from the national grid is inadequate. In addition, there is emergence of solar off-grid industry where they offer customers plug and play solar systems for home lighting and phone charging. These are some of the basic power needs by the people living in rural areas. With this solar off-grid industry, clients can be provided with standalone solar panels which require less expertise and have low maintenance costs.

There has been also a continuing decline in the cost per watt of RE resources. Due to government of Kenya subsidies on imported RE resources, cost per watt of solar panels, for instance, has reduced significantly with respect to cost per watt from non-renewable energy sources. This has seen many people opting for these RE resources because the final cost remains cheaper and affordable. This has influenced the ability of a ‘common man’ to purchase and maintain this technology.

Largely, when the customers have acquired these RE resources, they do not pay any_more monthly tariffs, as opposed to the similar services from utility companies. This has made them perceive the technology to be free. They ignore the fact that possessing these resources requires maintenance cost, human resource among other quantifiable costs.

People using RET, further through ignorance, use these resources without considering both the negative and positive environmental impacts and the net economic contributions by it. It is in this regard that the awareness should be created.

1.2 Problem Statement

Many stakeholders have largely ignored the fact that wind and solar renewable energy sources have negative implications to the environment and economy. Instead, most of them have considered only few positive impacts during implementation process. This, from literature, has led to the loss of wildlife, deforestation and poor social life, health and ecosystem. It is in this view that before utilization, it is necessary to know both the positive and negative environmental and economic impacts of solar and wind energy sources for optimal utilization.

1.3 Objectives

Main Objective:

The main objective of this thesis is to develop an Economic and Environmental Decision Making Model for Optimal Utilization of Solar and Wind Energy by taking into consideration social, health, ecosystem, emissions and economic midpoint indicators for endpoint scores.

Specific Objectives: The following were the specific objectives:

i) To review Environmental effects (social, health, ecosystem) and Net Economic Contributions of Wind and Solar Renewable Energy Sources (RES) to the society.
ii) To formulate EEDMM for optimal solar and wind energy utilization.
iii) To simulate the results from EEDMM for economic and environmental impacts for optimal utilization.
iv) To analyze the results from the developed EEDMM for emissions, ecosystem, economic, health and social effects.

1.4 Justification of the Study

Due to the notion that wind and solar as renewable energies, are freely available and clean, there has been a rapid growth in the development and utilization of the two RE generation technologies as compared to non-renewable and other renewable energy technologies. This growth has significantly disregarded the positive and negative economic and environmental impacts during implementation and utilization of energy from the technologies. EEDMM is developed to aid in decision making based on the impacts. Apart from availing the resources for future generations, the model ensures that there is an optimal utilization of natural resources, once it is deployed.

1.5 Scope of Work

This thesis handles the net present value and net economic contribution of the technology to be utilized. It also takes into consideration resource costs and environmentally tackles the social effects, ecosystems, health and emissions from the technologies. More so, wind and solar are considered as the key renewable energy sources due to their widespread use, implementation and technological advancement. Simulation software used is MATLAB R2019b while Improved Strength Pareto Evolutionary Algorithm (SPEA2) is used for optimization of a 2.5MW solar and wind plants.

1.6 Thesis Organization

The rest of the Thesis chapters are organized as follows: Chapter 2 is the Literature Review and Research Gap Identification, Chapter 3 has the Problem Formulation; Chapter 4 contains the Materials and Methods, and Chapter 5 is the Results and Analysis while Chapter 6 is the Conclusion and Recommendations. Lastly, the References used are listed and finally Appendices of the MATLAB code blocks, Simulation results data, the IEEE Published Papers and signed Turnitin Similarity Index report are attached.

CHAPTER 2

LITERATURE REVIEW AND RESEARCH GAP IDENTIFICATION

This chapter comprises of literature review of related works and research gap identification.

2.1 Introduction

Onwards, section 2.2 introduces the literature review on the decision making model for solar and wind while positive and negative effects of wind and solar are examined in section 2.3. The review of available models and their existing gaps are represented in section 2.4. Further, section 2.5 introduces the reviews of Powersizing model as well as Modified ReciPe 1.3 in section 2.6. Finally, section 2.7 is the chapter conclusion.

2.2 Decision Making Model (DMM) for Solar and Wind

A few research works have reviewed DMM for solar and wind.

Musau, et al [2] proposed an Environmental Decision Making Tool for RE (EDMTRE) with the resources cost as constraints. The authors used the midpoint indicators of the Modified ReCiPe version 1.3 model to indicate the negative environmental impacts while the more accurate cubic cost function was used to model the positive impacts on health and ecosystem. In addition to health and ecosystem, the research also looked into reduction of emission. It was concluded that, with resource cost as a constraint, the determination of optimal environmental benefits is accurate. The findings indicate that the adverse effects of wind are four times less than those of solar. However, no research has been done on resource cost using the end-point indicator and no social aspect has been considered in the development of EDMMRE.

Sellami, et al [3] developed a thermo-economic cost model that was used to determine the environmental impact assessment on wind farms in Tunisia that use a biogas reactor that is energized using energy from wind and yeast with the capacity to generate 242.6MW and 123.27×10^6 kJ/day respectively. It was determined that from the wind farms, an area of $152{,}604m^2$ wind turbines was required to generate 2.6GWh electrical energy with the cost of wind energy being \$2939.4/GWh. The research found that every week an average of 216 birds were found dead in the area occupied by the wind farms. The research, however, could not look into other wind environmental impacts like life-cycle global warming, value of land, value of wildlife and the economic value of use of natural resources (wind).

Leicester, et al [4] used the Bayesian Network, to develop a socio-economic and environmental tool for modeling solar PV to reduce the deficits in the energy needs of England. The network predicted the energy generation levels per unit area estimating levels of Carbon (IV) Oxide reduction; based on the solar PV technology used. The project involved home based solar PV installations in England. Though the project met the needs of the energy sector by installing the PV cells on the rooftops, the installations failed to check the environmental impacts as the small-scale installations never helped determine if any birds would be killed and how many, the effect on the ecosystem, were the PV cells installed on a broad solar farm and also the scaling of the land needed to generate a given amount of solar energy. It also could not determine the number of employment opportunities that would, in the long term, be created were a solar farm been the option implemented.

Akella, et al [5] employed the Renewable Energy Technologies (RET) such as biomass; used municipal waste in India to generate electricity, solar PV, wind and small hydroelectric power generation. The authors determined socioeconomic and environmental impact of these energy sources through the determination on the levels of CO_2 emission from each of the sources for a given size of a renewable energy power plant. The study however fell short of determining the cost of land as a direct impact of setting up RE power plants and also the impact on the ecosystem by these RE power plants.

Guta [6] modeled, using the ordinary least squares method, the use and impact on the environment of charcoal and wood fuel in Ethiopia and as a consequence recommended the reduction in cost of other renewable energies so as to reduce the reliance on wood based biodegradable fuels. The consumption of these fuels led to deforestation of 14000 – 20000 hectare estimated forest cover loss per annum and this has greatly contributed to soil erosion. The conclusion was made by advocating the initialization of policy to control and subsidize other RES like biogas other than relying on the known traditional biomass. However, the study did not look into the economic effects such as fuel cost as well as the effects on the ecosystem and environmental pollution.

Bergmann, et al [7] studied the effect of the choice policy in Scotland on the use of a preferable source of energy by people against anticipated socioeconomic and environmental effects of RETs. As a consequence, an extra £53.71 is paid by the community per hour to curb effects on the ecosystem such as wildlife deaths and the loss of land's aesthetic value as a result of the use of a wind turbine. However, the issue of resource costs of renewable energy technologies in Scotland was not addressed as it was not within the scope of the study.

Álvarez-Farizo, et al [8] used the conjoint analysis and the choice experiment technique. The study discussed the environmental impact of wind energy power plants in Spain using a questionnaire to outline the projected impact of use of wind energy-based power in the area of study. The impact included alteration of the land use, visual features including blocking the use of air above the windmills and the loss of birds and their migration corridor among the displacement of other wildlife in the area under wind turbines. The use of choice technique and conjoint analysis technique resulted in the payment of an extra 6920Pta (Spanish Petesha) and 3978Pta annually showing the choice technique was costlier. However, the study dealt only with social impacts of wind farm development but other positive and negative environmental impacts such as pollution and elaborate studies of ecosystems were not taken into consideration. Besides, studies did not discuss the resource cost of wind farm development.

Hernandez, et al [9] used the Carnegie Energy and Environmental Compatibility (CEEC) model which is a decision support tool. This was used to evaluate the land cover potential and use to set up a utility scale solar PV installation of 160 solar panels. The environmental impact based on the effect to birds and the bird's migration corridor in the area in which the solar PV was installed was also evaluated. The study showed that 57% of solar PV installations were located in scrublands and shrub lands, 28% in croplands and pastures and 15% in compactible areas. However, the study did not focus on economic impact of solar PV installations.

The summary of the review on the DMM are shown in Table 2.1.

Table 2.1: Summary of the Review on the DMM and the Existing Gaps.

Reference			**What has been done on:**	**Existing Gaps Addressed**
[2]	**Economic Effects**	**Solar**	• Emissions with resource cost as the constraint	• Used the PowerSizing model to formulate resource cost of solar PV objective function
		Wind	• Emissions with resource cost as the constraint	• Used the PowerSizing model to formulate resource cost of wind objective function
	Environmental Impacts	**Solar**	• Reduction of Emissions and effects of Solar on ecosystem and health	• Looked into social effects due to solar PV projects
		Wind	• Reduction of Emissions and effects of Solar on ecosystem and health	• Looked into social effects due to wind energy projects
[3]	**Economic Effects**	**Solar**	• Determined the amount of electrical energy generated from solar	• Cost of setting up solar PV installations • Cost of solar generated electrical energy • Impact on the overall energy costs of solar energy PV generation.
		Wind	• Developed a model for the cost to generate wind power • Determined the amount of electrical energy generated from wind	• Impact of wind power generation on overall energy cost
	Environmental Impacts	**Solar**	• None	The effect on the ecosystem particularly land needed, wildlife affected through forced relocation and number of birds killed
		Wind	• Determined the amount of land required. • Showed the number of birds killed	Effect on rain by the use of wind turbines
[4]	**Economic Effects**	**Solar**	• Determined the cost of setting up solar PV cells	• The overall impact on the energy cost due to solar power generation
		Wind	• Not addressed	• The cost of utilizing wind energy • The impact on the overall energy

Reference			**What has been done on:**	**Existing Gaps Addressed**
				cost by wind power generation
	Environmental Impacts	**Solar**	• Levels of CO_2 reduction	• The environmental impact such as effect on global warming and effect on wildlife and human activity.
		Wind	• Not addressed	• The effect on the ecosystem such global warming.
[5]	**Economic Effects**	**Solar**	• Cost of solar power	• Effect solar on land
		Wind	• Cost of wind power	• Effect of wind on land
	Environmental Impacts	**Solar**	• Reduction of CO_2 levels and by extension global warming.	• Impact on ecosystem such as human activity
		Wind	• Reduction of CO_2 levels and by extension global warming.	• Impact on ecosystem such as human activity, birds and other wildlife
[6]	**Economic Effects**	**Solar**	• Not addressed	• Resource cost for solar PV energy and its overall economic effect to the community
		Wind	• Not addressed	• Resource cost for wind energy and its overall economic effect to the community
	Environmental Impacts	**Solar**	• Not addressed	• Social effects caused to the people, animals and forests by the installation of solar energy
		Wind	• Not addressed	• Social effects caused to the people, animals and forests by the installation of wind energy
[7]	**Economic Effects**	**Solar**	• Not addressed	• Anticipated cost of solar PV installations and effect on the overall energy cost
		Wind	• The cost to curb negative impact on ecosystem as a result of using wind turbine	• The impact on overall cost on energy as a result of use of wind energy
	Environmental Impacts	**Solar**	• Not addressed	• The effect on ecosystem and social life
		Wind	• The effect on wildlife such as deaths and displacement • The loss of land's aesthetic value	• The effect on ecosystem and social life

Reference			What has been done on:	Existing Gaps Addressed
[8]	**Economic Effects**	**Solar**	- Not addressed	- The solar energy resource cost and fuel cost constraint
		Wind	- Not addressed	- The cost of setting up wind power plants - The impact of wind power on overall energy cost
	Environmental Impacts	**Solar**	- Not addressed	- Impacts of solar PV on social life of organisms in the ecosystem
		Wind	- The loss of life by birds - Displacement of wildlife and effect on their migration corridor - Alteration of land use	- Impacts of wind energy on social life of organisms in the ecosystem
[9]	**Economic Effects**	**Solar**	- Not addressed	- Cost of setting up solar PV - The overall impact on the energy cost due to solar power generation
		Wind	- Not addressed	- The cost of setting up wind power plants - The impact of wind power on overall energy cost
	Environmental Impacts	**Solar**	- The impact on the bird's migration route - The effect on bird's life - The lands under which solar PV was installed	- Impacts of solar PV on social life of the living organisms in the ecosystem
		Wind	- Not addressed	- Impacts of wind energy on social life of the living organisms in the ecosystem

Gaps Identified			
In this Thesis	**Economic Effects**	**Solar**	- Consideration of the resource cost of solar PV project and its aid in decision making before optimal utilization of the system. - Evaluation of NPV and NEC
		Wind	- Consideration of the resource cost of wind project and its aid in decision making before optimal utilization of the project - Evaluation of NPV and NEC
	Environmental Impacts	**Solar**	- Analysis of the impact of the solar PV plant on social, health, emissions and ecosystem; then aid in making optimized decision on the utilization of the project.
		Wind	- Analysis of the impact of the Wind plant on social, health, emissions and ecosystem; then aid in making optimized decision on the utilization of the project.

2.3 Positive and Negative Environmental Effects of Wind and Solar

RES refers to sources of energy that are not exhaustible from the earth as there is a mechanism for replenishing them such as wind energy, solar energy, biomass energy, hydro-energy and geothermal energy. This is unlike non-renewable energy sources that are depleted from the environment with time as the rates of replenishing their supplies are very low or nonexistent such as coal and petroleum fuels.

RES have been credited with reducing global warming, and the level of greenhouse gases being emitted as their use does not emit the greenhouse gases. They have also helped reduce negative environmental effects such as acid rain formation, release of carcinogenic materials when fuels such as leaded petroleum products are used, ozone layer depletion and destruction of ecosystems as they have a minimal impact on the environment [10 –15].

2.3.1 Wind Energy

2.3.1.1 Wind Energy on Health

On the positive side, wind does not produce greenhouse gases such as carbon (IV) oxide thus its use as an alternative energy source reduces the amount of greenhouse gases in circulation and thus reduce global warming [10, 12, 16, 17]. Further, wind energy produces mechanical noise from the motor and gearbox and also produces aerodynamic noise from wind passing over the wind turbine both of which are of the low frequency noise and infrasound range where numerous extensive studies and research has shown no negative impact on the health of human beings or animals [11, 12, 16, 18]. Wind turbines help set up air currents in their environs when in rotation thus improving the environmental conditions by making a place cooler and thus more habitable [10, 11, 16]. In addition, wind energy is used as a replacement of thermal energy sources reduces the emission of compounds such as Sulphur dioxide that are carcinogenic making the environment safer [11, 17].

However, wind turbines rotation produces shadow flickers which if they are of flash frequencies above 3Hz would have a potential to provoke photosensitive seizures [17]. Noise from wind turbines creates negative impacts on human health [11, 17, 19]. Moreover, wind causes a reduction of bird population due to collision with turbine blades [20].

2.3.1.2 Wind Energy to the Ecosystem

Use of wind energy as an alternative energy source results in the reduction of greenhouse gas emissions such as carbon (IV) oxide and CFCs, thus, helping curb global warming. A 500kW wind turbine realizes the CO_2 cleaning effect equal to that of about 57,000 trees thus is even more effective in curbing global warming and GHG emission as it itself occupies a smaller area but with greater impact [12]. As a result of the reduced global warming, there is reduced ecosystem destruction such as destruction of snow on mountain tops, icebergs at sea and rising sea levels that would lead to the submerging of lands near oceans and seas [16, 20]. On the same note, land used for wind power generation can still be used for agricultural purposes such as livestock grazing and crop cultivation [19].

On the other hand**, b**ird populations are killed or injured when they fly into the rotating wind turbines which alter the population of birds [17]. It is also good to note that wind turbine causes a lot of noise. Though the noise from wind turbines has a little effect on health, it is a source of annoyance [19]. When the setting up of a wind farm is done a lot of trees are destroyed thus leads to altering of the ecosystem. This even leads to soil erosion [12, 20].

2.3.1.3 Wind Energy to Social Life

Wind farms are normally set up in areas outside densely populated zones such on hilltops and other raised grounds thus do not disrupt the social order or displace the population [10, 17]. With no disruption of social order, the wind farms also provide a lot of employment opportunities during the stage of setting them up as well as when it is running and during maintenance [16, 18]. Some of the wind farms become tourist attraction zones and thus open up the areas to greater investment and also integrate the local community and tourists [16, 18].

However, setting up the wind farms leads at times to destruction of recreational sites as they are normally on hilltops used for hiking. They are also archaeological sites thus it leads to destruction of historical artifacts and historical areas [17]. People living on hilly areas are displaced and migrated leading to congestion and social disputes [16].

2.3.1.4 Wind Energy to the Economy

Use of wind energy enhances industrialization and research as industries are set up to produce wind turbines and others to research on how to produce more effective wind turbines [10, 17]. The industrialization and setting up of wind farms lead to more employment opportunities thus positively impacting the economy [17, 18]. More so, it is cheaper to produce electrical energy from wind than from other sources such as thermal thus overally reduces the cost of electricity and the cost of production in industries [10, 16].

However, as governments offer tax breaks to wind energy investors and its reduces reliance on traditional energy sources, it leads to a reduction of government revenue from taxes thus leading to increase in other taxes to enhance government revenue collection and an increase in the cost of living in the short term [16]. As pointed out before, wind takes up significant portion of land which might have otherwise been used for farming [17].

2.3.2 Solar Energy

2.3.2.1 Solar Energy on Health

Solar energy use as an alternative energy source helps reduce the emission of greenhouse gases that lead to global warming with the effect of reduction in ozone layer depletion. The ozone layer helps trap UV rays that could cause cancers thus its preservation is a boost on the health of a population [10, 20]. Based on the resources, solar PV panels do not make noise and they are pollution free when in operation. These enable the system to be friendly to living organisms hence cause no health implications [20]. Solar systems do not require water resources hence reducing the strain on local water resources and the water available can be used for human healthy survival [16]. Finally, with use of solar there is proper land utilization and reduced risks on the plant and organism health [16, 17].

On the other hand, solar panels are made of many toxic materials which are sprayed on the solar cells and can be easily inhaled and whose inhalation results in one inhaling carcinogenic materials. They have adverse effects on health [16, 17]. Similarly, the high temperatures in the zones around solar farms can result in human beings suffering sunburns [17, 20].

2.3.2.2 Solar Energy on Ecosystems

With reduced emission of greenhouse gases and thus reduced global warming, the snow on mountain tops and icebergs at sea are being preserved preventing rising sea levels that would otherwise submerge sea towns. Also, global warming would lead to death of animals and plants but its reduction otherwise helps preserve them. Solar energy is, thus, environmental friendly as there is no pollution due to its use such as production of carcinogenic substances or particles that would lead to respiratory diseases [16 – 18].

Regarding the negative implications, the toxic substances used in the production of solar cells pose a challenge to their disposal and if not well-disposed lead to environmental pollution as they are non-biodegradable. To curb this however, solar cells manufacturers are encouraged to recycle these substances to curb environmental pollution [16 – 18]. In addition, solar farms result in very high temperatures as they concentrate the heat above them in one area and lead to birds burning to death as they pass over them thus leading to the altering of the bird's population and ecosystem [16 – 18]. The solar farms require large tracts of land for installation leading to displacement of both human and wildlife populations and in the process altering the environment ecosystem. Wildlife especially birds, may also leave the region as a survival tactic as more are killed [16 – 18]. When concentrated solar power systems (thermal solar systems) are used as the source of solar energy, they require large amounts of water for cooling or as the working fluid to produce steam to drive turbines or for washing the reflective surfaces and since they use a large amount of water, this affects the water quality in the environment as it mixes with toxic substances in the solar cells. This is water pollution [16 – 18].

2.3.2.3 Solar Energy on Social Life

The installation of solar farms results in creation of employment for many people both in solar cells industries as well as at the solar farms themselves. This improves their quality of life and spurs economic growth [16 – 18].

However, there is displacement of people to pave way for solar farms thus disrupting social order [16 – 18].

2.3.2.4 Solar Energy to the Economy

Solar energy is a cheaper alternative source of energy thus makes the cost of electrical energy cheaper and lowering the cost of production in industries spurring economic growth [16, 17, 21]. Many times solar energy is used to power micro-grids in previously unconnected regions and thus improves the economic conditions in such regions [16, 17, 21].

Since large tracts of land are required to set up solar farms, this leads to an increase in the cost of land for such purposes [16, 17].

In summary, considering both the merits and demerits of solar and wind economic and environmental impacts, it can be concluded that these renewable energy sources are not free, clean and harmless fuels. A decision making model is, therefore, worth putting in place for maintenance of these natural resources and making sure they are well utilized and available at any particular time without causing harm and burden to the consumers and wildlife in the long run.

2.4 Available Models and their Weaknesses

This section reviews some of the available decision making models and their gaps. These models include:

i) Hybrid Optimization Model for Electric Renewable (HOMER)
ii) Electrical Transient Analyzer Program (ETAP®)
iii) PLEXOS software
iv) Energy-Environment-Economy Model at the Global (E3MG)
v) The Integrated MARKAL – EFOM System – Gauteng Energy and Emissions Cost Optimization (TIMES-GEECO)
vi) Global Trade Analysis Project (GTAP)
vii) Life Cycle Costing (LCC)
viii) Wien Automatic System Planning (WASP)
ix) Open Source Energy Modeling System (OSeMOSYS)
x) Hybrid Renewable Energy Forecasting (HyRef)
xi) Mixed Objective LP (MOLP)

2.4.1 HOMER Energy

HOMER is software that is used for the designing, modeling and analysis of renewable energy systems. It was developed by the US Renewable Energy Laboratory with an aim to come up with more efficient renewable energy microgrid and has over time evolved to be a tool to design smart, more environmental friendly energy microgrid.

The HOMER software utilizes inputs as load demand and the available energy resources as well as the components of the power system in its calculations to design an optimal system. It reviews all available energy sources in all possible combinations. The design and analysis process is at times tasking due to uncertainties such as cost of fuel and power as well as future load size. To determine the system size, an optimization system statement is formulated that minimizes the total construction and operation costs with the maximum possible allowed risks determined. To do this, parameters such as wind speed, solar irradiation and load profile are determined.

System optimization is done after considering several combinations of hybrid renewable energy solutions based on the total net present cost (TNPC). The optimal system is then the one with the lowest TNPC [22].

2.4.2 ETAP®

ETAP® is energy management software that is used to monitor, control and optimize the performance of power generation and transmission systems through a suite of programs. It does real time evaluation of data available to enhance the reliability, security and performance of an electrical system. It also has a module that is used to check out environmental controls that is levels of environmental emissions.

Through collected data, ETAP® is able to do load forecasting as well thus help in planning a power generation schedule to enhance efficiency and reduce wastage thus making power generation economical. With its automated features, ETAP® is able to determine which loads should be shed in case power generated does not meet power demand with minimal disruptions.

ETAP® is thus software that does load and energy forecasts and automates a power system making it robust and efficient [23].

2.4.3 PLEXOS Software

PLEXOS is a modeling and optimization software tool that is used to design, analyze, simulate and automate the power generation, transmission and distribution processes while being able to deal with emerging uncertainties. Using PLEXOS, one can be able to optimize the use of renewable energy solutions in power generation, map out future capacity expansion and dispatch planning and calculate the costs of generation. The inputs for PLEXOS are the power generation resources, anticipated load and the transmission and distribution line parameters. A newer version of PLEXOS incorporates Gas Modeling Module that enables it model the cost of delivering gas from its source in the exploration fields to the end user through its storage and pipeline facilities enabling gas producers and marketers model the production and distribution costs and constraints. The whole cycle of using PLEXOS as a modeling tool involves the production cost, midterm optimization, reliability evaluation and capacity for expansion and future planning which thus enables power production and expansion over the long term to be mapped out. It is also able to, in the process; model the reliability of the energy sources.

PLEXOS in its modeling of energy production considers the economic and environmental effects by considering renewable energy against other forms of energy sources. It, however, does not consider the health and social effects [24].

2.4.4 E3MG

This is a hybrid model that employs a large scale non-linear macroeconomic simulation model to assess the cost implications of utilizing renewable energy resources in curbing the levels of CO_2 emissions in the environment in the long term around the globe. That is also how it derives its name. It combines a top down macroeconomic approach and a top down technological approach in obtaining its optimal solutions. It utilizes many different energy sources to determine the effects on evolution of technology with regards to energy costs providing information on barriers of implementation for low carbon technologies since it’s a model whose emphasis is on reducing levels of CO_2 emissions using a combination of different energy technologies but taking their costs into account. It is not exclusively a simulation or optimization model but incorporates both.

The factors considered are load demand, energy outputs, wages, employment, industrial and housing sector growth as these have a direct impact on the energy demand growth. Economic growth is factored as well.

The E_3MG model embodies the belief that by studying the past, one can use the behavioral trends to predict future trends. However, this has limitations because at times there are economic and industrial changes that are previously unforeseen that render forecasted results unrealistic and unusable [25].

2.4.5 TIMES-GEECO

This model was used to carry out a scenario analysis, which is a tool used to analyze the impact of long term high investment decisions on different energy scenarios, to identify measures that could be undertaken to reduce greenhouse gas emissions through the use of renewable energy. The model is particular to the Gauteng Province of South Africa. Different incomes group and the different household and transport technologies used are considered to determine the level of emissions to best capture attendant policy decisions needed. Biofuel sources such as sugarcanes and soya beans are considered as they are a source of energy that can be stored for future use. On the side of energy consumption, all sectors are considered from residential buildings to industries to the transport sector and even these sectors further broken down.

From this analysis, only attendant policies to reduce CO_2 emissions are implemented such as solar water heating and use of biofuels [26].

2.4.6 GTAP

Global Trade Analysis Project is modified to take account energy parameters and carbon (IV) oxide emissions and emissions trading. It calculates the amount of carbon emissions based on the fuel usage. It therefore has 3 modules namely E module for energy calculations, C module for carbon emissions and T module for trading emissions.

Therefore, from the above description GTAP considers social, environmental and economic impact but does not regard the health impact directly [27].

2.4.7 LCC

LCC is a method of economic analysis on the cost of construction, operation and maintenance of a project to determine its viability. This may be a building construction or an energy project. With regards to an energy project, LCC will examine the viability of the project, its effectiveness on energy consumption efficiency and reduction in CO_2 emissions. This is because among the greatest threat to human existence is global warming spurred in part by the soaring greenhouse gas emissions such as CO_2. LCC can also be extended to energy projects to estimate the combinations that will yield less CO_2 emissions while providing energy that is cost effective and has a longer life span [28,29].

There are many parameters of analysis [30] used to consider the LCC model such as Payback, Overall Rate of Return and Net Benefits and Net savings among other parameters.

2.4.8 WASP

Wien Automatic System Planning (WASP) is a computer program developed by the IAEA (International Atomic Energy Agency). Initially its purpose was to determine the viability of nuclear power generation against other methods of power generation. Over the years more enhanced versions have been produced with the linear programming technique being employed to find the optimal generation capacity of various methods of power generation taking into accounts constraints such as fuel availability, electricity generation by a combination of plants, environmental emission calculations for each plant based on the fuel it uses, maintenance schedule and energy storage technologies [31].

It is thus an optimization tool that is used for energy generation planning but at the same time placing environmental emissions such as CO_2 in its centrality in line with a resolve by countries to reduce CO_2 emissions. This model thus addresses environmental and economic impact but does not really address social and health impacts directly.

2.4.9 OSeMOSYS

The Open Source Energy Modeling System is free software that has been developed to aid in planning the energy mix (energy generation and distribution). It uses linear programming and accepts various input constraints such as energy demand (load), different power generation technologies, storage technologies, environmental emission calculations and cost of power generation as well as period of load demand. This model thus can be used for energy planning while at the same time being used to model combinations that will reduce the amount of environmental emissions. This model addresses the social, environmental and economic impact but does not directly address the health impact when the model is used for energy planning [32].

2.4.10 HyRef

Hybrid Renewable Energy Forecasting is a computer modeling tool that uses the high computing power of supercomputers to develop a forecast of renewable energies for up to one month and down to 15 minute intervals thus enabling energy planning for solar power and wind energy and thus maximizing on power generation. It is developed by IBM. HyRef enables the process of energy forecasting and planning so that the cost of power comes down since expected power generation from renewable energy sources is known and thus with proper planning power from other sources will be generated on a per need basis therefore eliminating wastage. It utilizes advanced computer modeling power, cloud imaging, sky facing cameras and onsite cameras [33].

2.4.11 MOLP

With MOLP, each of the constraints in energy planning is considered an independent objective with upper and lower bounds and to determine an optimal solution, a weighted sum of the independent objectives is obtained. This way, the solution considers the allowable environmental emissions and the desired power generation and storage capacity and the available renewable energy resources. This is, unlike cases in which all the different constraints are taken as one single objective, making it difficult to individually optimize each aspect of the power generation cycle [30].

The summary of the reviewed tools and the existing gaps are shown in Table 2.2.

Table 2.2: Summary of the Reviewed Tools and the Exisiting Gaps

Reference	Tool	Content	Existing Gaps
[22]	Hybrid Optimization Model for Electrical Renewable (HOMER) Energy	• Designing, modeling and analysis of renewable energy systems by considering wind speed, solar irradiation and load profile. • Optimization of renewable energy system based on the lowest TNPC	• Only considers CO_2 emissions in its analysis of RE systems • Does not consider social impacts directly • Does not consider health impacts directly
[23]	Electric Transient analyzer Program (ETAP®)	• Monitoring, controlling and optimization of the performance of power generation and transmission using a suite of programs. • Evaluation of real time data for reliability, security and performance of an electrical system. • Checking and controlling of the environmental emission levels for electrical systems. • Forecasting of load and planning of power generation schedule.	• The model does not address the social impacts of RE directly. • ETAP® ® does not make decisions on health impacts due to RE systems.
[24]	PLEXOS	• Designing, simulating, analysis and automation of power generation, transmission and distribution processes. • Capacity expansion and dispatch planning of power generation. • Calculation of costs of generation.	• This tool does not directly address the social impacts caused by the renewable energy systems • It does not optimize health effects from RES • PLEXOS does not tackle emission levels due to RE systems
[25]	Energy-Environment Model at the Global (E_3MG)	• Assessing the cost implications of utilizing renewable energy resources in curbing the levels of CO_2 emissions • Determining the effects of evolution of technology with regard to energy costs.	• Only deals with CO_2 emissions. • Does not directly address social effects brought about by RET. • Does not clearly address health effects on the ecosystem due to RES.
[26]	TIMES-GEECO	• Analyzing the impact of long term investment decisions on different energy scenarios.	• Cannot make decisions directly on the social impacts as a result of RET
[27]	Global Trade Analysis Project (GTAP)	• Calculating the amount of energy and carbon emissions based on fuel usage.	• No health impact is optimized by the tool
[28] [29]	Life Cycle Costing (LCC)	• Economic analysis on the cost of construction, operation and maintenance of energy project to determine its viability.	• Only considers economic impacts of a project. No social and health impacts are tackled directly. • Considers only CO_2 emissions

Reference	Tool	Content	Existing Gaps
		• Looking for effectiveness of energy consumption efficiency and reduction of CO_2 emissions.	which are not the only emissions in the ecosystem.
[31]	Wien Automatic System Planning (WASP)	• Finding the optimal generation capacity of various methods of power being employed to find the optimal generation capacity accounting for fuel availability constraint. • Optimization tool for energy generation planning. • Time placing environmental emissions like CO2 in its centrality for the reduction.	• The tool does not directly address the social and health impacts caused by the solar and wind energies.
[32]	Open Source Energy Modeling System (OSeMOSYS)	• Planning of the energy mix (energy generation and distribution). • Modeling combinations that reduce amount of environmental emissions.	• The tool does not directly address health impacts when used for the energy planning.
[33]	Hybrid Renewable Energy Forecasting (HyRef)	• Forecasting and planning for solar power and wind energy. • Maximizing on power generation and minimizing on cost of power.	• This model does not address the health and social effects caused by solar and wind sources of energy.
[30]	Mixed Objective Linear Programming (MOLP)	• Determining of an optimal solution and obtaining of a weighted sum of the independent objectives of energy planning constraints.	• Does not address social and health effects due to solar and wind energies.

In this Thesis	**EEDMM**	• Considered the resource cost of solar PV project and aid in decision making before optimal utilization of the project • Considered the resource cost of wind project and aid in decision making before optimal utilization of the project • Analyzed the effects of the solar PV plant on social impacts, health, emissions and ecosystem then aid in making optimized decisions on the optimal utilization of the project. • Analyzed the effects of the Wind plant on social impacts, health, emissions and ecosystem then aid in making optimized decision on the optimal utilization of the project.

Since there are existing gaps from the reviewed tools, besides the negative and positive impacts of wind and solar, there is need to develop a mathematical model to aid in decision making for optimal utilization of these RETs. In order to formulate these models, a review of PowerSizing model and ReCiPe 1.3 model is required. These models are used later in formulation and simulation of the problem.

2.5 PowerSizing Model

Renewable energy economic analysis refers to the analysis of the cost of power generation using renewable energy and the economic benefits that it gives to its users relative to other sources of energy. Depending on the size of the intended renewable energy project, provided the energy resources are sufficient, the estimates may be detailed or semi-detailed but the economic benefits, as analyzed, should be more than the cost of setting up the project in totality else the project would be rendered economically unviable.

Using the PowerSizing model, the cost of setting up a power plant can be determined by determining the cost of equipment and the scale of the size of the desired power plant non-linearly using the PowerSizing exponent, x, since the size of power plant to generate twice the amount of electrical power must not necessarily be twice the size of the other power plant. The PowerSizing model formula is [34, 35]:

$$\frac{Cost\ of\ Equipment\ A}{Cost\ of\ EquipmentB} = \left(\frac{Size\ of\ Equipment\ A}{Size\ of\ Equipment\ B}\right)^{X} \tag{2.1}$$

where $0 < X < 1$ is the PowerSizing exponent provided by equipment manufacturer while A is the equipment in the new power plant whose cost is being estimated and B is the equipment in the old power plant used as a point of reference. The units for the size of equipment should be the same. If the cost of an equipment known was about n years ago, the current cost can be determined as follows using the cost index:

$$\frac{equipment\ cost\ today}{equipment\ cost\ n\ years\ ago} = \frac{cost\ index\ value\ today}{cost\ index\ value\ n\ years\ ago} \tag{2.2}$$

Thus using the two formulas, the cost of the new equipment A is determined as:

$$cost\ of\ equipment\ A = \left(\frac{cost\ index\ value\ today}{cost\ index\ value\ n\ years\ ago}\right) . \left(\frac{Size\ of\ Equipment\ A}{Size\ of\ Equipment\ B}\right)^{X} . (Cost\ of\ Equipment\ B) \tag{2.3}$$

2.6 Modified ReCiPe 1.3

ReCiPe is one of the available Life Cycle Assessment models. A Life Cycle Assessment (LCA) refers to the factual assessing of the life span of equipment through its useful years in terms of sustainability. It looks at the inputs and outputs of the equipment as well as the effect of social and economic decisions to the life of infrastructure. The aspects considered are production, distribution, operation and the disposal at the end of useful life. Phases of LCA [13 – 15, 36] are:

i) Goal and Scope – defines reasons for executing LCA, determines the scope and then defines the product and operation boundaries.
ii) Inventory Analysis – defines the environmental inputs and outputs such as energy and raw materials emitted as well as the waste streams.
iii) Impact Assessment – Here the environmental impact is determined.
iv) Interpretation – The conclusions are well substantiated and shared with decision makers for the final decision to be made.

ReCiPe was first used by Goedkoop et al in 2008 and later modified in 2016 [13]. ReCiPe is a lifecycle assessment model that uses indicators (harmonized category) at the mid and endpoint levels by giving a ReCiPe for scheming life cycle category effective indicators. ReCiPe is not just applicable to electrical equipment but also to buildings, vehicles, dams, roads, bridges and railway lines among others. It has been adopted and modified across the globe after first being used across the European Union through use of various category indicators at the midpoint such as climate change, ionizing radiation and fossil fuel depletion among other that total up to 18 factors and indicators at the endpoint that consist of damage to the health of human, damage to economic diversity and destruction to the available resources [13, 34]. ReCiPe’s goal is the use of midpoint and endpoint indicators to form a single harmonized framework that can be used to do a Lifecycle Impact Assessment (LIA) study. ReCiPe thus looks at the social and economic impacts of the use of equipment as well as socioeconomic and political happenings to the life of infrastructure. In this thesis, the three areas of protection are maintained but optimal emissions and social impacts have been added to make a total of five endpoint indicators.

Midpoint level characterization

At this level characterization is done using the formula in (2.4) [14], as:

$$I_m = \sum_j Q_{m,j} m_j \quad (2.4)$$

Where I_m *is* the indicator outcome for category m midpoint impact, $Q_{m,j}$ the factor of characterization which links intervention j with category m midpoint impact and m_j is the magnitude of intervention.

Endpoint level characterization

At this level, there are 2 ways in obtaining characterization. The first one involves intervention devoid of intermediate points [15] and is calculated as:

$$I_e = \sum_j Q_{e,j} m_j \quad (2.5)$$

Where I_e *is* the indicator outcome for category e endpoint impact, $Q_{e,j}$ is the factor of characterization which links intervention j with category e midpoint impact and m_j the magnitude of interventionQ_{ei}.

The 2nd way starts from the intermediate midpoints [15]. The formula is

$$I_e = \sum_{im} Q_{eim} m_{im} \quad (2.6)$$

Where m_{im} *is* the indicator outcome for category im midpoint impact, Q_{eim} is the factor of characterization which links category im midpoint impact with category e endpoint impact and I_e is the indicator outcome for category e endpoint impact.

The inputs for this ReCiPe model are raw materials used, land used, and waste materials such as VOS (Value of Solar), CFCs, PAH (Polycyclic Aromatic Hydrocarbon), cadmium(Cd) , phenyl (P) and emissions from combustion of fuel such as CO_2, NO_2 and SO_2 [15].

There are twenty-four categories of midpoint impacts and five categories of endpoint impacts in this thesis. At the endpoint level, the categories of midpoint impacts are transformed and aggregated into these five categories of endpoints [13, 15]:

i) Damage to ecosystem diversity (ED) – this revolves around change in climatic conditions such as global warming, terrestrial Eco-toxicity destroying life on the earth through factors such as terrestrial acidification that destroys organisms in the soil altering the composition of soil, the toxification and acidification of marine environment and freshwaters and the urbanization of rural lands altering the agricultural production.

ii) Damage to human health (HH) – this is brought about by altering the aspects of the environment that have shielded human life from catastrophes through ozone layer depletion, radiation of UV rays, particle formulation, global warming and photochemical oxidant formation all which negatively affect human being's health.

iii) Damage to resource availability (RA) – the resources that human beings have depended on for their everyday activities are on their way to depletion or have been affected by climate change. The resources under threat are water, fossil fuels and minerals key to human survival and industrialization.

iv) Social Impacts (SI) – this models the impact on the socioeconomic aspects of a project on the society namely job opportunities created or destroyed, population displacement and infrastructural development in schools and hospitals as well as religious institutions that emanate from development of renewable energy projects.

v) Optimal Emissions (OE) – this model the emission of acidic gases namely CO_2, NO_2 and SO_2 and the depletion of the ozone layer leading to global warming. The acidic gases also lead to terrestrial acidification when acid rain falls.

The units of midpoints include compounds like CO_2 for climate change. This can make it difficult to a policy maker or an analyst to synthesize on the overall impact. In contrast, conceptualizing of the endpoints are much easier since they are expressed in form of tangible impacts using Disability Adjusted Life Years (DALY), number of affected species, dollar amounts or a point system, to which easier relationships are made [13, 15].

The endpoints indicators quality units are:

i) DALY for the damage on human health (HH) representing the lost years due to death or disability inflicted by an accident or disease.

ii) Those for damage to Ecosystem Diversity (ED) are species years relating the lost species found locally lost then integrated with time.

iii) Dollar is the unit for resource scarcity relating the extra costs utilized in the extraction of fossil fuels and minerals in future when the plants become operational.

CHAPTER 3

PROBLEM FORMULATION

3.1 Initial Cost of Investment for Wind and Solar (ICOI-WS)

This formulation considers variable cost (labor, direct materials) and fixed cost (capital equipment cost), which is given by equation (3.1), modified from equation (2.3).

$$(\mathrm{ICOI} - \mathrm{WS}_{\mathrm{new}}) = \frac{\mathrm{CI}_{\mathrm{t}}}{\mathrm{CI}_{\mathrm{n}}} \left(\frac{\mathrm{AR}_{\mathrm{new}}}{\mathrm{AR}_{\mathrm{exist}}}\right)^{\mathrm{x}} (\mathrm{ICOI} - \mathrm{WS}_{\mathrm{exist}}) \tag{3.1}$$

where, $(\mathrm{ICOI} - \mathrm{WS}_{\mathrm{new}})$ is the optimized new resource cost ($) for wind and/or solar PV, CI_{t} is cost index value today, CI_{n} is the cost index value n years ago, $\mathrm{AR}_{\mathrm{new}}$ is the amount of new resources (kWp), $\mathrm{AR}_{\mathrm{exist}}$ is the amount of existing resources (kWp), $\mathrm{x} = [0\ 1]$ is the PowerSizing exponent provided by resource manufacturer and $(\mathrm{ICOI} - \mathrm{WS}_{\mathrm{exist}})$ is the estimated existing resource cost.

3.2 Social Impact on Investment Decision Making Model (SIIDMM) for Optimal Utilization

SIIDMM is a model that identifies the effectiveness of capital and other resources utilization of a project towards creating value for the community in terms of environmental, social and economic impacts. In measuring SIIDMM, the following elements were considered; cost of resources invested, project outputs, that is, final products including trained human resource within the community, outcomes in terms of improved standards of living or new jobs created within the community and net impact to the community resulting from the project.

The SIIDMM is formulated as:

$$SIIDMM = \frac{SIV - ICOI}{ICOI}\ X\ 100\% \tag{3.2}$$

where; $SIIDMM$ is the social impact on investment (%), $ICOI$ is the initial cost of investment ($) and SIV is the social impact value given by equation (3.3).

$$SIV = \frac{P_O X P\{P_O\} X P_I}{P_C} \tag{3.3}$$

With P_O being project outcome (\$), $P\{P_O\}$is the probability of the project outcome, P_I is the philanthropic investment (\$) and P_C is the project total cost (\$).

2.3.2

3.3 Health and Ecosystem Decision Making Model (HEDMM) for Optimal Utilization

This is formulated in [1] as:

$$HEDMMOU = Ce(E_i) \tag{3.4}$$

where $HEDMMOU$ is the Health and Ecosystem Decision Making Model for the environment, C is the characterization factor and $e(E_i)$ is the environmental impact based on stressor matrix S, that is,

$$e(E_i) = S(E_i) \tag{3.5}$$

3.4 Optimization of Emissions with Fuel Cost Constraints using Solar and Wind (OEFCCSW)

An objective function for minimization of emissions is formulated in [2] as:

$$E\left(P_{j,3}\right) = \alpha_{3,j}P_{t,j}^3 + \alpha_{2,j}P_{t,j}^2 + \alpha_{1,j}P_{t,j}^1 + \alpha_{0,j} + \gamma_{3,j}e^{\left(\lambda_{3,j}\ \ P_j\right)} + \gamma_{2,j} \tag{3.6}$$

in which $E\left(P_{j,3}\right)$ = EMII (Emissions Minimization Impact Index) in tones per hour. The cost implication of EMII can be computed using environmental cost factor. $\gamma_{3,j}$, $\gamma_{2,j}$ and $\lambda_{3,j}$ are factors of emission as result of ramping effect of the jth unit whereas $\alpha_{0,j}$, $\alpha_{1,j}$, $\alpha_{2,j}$ and $\alpha_{3,j}$ are the coefficients of the emissions of the jth unit. CO_2, NO_X and SO_2 are the 3 main emissions that are factored. $P_{t,j}^3$, $P_{t,j}^2$, and $P_{t,j}^1$are the energy wasted for time t during emission of CO_2, NO_X and SO_2 respectively.

OEFCCSW objective function is formulated as:

$$\text{OEFCCSW} = E\left(P_{j,3}\right) = \sum_{j=1}^{L} E_j\left(P_{1,t}, P_{2,t}, P_{3,t}\right) \tag{3.7}$$

where L= total number of renewable energy sources (solar PV and wind) and thermal

$$L = PV + W + T \tag{3.8}$$

in which PV =number of solar generators, W= number of wind turbines and T = number of thermal generators in the power system. $P_{1,t}, P_{2,t}, P_{3,t}$are the energy sources for wind, solar and thermal for different units per source of energy.

2.3.3

3.5 Economic and Environmental Decision Making Model (EEDMM)

This model is formulated by minimizing the overall objective function as:

$$\boldsymbol{minimize}\left\{\left[[(\mathbf{1}-\boldsymbol{SIIDMM})+\boldsymbol{Ce}(\boldsymbol{E_i})]+\boldsymbol{hE}\left(\boldsymbol{P_{j,3}}\right)\right]+\boldsymbol{\beta}(\mathbf{ICOI}-\mathbf{WS_{new}})\right\} \tag{3.9}$$

Where h is the negative and positive impacts' weighting factor for solar and wind renewable whereas β is the weighting factor on the resource cost function in relation to the environmental impacts.

3.6 Net Economic Contributions

3.6.1 Thermal Cost Function (TCF)

TCF is formulated with an accurate 3rd order polynomial function as [21]:

$$TCF = \left\{a_{0i} + \sum_{j=1}^{L=3} a_{j,i} P_{ti}^{j} + \varepsilon_i\right\} + \left|r_i \sin g_i\left(P_i^{min} - P_i\right)\right| \tag{3.10}$$

Where P_i^{min} is minimum generation bound for ith unit, r_i, a_{0i}, $a_{j,i}$, and g_i are the coefficients of the cost in the unit ith and ε_i is the ith equation error.

3.6.2 Solar PV Cost Function (SCF)

SCF is formulated in a linear function as [21]:

$$SCF = F\left(pv_{ji}\right) + F_{pv,p,i}\left(pv_{ji,avg} - pv_{ji}\right) + F_{pv,ri}\left(pv_{j,i} - pv_{j,i,avg}\right) \tag{3.11}$$

In which $F\left(pv_{j,i}\right)$ = representation of solar irradiance cost constraint in a weighted cost function, $F_{pv,ri}\left(pv_{ji} - pv_{ji,avg}\right)$ = cost requirement for penalty reserve since the scheduled solar power is more than available power and $F_{pv,p,i}\left(pv_{j,i,avg} - pv_{j,i}\right)$ = penalty cost for failure of consuming the total solar PV available.

3.6.3 Wind Cost Function (WCF)

Similarly, the WCF is formulated almost as the same in equation (3.11) [21]:

$$WCF = F(W_{ji}) + F_{W,pi}(W_{ji,avg} - W_{ji}) + F_{W,ri}(W_{ji} - W_{ji,avg}) \quad (3.12)$$

Where, $F(W_{ji})$ is the jth wind generator scheduled output for the ith hour, $F_{W,ri}(W_{ji} - W_{ji,avg})$ is the cost requirement for penalty reserve since the scheduled wind energy is more than available energy and $F_{W,pi}(W_{ji,avg} - W_{j,i})$ is the penalty cost of failing to consume the total wind energy available.

3.6.4 Total Fuel Cost (FC_{Total})

Total fuel cost is found by summation the individual cost functions from the thermal, wind and solar energy sources

$$FC_{Total} = \sum_{j=1}^{L=3} CF_{T,W,S} = TCF + WCF + SCF \quad (3.13)$$

Where $CF_{T,W,S}$is the Cost Function for jth generator unit for thermal, wind, solar, any two or all.

3.6.5 Net Economic Contributions Equivalent Cost

For determination of the net economic effect of the renewable energy (solar and wind), Net Present Value (NPV) less total expenses and total fuel cost, SIV and Taxes are considered. This is after the decision is made by the EEDMM. $\{NPV - (FC_{Total} + Expenses)\}$ indicate net income from the renewable energy project, SIV is used to measure the benefits accrued as a result of the social responsibility played by the firm to the society at large and finally, Taxes indicate the amount of revenue the authorities are collecting from the project. These indicators when summed together will show the NEC. Thus, NEC is given as:

$$\boldsymbol{NEC = \{NPV - (FC_{Total} + Expenses)\} + SIV + Taxes} \quad (3.14)$$

Subject to

$$\beta(\mathrm{ICOI} - \mathrm{WS_{new}}) \leq EEDMT \leq \{\beta(\mathrm{ICOI} - \mathrm{WS_{new}}) + SIIDMOU_{min} + Ce(E_i)_{max} + hE(P_{j,3})_{max}\}$$

(3.15)

Where $NPV = \sum_{t=0}^{n} \frac{C_t}{(1+r)^t} - ICOI$ (3.16)

$C_t$is the Net Cash Flow (In-Outflows) for the time t, r is the discount rate or possible return to be earned in alternative investments and t is the periods number.

3.7 Constraints

3.7.1 Social Impact Constraint (SIC)

$$0 < SIIDMMOU \leq SIIDMMOU^{max} \qquad (3.17)$$

Where $SIIDMMOU^{max}$is the maximum Social Impacts on Investment which should be 100%. Ideally, this can only be achieved when the Initial Cost of Investment is twice the Social Impact Value (see equation 3.2).

3.7.2 Resource Cost Constraint (RCC)

$$\mathrm{ICOI} - \mathrm{WS}_{\mathrm{new}} \geq \mathrm{ICOI} - \mathrm{WS}_{\mathrm{exist}} \text{ if } CI_t > CI_n \text{ for } \mathrm{AR}_{\mathrm{new}} \geq \mathrm{AR}_{\mathrm{exist}} \qquad (3.18)$$

In order to minimize the resource cost, the new resource cost (variable and fixed) should be less than the existing resource cost for the same size of projects in line with fuel cost constraints.

3.7.3 EEDMM Constraint

This constraint is shown in equation (3.15) as:

$$\beta(\mathrm{ICOI} - \mathrm{WS}_{\mathrm{new}}) \leq EEDMM \leq \{\beta(\mathrm{ICOI} - \mathrm{WS}_{\mathrm{new}}) + SIIDMMOU_{min} + Ce(E_i)_{max} + hE\left(P_{j,3}\right)_{max}\}$$

This EEDMM is constrained between theweighted value of initial cost of investment for wind/solar and the sum of weighted value of $\mathrm{ICOI} - \mathrm{WS}_{\mathrm{new}}$, minimum cost of social impact on investment, EMII and maximum weighted emissions.

CHAPTER 4

MATERIALS AND METHODS

4.1 Optimization Methods

Optimization methods can be classified according to their method of operation, that is, deterministic and probabilistic methods. When there is a distinct relationship between the possible solution characteristics and their utility for a given case, then the deterministic methods are the most appropriate. In this method, the search space can be explored efficiently through methods such as divide and conquer [34].

However, when the search space has a high dimensionality or the relation between a candidate solution and its fitness are complicated, then a deterministic optimization would not be appropriate. In such a scenario, probabilistic algorithms are handy. Most probabilistic optimization techniques are Monte-Carlo-based and deal in bonded accuracy of the results for a briefer runtime [34].

Heuristics are normally engaged in worldwide optimization functions that aid to determine which set of possible results that should be tested next. In deterministic approaches heuristics are employed to define the processing order of the candidate solutions while in probabilistic approaches, heuristics are used to select elements of the search space in further computations [34].

When the objective function and heuristics are combined in an abstract and perhaps efficient way, it becomes a meta-heuristic method. The combinations are usually effected stochastically using statistics retrieved from search space samples or based on a physical process or a model of a natural phenomenon. For example, in simulated annealing, a candidate solution to be evaluated is decided according to the Boltzmann probability factor of atom configuration of solidifying metal melts [34]. In evolutionary algorithms, the behavior of natural evolution is emulated and candidate solutions are treated as elements that compete in a virtual environment. The algorithm encompasses all algorithms that are founded on a set of multiple candidate solutions that are refined iteratively [34].

Classification of optimization methods is summarized in figure 4.1.

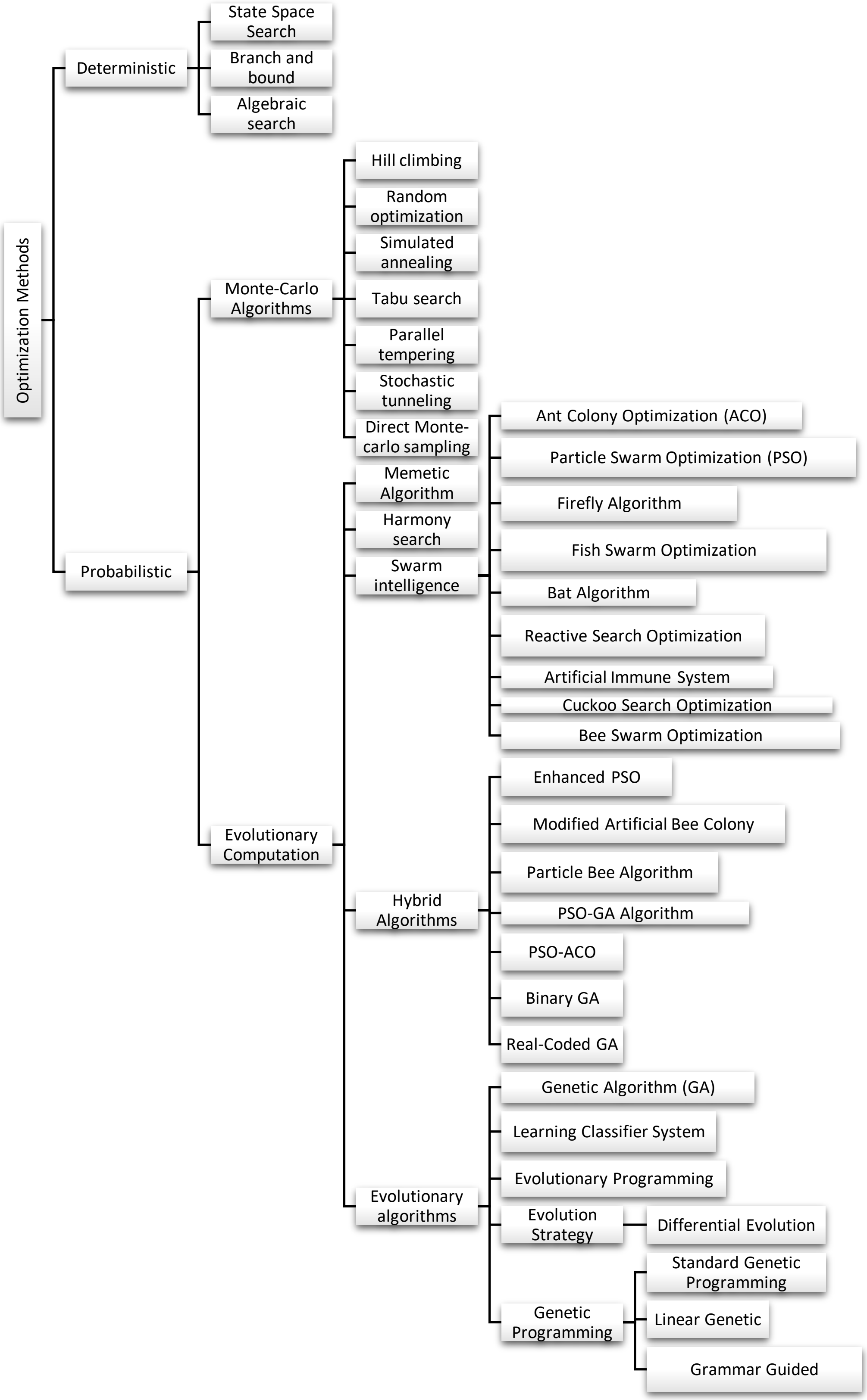

Figure 4.1: Classification of Optimization Methods

4.2 Reviews of Previous Methods

Musau, et al [2] proposed Modified Firefly Algorithm with Levy Flight and Derived Mutation (MFA-LF-DM) to solve the problem as it has a fast convergence rate, dealing with natural global optimization and efficiently has a high success rate. However, this hybrid method could not address the economic optimization of the project to be undertaken since the algorithm antagonistic objectives are not clearly defined.

Musau, et al [2] further modelled the uncertainties of RE using Structural Path Analysis (SPA) in ecological networks. However, the SPA is based on linear analysis and limited to extraction, enumeration and ranking of the paths. Therefore, the authors further used accurate cubic cost function in order to minimize errors.

Sellami, et al [3] used Thermo-Economic Cost Modelling to assess the environmental impacts of biogas reactor energized by energy from yeast and wind energy. This method involves energy conception with respect to economic aspects for the selection of equipment, the choice of operation mode and the optimization of the design of the thermal plants. However, this method is too inflexible to be implemented for Solar and Wind Renewable Sources of Energy.

Leicester, et al [4] used Bayesian Network to evaluate Solar PV to reduce energy poverty in England. This probabilistic graphical model is widely used to represent variable sets with their dependency conditions through a directed acyclic graph which is very difficult to converge at the optimum loop because of many vertices and edges.

Guta [6] used Ordinary Least Square (OLS) to analyze the consumption assessment of wood and charcoal in Ethiopia. This is a linear regression method that is applied to closely fit the data into the function. This method cannot therefore be applied to non-linear problems.

Bergmann, et al [7] and Álvarez-Farizo, et al [8] used Choice Experiment. In [7] this method was used to investigate the preferences of people over the environment and socio-economic effects on the RET. On the other hand, [8] used the method together with conjoint analysis to discuss the environmental effects of wind energy plants in Spain. This method is widely used to put economic value of environmental services and goods. It is limited mostly on interviews through carrying out surveys.

Finally, Hernandez, et al [9] used Carnegie Energy and Environmental Compatibility (CEEC) model to assist in evaluation of the land cover potential and utilization of the land for more than 160 solar installations. This model is a tool for making decisions for calculation of the solar PV potential and land use ability by considering resource opportunities with their constraints. This method uses a satellite-based model and therefore can only be applicable where there is satellite coverage and National Renewable Energy Lab.

In all these methods used, none has addressed both environmental and economic impacts addressed in this thesis. Some of the methods are not multiobjective and others are not intelligent. Furthermore, none of the methods have an antagonistic property that could aid in maximization of social impact and minimization of other environmental impacts as laid out in the formulated problem of Chapter 3. It is on this basis that Improved Strength Pareto Evolutionary Algorithm is proposed.

4.3 Improved Strength Pareto Evolutionary Algorithm (SPEA2)

In order to identify a method, this thesis first started by reviewing the environmental effects based on social, health and ecosystem and further looked into the net economic contributions of wind and solar renewable sources of energy to the society. This objective [objective (i)] was useful for the author to understand both the negative and positive impacts of these RES and note that these energies are not actually ‘harmless’, ‘clean’ and ‘free’ as perceived before. It went further to review the available optimization tools for RE (solar and wind) and proved that there is no single tool available to address all the outlined factors (resource cost, social, health, ecosystem and net-economic contribution). It is on this basis that a gap was widely identified and there was need for a new model that, probably, would address the issues at hand. Once the gap was clearly identified, the problem was formulated (objective ii) after doing a thorough and an elaborate research. In order to solve the problem that was formulated, the data was collected and an optimization tool was identified for simulation of the results.

The Strength Pareto Evolutionary Algorithm [37] is useful in optimizing both negative and positive environmental effects and improving the solution from it. SPEA2 [37] further optimizes both the resource cost and fuel cost then the best decision is made based on the two optimizations. The uncertainties of Wind and Solar are also considered. This thesis uses Improved Streghth Pareto Evolutionary Algorithm (SPEA2).

SPEA2 is an extension of SPEA which is an Evolutionary and a Multiple Objective Optimization Algorithm. The SPEA has an objective of locating and maintaining a front of non-dominant set of Pareto Optimal solutions. This is realized by using the evolutionary process (which explores the search space) and a selection process. The selection process uses a combination of the level in which candidate solution is dominated and the density of the Parent front estimation as an assigned fitness. A population of candidates and an Archive of the non-dominant set are separately maintained. This provides a form of superiority (elitism) [37].

As opposed to SPEA, SPEA2 has an improved scheme of fitness assignment. In this scheme, each individual is taken into consideration to know the number of individuals it dominates or dominate it. Besides, there is incorporation of the nearest neighbour density estimation method. This allows a precise guidance of the process of searching. Finally, SPEA2 employs new archive truncation techniques where the boundary preservation results are guaranteed. However, this algorithm only considers the minimized distance to the optimal front [37].

Fitness Assignment: Each individual ***j*** is taken into account to know the individual numbers it dominates or dominate it. The quantity of solutions dominated by particular individual ***j*** in the population $\boldsymbol{P_n}$ and the archive ***A*** is assigned a value of strength ***S(j)*** given by [13]:

$$S(j) = |\{i|i \in P_n \cup A \wedge j \succ i\}| \tag{4.1}$$

Where $|.|$ is the cardinal of a set, $\cup$ is the multiset union and $\succ$ is the Pareto dominance relation.

Based on the values of ***S(j)***, the individual ***j*** raw fitness $\boldsymbol{R_f(j)}$ is given by:

$$R_f(j) = \sum_{i \in P_n \cup A, i \succ j} S(i) \tag{4.2}$$

This implies that the dominators strengths determine the raw fitness in both $\boldsymbol{P_n}$ and ***A.*** Note that the minimization of $R_f(j)$ is to be done. For $R_f(j) = 0$ then the correspondence is taken to be a non-dominated individual and if $R_f(j) = high\ value$ then it implies that ***j*** is dominated by big number of individuals which in turn leads to dominance of many individuals. However, the raw fitness may fail if the domination of each other by the most individuals do not occur. This problem can be solved by the additional density information.

Density Estimation, k: This is useful to discriminate between individuals with similar raw fitness values. For particular individual ***j,*** the distances involving total individuals, ***i*** in ***A*** and $\boldsymbol{P_n}$ are computed and kept in the list. The list is then classified in ascending order for the *t-th* element to give the distance sought, σ_j^t.

t is assigned to be the square-root of the sample size, $t = \sqrt{M + \bar{M}}$, followed by the calculation of the density ***D(j)*** for the corresponding ***j*** as:

$$D(j) = \frac{1}{\sigma_j^t + 2} \tag{4.3}$$

At the end, the fitness ***F(j)*** is then calculated as the sum of the density and the raw fitness, that is,

$$F(j) = R_f(j) + D(j) \tag{4.4}$$

Run Time: The density estimator ($\mathcal{O}(N^2 logN)$) dominates the run time of fitness assignment procedure. $\boldsymbol{R_f(j)}$ and ***D(j)*** is of complexity of $\mathcal{O}(N^2)$ with $N = M + \bar{M}$.

Mating Selection: The search of Pareto-optimal front is guided by the mating selection where the individuals for offspring production are selected by assignment of a pool of fitness values and individuals ***i.*** This procedure for filling the mating pool is usually randomized.

Environmental Selection: This selection decides on which individuals to keep during the process of evolution. Here deterministic selection is mostly used. In this selection, there are two cases:

i) When there is constant quantity of individuals, over time, in the archive.
ii) When the boundary conditions cannot be removed due to truncation method *(Archive Truncation).*

To get the ***new generation (offspring or new archive)*** from the individuals, ***i,*** and investigate the above two cases, equation (4.5) is used.

$$New\ Archive, A_{n+1} = \{j | j \in P_n + A_n \wedge F(j) < 1\} \tag{4.5}$$

When $New\ Archive, A_{n+1} = A_n = power\ output\ A,$ then there is completion of the environmental selection (case i).

When $New\ Archive, A_{n+1} < A_n$ (too small archive), then there is copying of the best $A_n - |A_{n+1}|$ dominated individuals from the previous population and archive to the new archive.

When $New\ Archive, A_{n+1} > A_n$ (too large archive), then there is invocation of procedural archive truncation. This iteratively takes away individuals from A_{n+1} until$New\ Archive, A_{n+1} = A_n$. This is achieved by taking the individual with shortest distance to another individual chosen at every stage. The tie is broken by choosing the 2nd smallest distance if there are many individuals with the least distance and so forth.

4.4 Mapping of the Problem to the Proposed Method

In this thesis, the EEDMM is minimized by considering ICOI-WS, Social Impact on Investment Decision Making Model (SIIDMM), Health and Ecosystem Decision Making Model (HEDMM) and Optimization of Emissions with Fuel Cost Constraints using Solar and Wind (OEFCCSW). Since each area is simulated before combining them as in equation (3.9), there is need to map each separately.

The mapping is summarized in Table 4.1.

Table 4.1: Mapping of the Problem to SPEA2

METHOD PARAMETER	**ICOI-WS**	**SIIDMM**	**HEDMM**	**OEFCCSW**	**EEDMM**
Population, P_t (input)	Cost of index value (today and n years ago)	Project total cost ($)	Total Environmental Impact	Emissions minimization impact index (tones/hr)	Mid-point indicators
Individuals, i (input)	Amount of Existing Resources (kWp)	Initial cost of investment ($) Philanthropic Investment ($)	Instantaneous environmental impact	Wind, solar and thermal constraints	ICOI-WS, SIIDMM, HEDMMOU and OEFCCSW

METHOD PARAMETER	**ICOI-WS**	**SIIDMM**	**HEDMM**	**OEFCCSW**	**EEDMM**
Archive, A_t (output)	Optimized Resource cost ($)	Social Impact on Investment (%)	Heath and Ecosystem outcome	Optimized emissions with fuel cost (tones/hr)	Objective function EEDMM
Crossover	Link between cost of index value n years ago and today	Link between social impact value and initial cost of investment	Link between health and ecosystem	Link between emissions and fuel cost	Updates emissions and negative environmental and economic impacts at each iteration
Mutation	Link between estimated resource cost and amount of new resources	Link between project total cost, philanthropic investment and project total outcome	Link between characterization factor and environmental impact	Link between solar PV, wind and thermal	Updates emissions and positive environmental and economic impacts at each iteration
New Archive, A_{t+1}	Newly acquired resource cost ($)	Newly acquired Social Impact on Investment (%)	Newly acquired health and ecosystem outcome	Newly acquired emissions with fuel cost	Newly acquired EEDMM
Distance sought, σ_i^k	Weighting factor β [0 1]	Probability of the project outcome [0 1]	Characterization factor	Weighting factor h [0 1]	PowerSizing Exponential x

This mapping is illustrated in flowchart of figure 4.2. During simulation, we first initialize the parameters and read system data. We then randomize generation of power, Pt and current, I then we check the current population. The flowchart illustrates the simulation process until the optimum values of EEDMM are achieved. See figure 4.2.

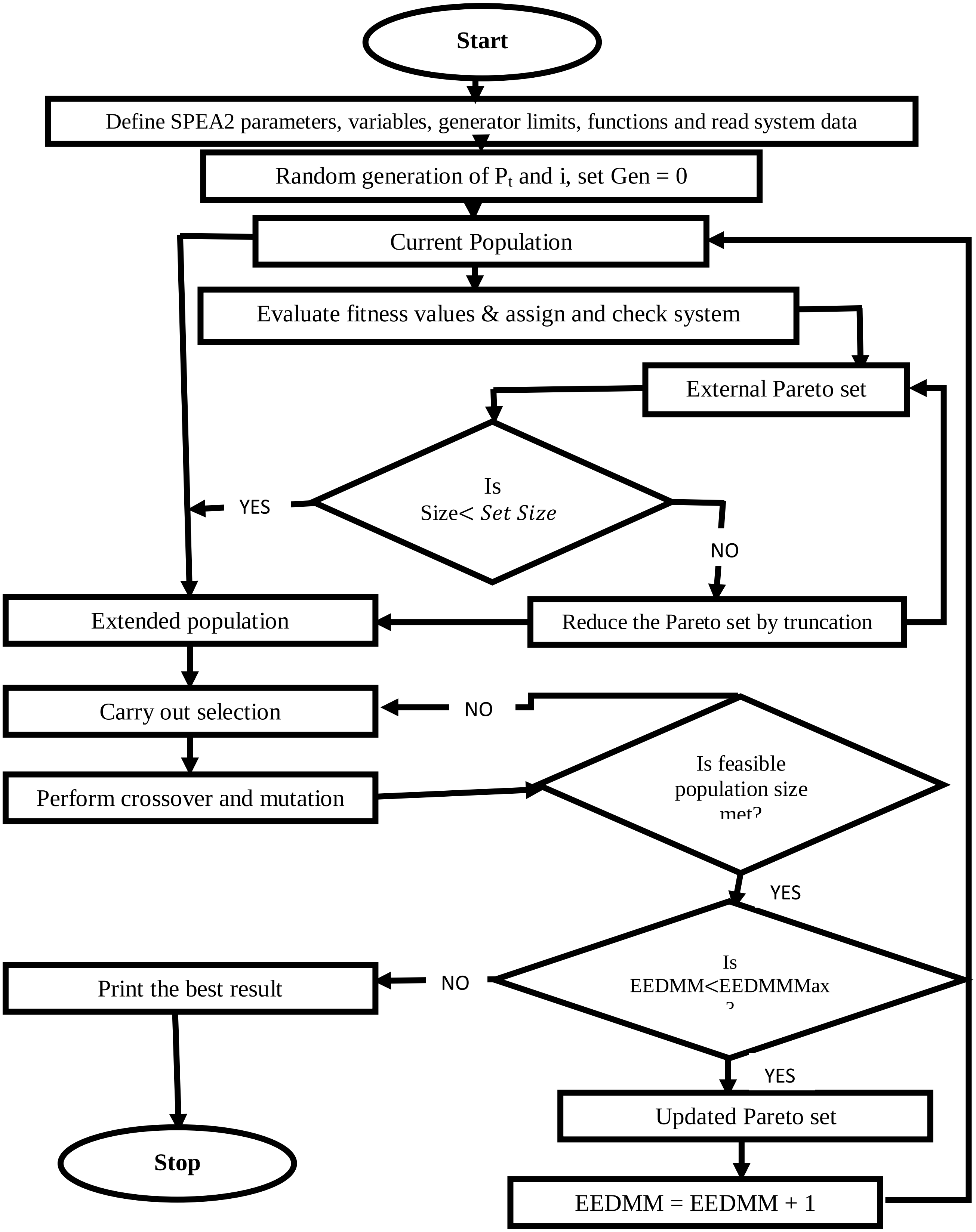

Figure 4.2: EEDMM Flowchart

4.5 Collection of Data and Information

In this thesis, secondary data sources were used to collect the data. Data collected were costs of solar and wind farms for 2MW capacity. These costs included initial costs of investments, philanthropic investment and project outcome. Others were Kenya's cost index ratios for different years, Powersizing exponential for solar PVs and wind turbines. Besides, ReCiPe model midpoint indicators were also collected. Review of different documents, data archives, sites, databases and journals, collecting relevant and quality data was the approach used in this case.

4.6 Quality of Data Collected

Comparison of various data from different management information systems was done before using it. This was to make sure that the data used in very accurate and up to date. The data used in this thesis came from very reputable and reliable organizations and institutions. Due to ethical considerations and confidentiality, these organizations and institutions remain anonymous.

CHAPTER 5

RESULTS AND ANALYSIS

In this chapter, Section 5.1 documents New Initial Cost of Investment referred to as ICOI-WSnew (New Resource Cost of Wind/Solar), section 5.2 introduces the results and analysis of Social Impact on Investment Decision Making Model for Optimal Utilization (SIIDMM) of Solar and Wind and section 5.3 considers Health and Ecosystem Decision Making Model (HEDMM) for Optimal Utilization. Furthermore, Emissions from Thermal, Solar and Wind Energies are in section 5.4 with objective function, referred to as EEDMM (Economic and Environmental Decision Making Model), being represented in section 5.5. Finally, section 5.6 represents Net Economic Contribution from a valid wind/solar project.

Installed generation capacity of Solar, Wind and Thermal energy sources was 2.5MW each and the existing initial cost of investment being 5 million US Dollars for each. These are chosen in order to standardize sources for endpoint scores comparison. Thermal is used as a base system.

5.1 Initial Cost of Investment for Wind and Solar (ICOI-WS)

The results for the new initial cost of investment, with different cost indices of 1, 1.04 and 1.12, are shown in Table 5.1 with x being the Powersizing Exponential ranging from 0 to 1. These results are simulated using the MATLAB code in Appendix A1 and data from Appendix Table B1.

Table 5.1: New Initial Cost of Investment (million USD) for different CIRs with varying power exponentials (x)

x	**ICOI-WSnew for CIR = 1 (million)**	**ICOI-WSnew for CIR = 1.04 (million)**	**ICOI-WSnew for CIR = 1.12 (million)**	
0	USD 5.00000	USD 5.20000	USD 5.60000	
0.1	USD 5.11283	USD 5.31734	USD 5.72637	
0.2	USD 5.22820	USD 5.43733	USD 5.85558	
0.3	USD 5.34617	USD 5.56002	USD 5.98771	Solar
0.4	USD 5.46681	USD 5.68548	USD 6.12283	
0.5	USD 5.59017	USD 5.81378	USD 6.26099	Wind
0.6	USD 5.71631	USD 5.94497	USD 6.40227	
0.7	USD 5.84530	USD 6.07911	USD 6.54674	
0.8	USD 5.97720	USD 6.21629	USD 6.69447	
0.9	USD 6.11208	USD 6.35656	USD 6.84553	
1.0	USD 6.25000	USD 6.50000	USD 7.00000	

The results from Table 5.1 are plotted in Figure 5.1. It can be observed that as the cost index ratios increase, the initial cost of investment is also increasing. For instance, taking the average Powersizing Exponential of solar and wind as 0.3 and 0.5 respectively, the new resource costs are million USD 5.34617, 5.56002, 5.98771 for Solar and million USD 5.59017, 5.81378, 6.26099 for wind with cost index ratios 1, 1.04 and 1.12 respectively. This has seen an increase of 4% from index ratio 1 to 1.04, 7.6% from index ratio 1.04 to 1.12 and 12% from ratio 1 to 1.12.

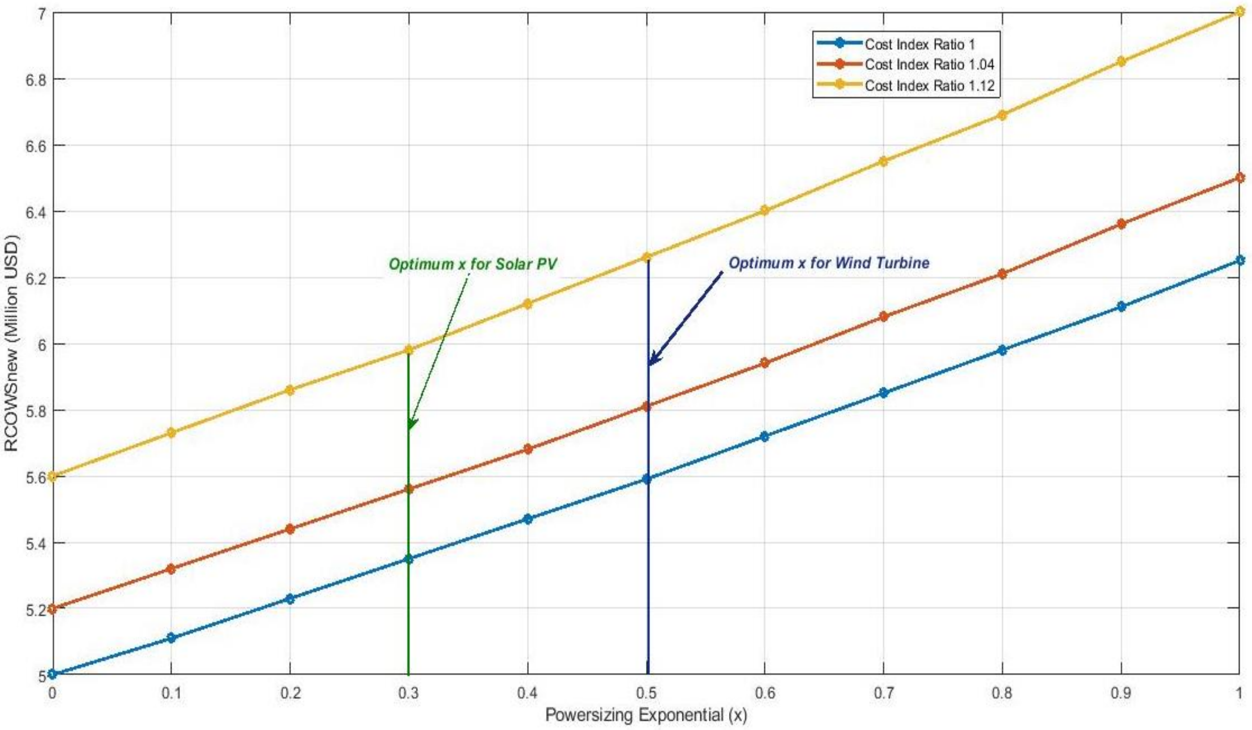

Figure 5.1: A Graph of New Initial Cost of Investment for varying Powersizing Exponential with different CIRs

This shows that before an investor thinks of setting up wind or solar project in a place, he needs to consider the optimum initial cost of investment during when the inflation rates of a country are favourable (low). Based on the lifespan of the project, any initial amount exceeding the optimum cost of investment will render the project not to be economically viable. More so, the cost of investment should not exceed 120% for solar and 125% for wind power projects.

In a summarized decision making for optimal utilization of wind and solar, existing cost of investments were varied and the new initial cost of investment recorded as shown in Table 5.2.

Table 5.2: New Initial Cost of Investment for varying Existing Cost of Investment with different CIRs

ICOI-WSexist (million USD)	**Solar (million USD)**			**Wind (million USD)**		
	ICOI-WSnew for CIR = 1	**ICOI-WSnew for CIR= 1.04**	**ICOI-WSnew for CIR = 1.12**	**ICOI-WSnew for CIR = 1**	**ICOI-WSnew for CIR = 1.04**	**ICOI-WSnew for CIR = 1.12**
0	0	0	0	0	0	0
1	1.06923	1.11200	1.19754	1.11803	1.16276	1.25220
2	2.13847	2.22401	2.39509	2.23607	2.32551	2.50440
3	3.20770	3.33601	3.59263	3.35410	3.48827	3.75659
4	4.27694	4.44802	4.79017	4.47214	4.65102	5.00879
5	5.34617	5.56002	5.98771	5.59017	5.81378	6.26099
6	6.41541	6.67202	7.18526	6.70820	6.97653	7.51319
7	7.48464	7.78403	8.38280	7.82624	8.13929	8.76539
8	8.55388	8.89603	9.58034	8.94427	9.30204	10.0176
9	9.62311	10.0080	10.7779	10.0623	10.4648	11.2698
10	10.6923	11.1200	11.9754	11.1803	11.6276	12.5220

From Table 5.2, 3-D bar graphs are plotted in order to bring clear a graphical representation of the results. From Figures 5.2 and 5.3, it can be observed that as the existing cost of investment increase, the changes remain slightly constant at 20%. These two graphs are part of the decision making model for optimal initial cost of investment.

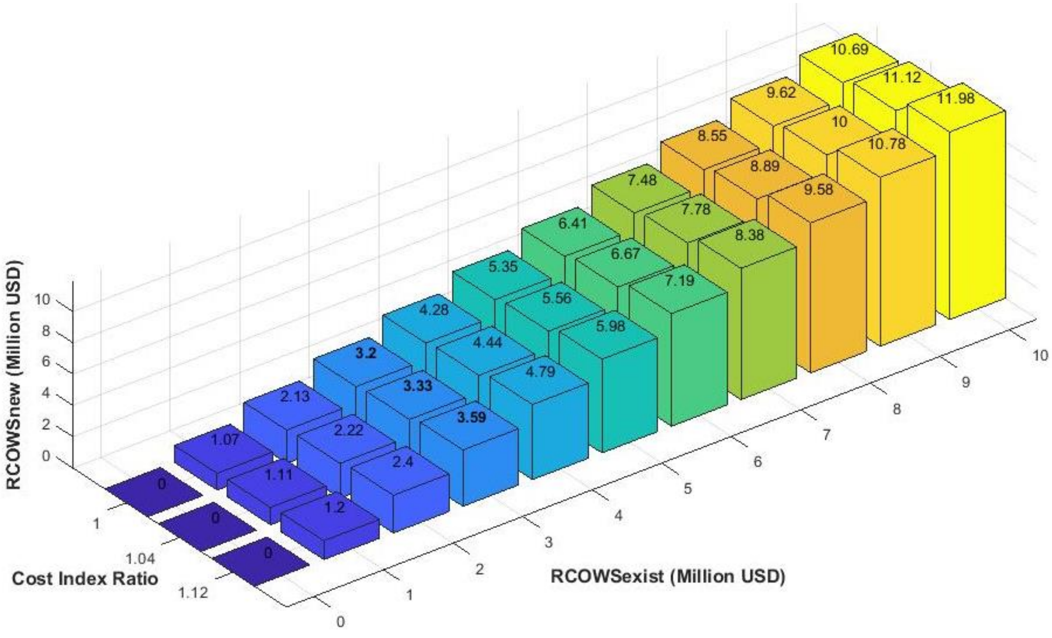

Figure 5.2: ICOI-WSnew versus ICOI-WSexist for varying CIRs for Optimal Solar PV Utilization

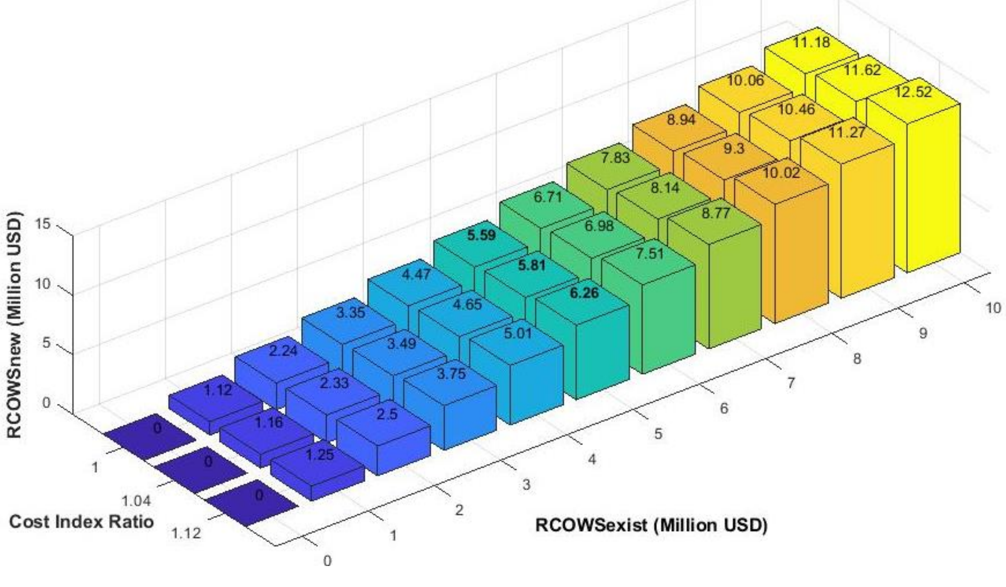

Figure 5.3: ICOI-WSnew versus ICOI-WSexist for varying CIRs for Optimal Wind Utilization

The changes in new cost of investment for different cost index ratios are shown in Figure 5.4. From Figure 5.4, as the value of existing initial cost of investment increases, the change in value of the new initial cost of investment also increases with respect to increase in cost index ratios. Even though the trend is depicted as an increment with increase in wind costs, the percentage changes remain averagely constant as 10.50, 15.00 and 23.75% for the cost index ratios of 1.0, 1.04 and 1.12 respectively.

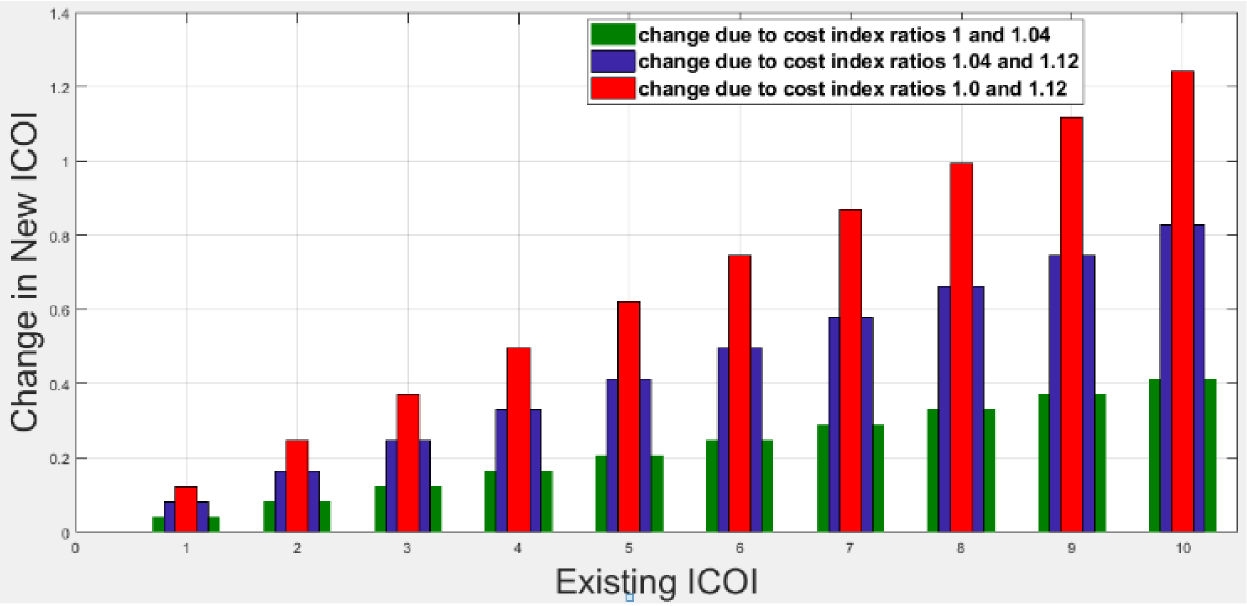

Figure 5.4: Change in New Initial Cost of Investment for CIRs of 1, 1.04 and 1.12

After making decisions on the new initial costs of investment, the cost are used to work out the Social Impact on Investment in order to make the final decision on the optimal utilization of the RETs. Here, the initial costs of million USD 5.59, 5.81 and 6.26 for Wind project and million USD 5.35, 5.56 and 5.98 for solar PV project are used. The figures for SIIDMM are shown in Section 5.2.

5.2: Social Impact on Investment Decision Making Model for Optimal Utilization (SIIDMM)

From the values of new resource cost of wind and solar projects stated above, the social impact on investment is simulated. Tables 5.3 and Table 5.4 show the results of Social Impact Values (SIV) and SIIDMM for both solar and wind sources of energy respectively. The results are simulated from the code in Appendix A2 and Appendix Table B2. The graph of SIIDMM against probability of project outcome for solar project was shown in Figures 5.5. Since the wind results showed the same behaviours as those of Solar, only one graph for solar was plotted.

Table 5.3: Solar PV SIIDMM

Probability of Project Outcome	**CIR = 1**		**CIR = 1.04**		**CIR = 1.12**	
	SIV (million USD)	**SIIDMM**	**SIV (million USD)**	**SIIDMM**	**SIV (million USD)**	**SIIDMM**
0	0	-1.0000	0	-1.0000	0	-1.0000
0.1	0.7412	-0.8614	0.7412	-0.8667	0.7412	-0.8762
0.2	1.4823	-0.7227	1.4823	-0.7334	1.4823	-0.7524
0.3	2.2235	-0.5841	2.2235	-0.6001	2.2235	-0.6287
0.4	2.9646	-0.4455	2.9646	-0.4668	2.9646	-0.5049
0.5	3.7058	-0.3068	3.7058	-0.3335	3.7058	-0.3811
0.6	4.4470	-0.1682	4.4470	-0.2002	4.4470	-0.2573
0.7	5.1881	-0.0296	5.1881	-0.0669	5.1881	-0.1335
0.8	5.9293	0.1091	5.9293	0.0664	5.9293	-0.0098
0.9	6.6704	0.2477	6.6704	0.1997	6.6704	0.1140
1.0	7.4416	0.3863	7.4416	0.3330	7.4416	0.2378

Table 5.4: Wind Plant SIIDMM

Probability of Project Outcome	**CIR 1**		**CIR 1.04**		**CIR 1.12**	
	SIV (million USD)	**SIIDMM**	**SIV (million USD)**	**SIIDMM**	**SIV (million USD)**	**SIIDMM**
0	0	-1.0000	0	-1.0000	0	-1.0000
0.1	0.7750	-0.8614	0.7750	-0.8667	0.7750	-0.8762
0.2	1.5499	-0.7227	1.5499	-0.7334	1.5499	-0.7525
0.3	1.5499	-0.5841	1.5499	-0.6001	1.5499	-0.6287
0.4	2.3249	-0.4455	2.3249	-0.4668	2.3249	-0.5049
0.5	3.0998	-0.3068	3.0998	-0.3335	3.0998	-0.3811
0.6	3.8748	-0.1682	3.8748	-0.2002	3.8748	-0.2574

Probability of Project Outcome	**CIR 1**		**CIR 1.04**		**CIR 1.12**	
	SIV (million USD)	**SIIDMM**	**SIV (million USD)**	**SIIDMM**	**SIV (million USD)**	**SIIDMM**
0.7	4.6497	-0.0296	4.6497	-0.0669	4.6497	-0.1336
0.8	5.4247	0.1091	5.4247	0.0664	5.4247	-0.0098
0.9	6.1996	0.2477	6.1996	0.1997	6.1996	0.1140
1.0	7.7495	0.3863	7.7495	0.3330	7.7495	0.2377

According to the decisions made based on social impacts like level of philanthropic investments, project outcome and total project cost, from Figure 5.5, the SIIDMM is only valid when it is positive, that is, greater than 0. For instance, it is observed that the valid SIIDMM is reached upon when the probability outcomes are 0.72, 0.75 and 0.81 for cost index ratios 1, 1.04 and 1.12 respectively. The highest SIIDMM is 0.4 (the best) and the lowest is -1 (the worst) for a 2.5MW RE system. After knowing the probability of project outcome, the decision is made and settles on the best probability project outcome. Once this decision is made, the Social Impact Value (in million USD) is determined. This equates the social impacts to monetary value. This assists the investor to set aside optimum costs located for social responsibilities to be played by the project on the community – both direct and indirect responsibilities. This decision graph is shown in Figure 5.6.

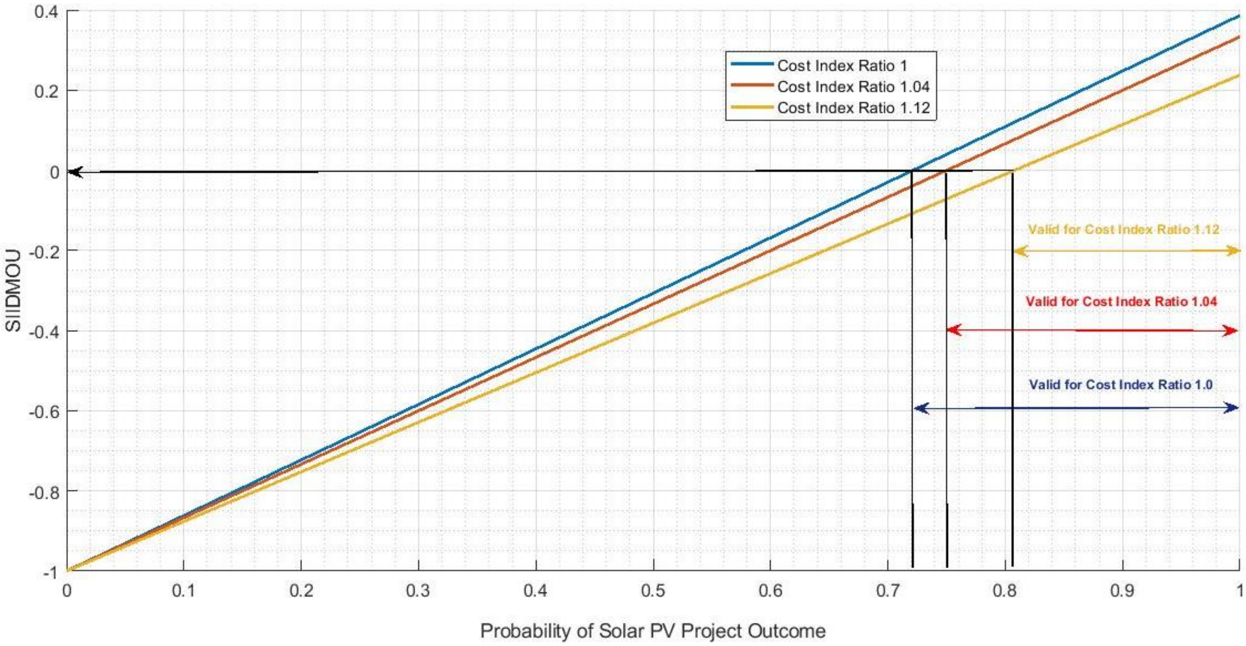

Figure 5.5: SIIDMM versus Probability of Solar PV Project Outcome

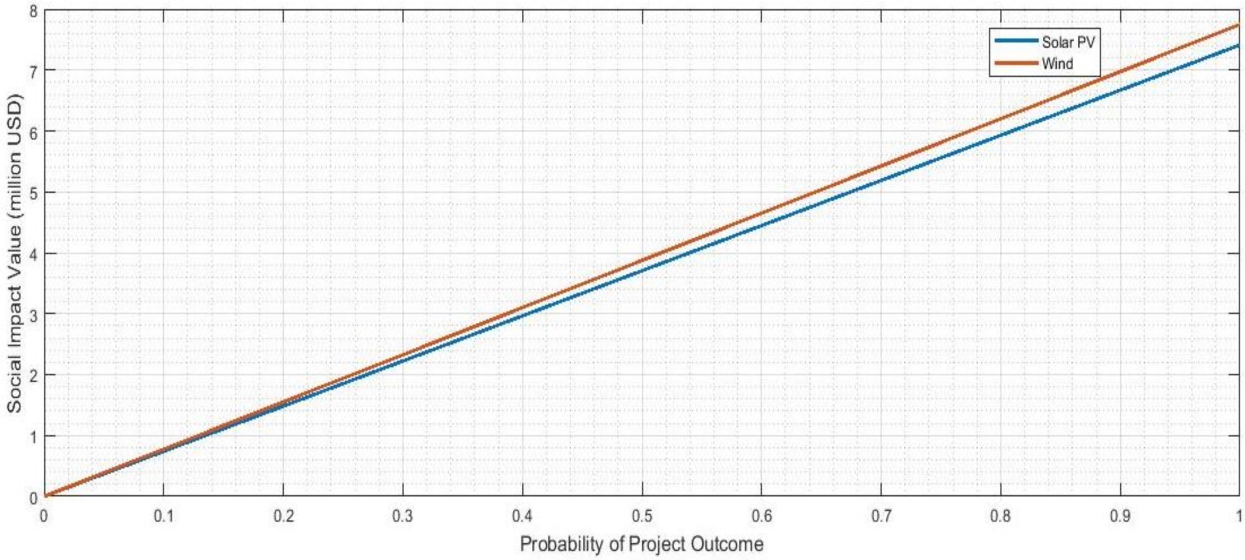

Figure 5.6: A graph of Social Impact Value versus Probability of Project Outcome

Once the decision on SIV has been made, there is need to investigate Health and Ecosystem Impacts. These are well illustrated in Section 5.3.

When valid SIIDMM is ignored by the investors, there would be lack of employment opportunities, displacement of the local community and poor infrastructural development.

5.3: Health and Ecosystem

The results in this section are simulated using the code in Appendix A3 and Appendix Table B3.

2.3.4 5.3.1 Health Impacts

In this section, we look into the Health Impacts using the midpoint indicators of ReCiPe model. From the simulated results, the Endpoint Scores (kg/kWh) for different Health Midpoint Indicators are shown in Table 5.5

Table 5.5: Health Endpoint Scores

Midpoint Indicator	**Endpoint Scores (kg/kWh)**		
	Wind	**Solar**	**Thermal**
Ozone Depletion, H1	1.6059	6.1851	8.8549
Human Toxicity, H2	7.5389	27.8809	91.5034
Ionization Radiation, H3	50.3340	300.098	150.623
Particulate Matter Formation, H4	22.5611	39.5767	160.515
Photochemical Oxidation Formation, H5	3.0026	3.0082	3.7301
Climate Change, H6	2.0099	2.0016	2.3054

From Table 5.5, the graph was plotted as depicted in Figure 5.7. The mid-point indicators for Human Health that were considered include: H1 – Ozone depletion, H2 - Human Toxicity, H3 – Ionization Radiation, H4 – Particulate Matter Formation, H5 – Photochemical Oxidant formation and H6 – Climate change.

From Figure 5.7, it is observed that the use of wind reduces H1 by 81.86% and use of Solar increases H1 by only 30.15%. From the ReCiPe model, ozone depletion is related toNO_x. Solar, in comparison to wind, has larger negative contribution to ozone depletion because of the Chemicals used in PV cells such as Nitrogen trifluoride and sulfur hexafluoride that are used in the production of the solar cells. Combustion of these cells leads to an increased production of NO_x during manufacturing of solar panels hence contributing more negatively to human health than in wind. Wind leads to a reduction in ozone depletion because as compared to thermal and solar that use fossil fuels which are combusted to produce electricity, the wind source does not include any fossil fuel combustion to produce electricity.

Use of wind reduces H2 by 91.76% while Solar reduces H2 by 62.04%, and Hydropower reduces H2 by 69.53%. Human toxicity effects result from exposure to fine particles, tropospheric ozone and ionizing radiation. In the case of tropospheric ozone, the photochemical ozone formation potential reflects the rate and exposure of the above three. Since solar contributes the most negatively to human toxicity and particle matter formation, it is inarguable that it also contributes the most negatively to human toxicity in comparison to wind and the conventional thermal.

Wind reduces H3 by 66.58% and solar increases H3 by 99.24%. Using the conventional reservoir thermal power, solar contributes the highest to ionizing radiation. This is because only about 15% of the light absorbed from the sun by the solar panel is turned into electricity. The rest is re-radiated as heat which significantly contributes to ionizing radiation.

Wind reduces H4 by 85.94% as Solar reduces H4 by 75.34%. As in the case of global warming, solar has the highest negative contribution to particulate matter formation compared to. The solar photovoltaic technologies emit approximately the same amount of particulate matter as a natural gas power plant. This is due to the manufacturing process, where fossil fuels are combusted, and also due to the wafer sawing process, which creates fine silicon dust particles.

Wind reduces H5 by 19.50% while Solar reduces H5 by 19.35%. Generally, the deployment of RE reduces photochemical oxidant formation significantly. PCOF involves a series of complex phenomena leading to the formation of O_3 and other oxidizing compounds such as Hydrogen Peroxide and Nitrates from primary pollutants mainly NO_x andCO_2 . From the analysis of climate change and ozone depletion in Table 5.5, solar has the highest negative impact on global warming and ozone depletion that are closely linked to NO_x and CO_2 of the two RE sources, mainly due to incomplete combustion of fossil fuels during the solar PV manufacturing process. Hence, causes the least reduction to PCOF on the thermal base as compared to wind.

Wind reduces H6 by 12.82% while Solar reduces H6 by 13.17%. Of the RE energies, solar has the highest CO_2 emissions that is linked to climate change and global warming in the ReCiPe model. Solar PV makes a significant impact to global warming due to the energy-intensive silicon purification process where fossil fuels are combusted.

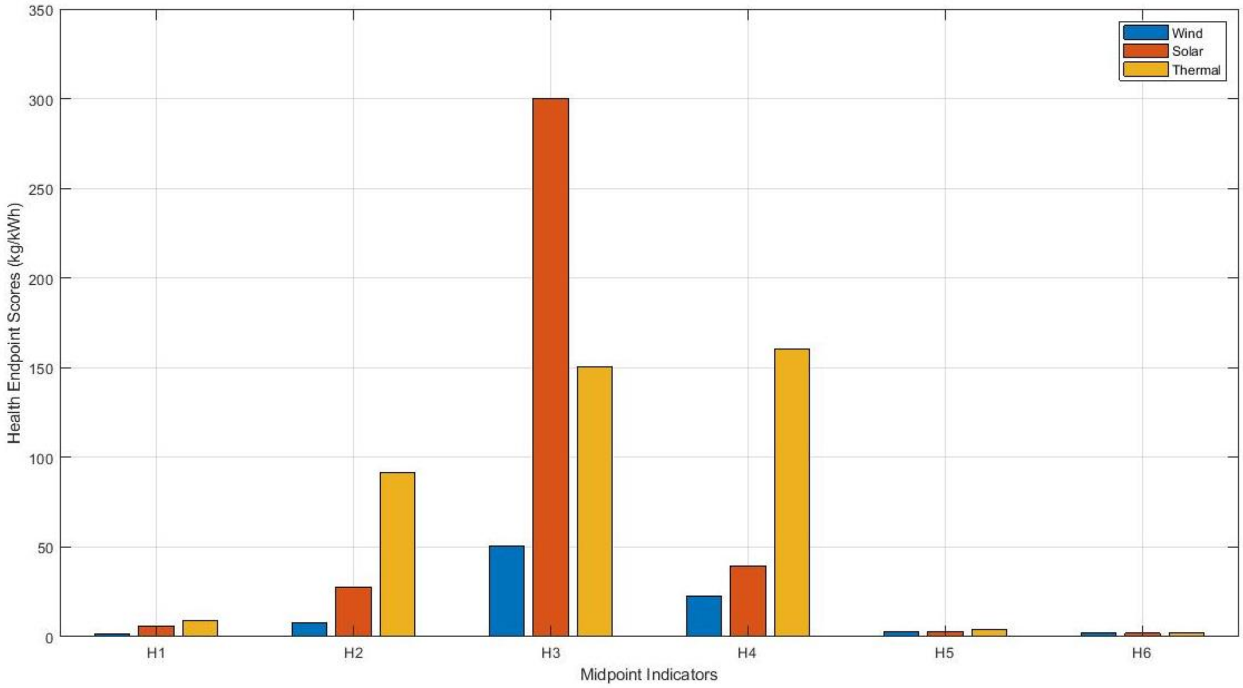

Figure 5.7: Health End Point Scores for 2.5MW project

2.3.5 5.3.2 Ecosystem Endpoint Scores

This section considers the Ecosystem Endpoint Scores using the midpoint indicators of ReCiPe model. The midpoint indicators for ecosystems effects include: E1 - Terrestrial Acidification, E2 – Terrestrial Eco-toxicity, E3 – Marine/Freshwater Eco-toxicity, E4 – Marine/Freshwater Eutrophication, E5 - Land Occupation and E6 - Land Transformation. Simulated results of the Endpoint Scores are shown in Table 5.6.

Table 5.6: Ecosystem Endpoint Scores

Midpoint Indicator	**Endpoint Scores**		
	Wind	**Solar**	**Thermal**
Terrestrial Acidification, E1	1.0053	1.1151	3.3055
Terrestrial Eco-toxicity, E2	0.0020	0.0044	0.0045
Marine/Freshwater Eco-toxicity, E3	1.2103	1.4659	4.0158
Marine/Freshwater Eutrophication, E4	1.0011	1.0029	1.3563
Land Occupation, E5	2.2634	2.9058	26.0159

Midpoint Indicator	**Endpoint Scores**		
	Wind	**Solar**	**Thermal**
Land Transformation, E6	2.6100	5.7400	17.3100

From Table 5.6, the graph was plotted as depicted in Figure 5.8. It is observed that wind reduces E1 by 69.58% while Solar reduces E1 by 66.26%. Terrestrial acidification is closely associated withSO_2. Of the two REs studied, solar has higher SO_2 emissions than wind. Solar PV has a notable impact due to the use of fossil fuels used in the manufacturing process of the PV cells. Manufacturing of PV modules requires large amounts of energy. Large volumes of water is required for cooling or as a working fluid, or for washing reflective surfaces which affects water quality thus causing water pollution.

Wind reduces E2 by 55.56 and solar reduces it by 2.22%. Solar has higher negative contribution to terrestrial Eco-toxicity. This is because of use of chemicals in photovoltaic (PV) cells in the manufacturing facility, the installation site, and the disposal or recycling facility and the accidental release of heat transfer fluids (water and oil) from parabolic trough and central receiver systems that cause health hazards and contribute to the release of toxic substances.

Wind reduces E4 by 26.18% as opposed to solar which reduces E4 by 26.06%. These two sources of energy almost have negligible effects on marine/freshwater eutrophication because use of wind turbines requires zero water as solar PV modules require periodic maintenance by washing the absorptive surfaces with a little water. This rarely pollutes the water since it occurs only during maintenance hence the small impact.

Wind reduces E5 by 91.30% while solar by 88.83%. Land occupation encompasses both agricultural and urban land. The situation with land occupation sometime leads to eviction of people to pave way for the construction of these RES of Energies. There is Land degradation and habitat loss when large scale solar facilities are set up compared to wind sources of energy.

Wind reduces E6 by 84.92% and solar reduces the land transformation by 66.83%. The Solar PV panels set up has a negative value for land transformation due to the fact that the technologies flood significant areas of land, which is frequently wilderness, or natural land, prior to the project being implemented. The result would be true and significantly larger for the larger capacity technology, which would lead to extinction of vegetation and soil erosion.

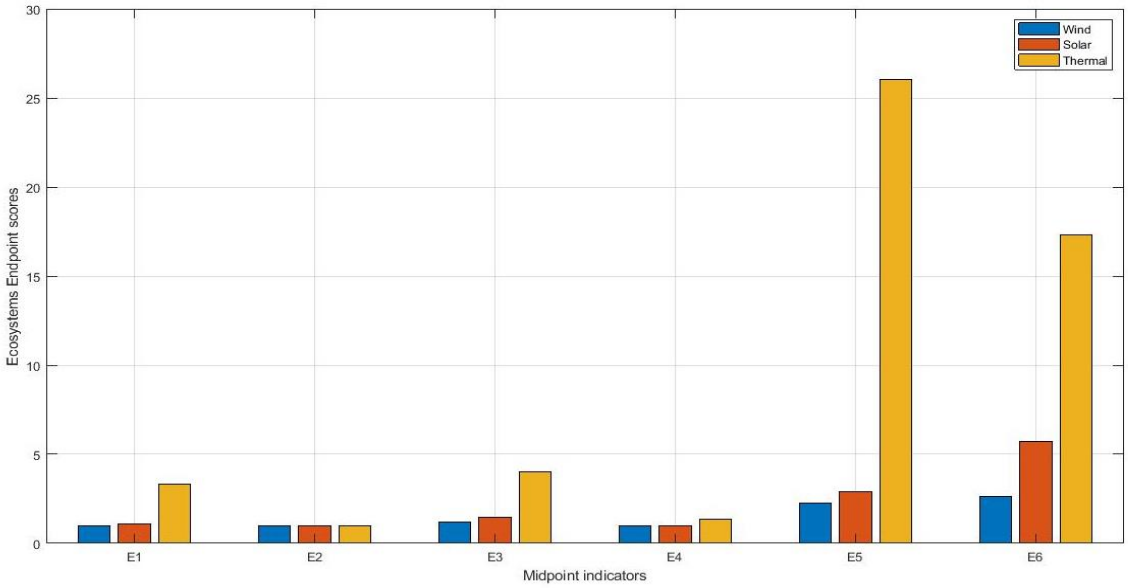

Figure 5.8: Ecosystem End Point Scores for 2.5MW project

5.4: Optimization of Emissions with Fuel Cost Constraints using Thermal, Solar and Wind

In this section, a nominal load of 2.5MW loading at 75% and 125% are considered for comparison. Table 5.7 shows the optimized emissions from thermal, solar and wind energy sources with cost as a constraint. The results here are from the code in Appendix A4 and Appendix Table B4.

Table 5.7: Optimized Emissions from Thermal, Wind and Solar Energy Sources

Source	Main type of emission	75% Nominal Load (kg/kWh)		Nominal Load (kg/kWh)		125%Nominal Load (kg/kWh)	
Wind	Carcinogenic	0.4865		0.5101		0.5387	
Solar	Carcinogenic	0.1543		0.2749		0.3968	
Thermal	CO_2	0.91000	0.9212	0.91667	0.9412	0.92347	0.9616
	SO_2	0.00694		0.01361		0.02041	
	NO_x	0.00422		0.01089		0.01769	

The extracted results are plotted in Figure 5.9. From the figure, it can be observed that wind reduces the level of emissions from noise, dust, CO_2, SO_2 and NO_x by 47.19% for 75%NL, 45.80% for 100%NL and 43.97% for 125%NL cumulatively. Similarly, solar reduces the level of emissions by 83.25% for 75%NL, 70.79% for 100%NL and 58.74% for 125%NL. The trend shows that as the nominal load increases, the percentage emissions changes keep on decreasing although the overall level of emissions per unit energy will be increased. These behaviors are due to the fact that as the load increases with constant generation, there is overloading of the system hence increase in friction would cause the emissions of gases due to overheating and wear and tear.

Since optimal resource availability is considered as an area of protection in our modified ReCiPe model, it is more accurate to determine the optimal emissions with the resource cost as a constraint. The optimal emissions obtained are then applied together with the inter-industry, characterization, stressor and aggregation matrices for the evaluation of the three remaining areas of protection i.e. Health, Ecosystems and Social. It is worth to note that aside from land transformation and land occupation, all the other midpoint indicators are dependent on emissions that are released during the life cycle of the RE technology.

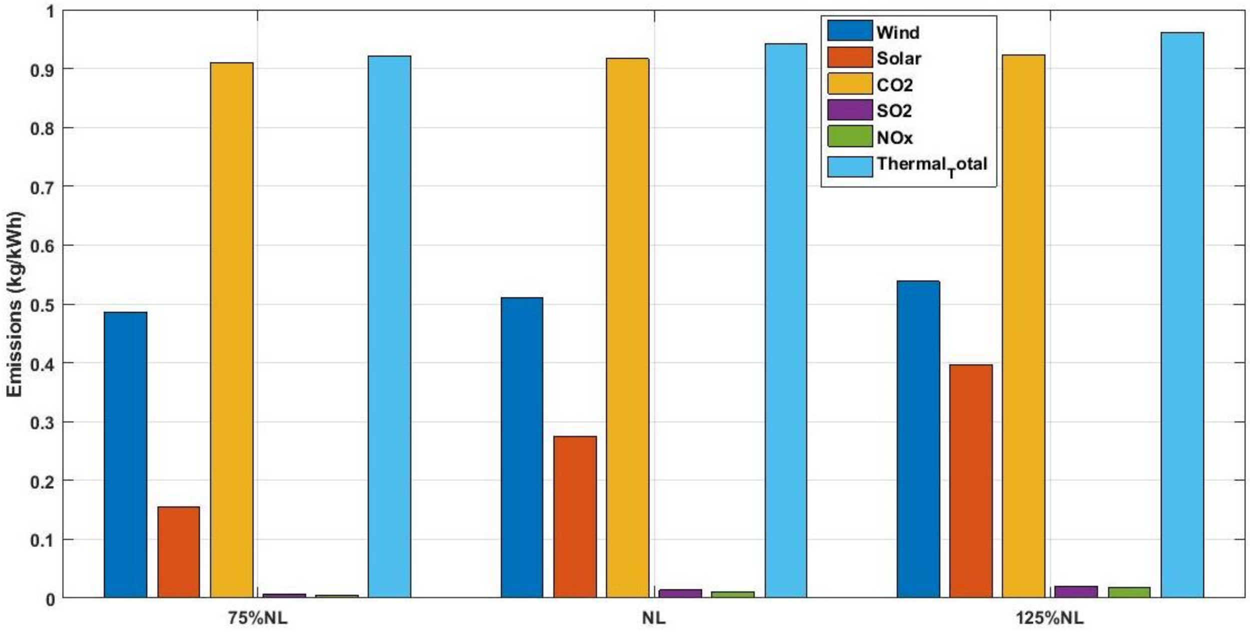

Figure 5.9: Emissions Level for different Nominal Loads

It can also be observed that in thermal emissions, CO_2 is highly emitted followed by SO_2 and NO_x being the least emitted gas. This is because in thermal, coal is burnt and the content is full of carbon. With reduction in utilization of thermal energy, there will be reduction in emission of these gases and this will reduce effects of climate change and global warming.

5.5 Economic and Environmental Decision Making Model (EEDMM)

Once the initial cost of investment is determined and the social impact on investment decision is made as well as the health and ecosystem impacts and emissions are analyzed, a decision is then made by optimizing all the considered factors together. The decisions are made based on whether the cost of investment is inadequate, adequate or too high, the social impact on investment is valid or Unviable and whether or not the health and ecosystem impacts and emissions are favorable. The simulated results from the EEDMM are shown in Table 5.8. The results are simulated using the code in Appendix A5.

Table 5.8: EEDMM Results for 2.5MW RE with different CIRs

Instances	**CIRs**		
	1	**1.04**	**1.12**
1	1.5000	1.5200	1.5600
2	41.0873	41.1327	41.2222
2	80.6746	80.7453	80.8843
4	120.2620	120.3580	120.5465
5	159.8493	159.9706	160.2087
6	199.4366	199.5833	199.8709
7	239.0239	239.1959	239.5330
8	278.6112	278.8086	279.1952
9	318.1986	318.4212	318.8574
10	357.7859	358.0339	358.5196
11	397.3732	397.6465	398.1817

It can be observed that as the cost index ratios increase, the EEDMM is also increasing. This is due to the fact that the initial cost of investment will increase as well as Social Impact Value (SIV) which leads to higher project outcome. This intern will increase the value of philanthropic investment and the total cost of project. Based on these, some decisions have to be made on the Social Impacts, Health Impacts, Ecosystem Impacts and Emissions for optimum conditions leading to overall decision on whether the project is Unviable, recommended or highly recommended. These are summarized in Table 5.9.

Table 5.9: EEDMM Decisions based on the Output Results

EEDMM	**Social Impacts**	**Health Impacts**	**Ecosystem Impacts**	**Emissions**	**Resource Cost**	**Overall Decision**
0 – 100	Invalid	Unfavorable	Unfavorable	Unfavorable	Inadequate	**UnviableProject**
101 – 200	Invalid	Unfavorable	Unfavorable	Unfavorable	Adequate	**Unviable Project**
201 – 300	Invalid	Favorable	Favorable	Favorable	Adequate	**Recommended**
300 – 400	Valid	Slightly Favorable	Slightly Favorable	Favorable	Adequate	**Highly recommended**
>400	Valid	Unfavorable	Unfavorable	Unfavorable	Too high	**Unviable Project**

The results from Table 5.9 are represented as a chart in Figure 5.10. This chart is referred to as EEDMM chart that is useful to the end user for decision making once the output from EEDMM is known.

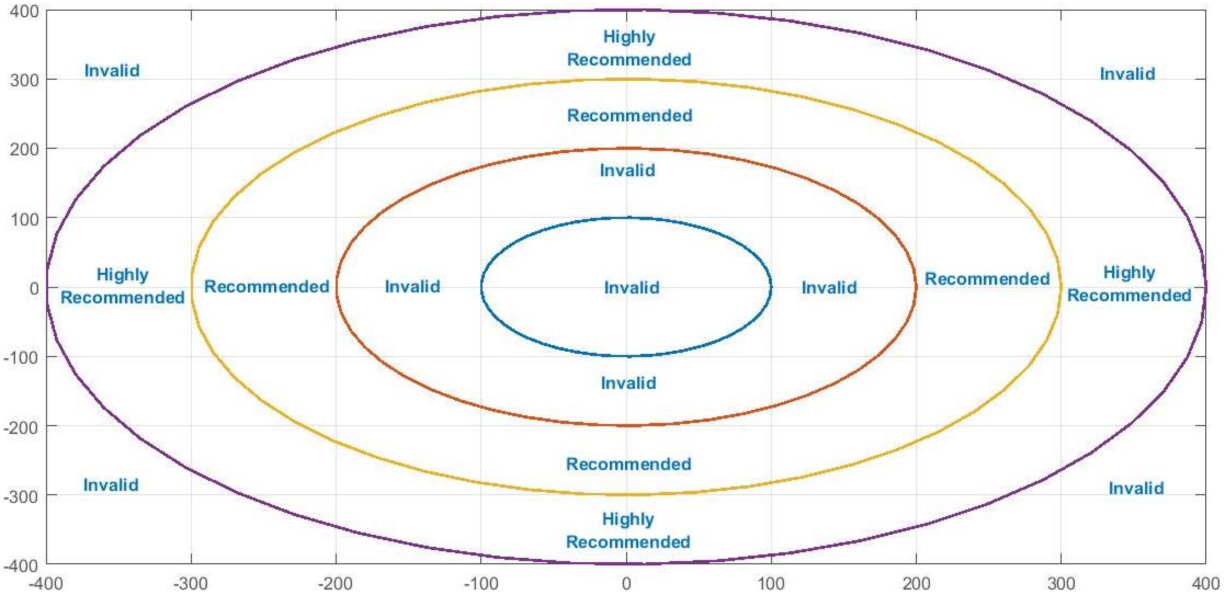

Figure 5.10: EEDMM Chart

5.6 Net Economic Contribution

Immediately a project is recommended to be viable, net economic contribution of the project is analyzed over the lifespan of the project. In this thesis, an average lifespan of 21 years is considered. Table 5.10 shows the results for Net Present Value (NPV) and Net Economic Contribution (NEC) for 2.5MW Solar and Wind Energy Sources. The results are simulated from the code in Appendix A6.

Table 5.10: NPV and NEC for Solar and Wind Energies in 21 years

Year	**Solar (Million USD)**		**Wind (Million USD)**	
	NPV	**NEC**	**NPV Wind**	**NEC Wind**
1	0.32495	0.42239	0.32460	0.38947
3	0.30044	0.41503	0.30011	0.38457
5	0.27777	0.40823	0.27747	0.38004
7	0.25681	0.40195	0.25653	0.37586
9	0.23744	0.39614	0.23718	0.37199
11	0.21953	0.39076	0.21928	0.36841
13	0.20296	0.38580	0.20274	0.36510

Year	**Solar (Million USD)**		**Wind (Million USD)**	
	NPV	**NEC**	**NPV Wind**	**NEC Wind**
15	0.18765	0.38120	0.18744	0.36204
17	0.17349	0.37696	0.17330	0.35921
19	0.16040	0.373030	0.16023	0.35660
21	0.14830	0.36940	0.14814	0.35418

From Table 5.10, the plots of the results are shown in Figure 5.11 and Figure 5.12 for Solar and Wind Sources of Energy respectively. It can be seen that at initial year, say year 1, the NPV for solar is 5.8% of the solar ICOI-WSnew and 5.6% of the wind ICOI-WSnew. In year 21, these percentages for solar and wind reduce to 2.7% and 2.5% respectively. This shows that as the years elapse, the project gets aged and the efficiency reduces hence the financial stability is also affected negatively.

In order to know how the project is performing overall to the economy of a country, NEC shows that in year 1, solar project contributed to the economy a cost mounting to 7.6% of the initial cost of investment while wind project was 6.7%. In year 21, these percentages reduced by 1.0% and 0.6% respectively that is, from 7.6% to 6.6% solar and 6.7% to 6.1% wind.

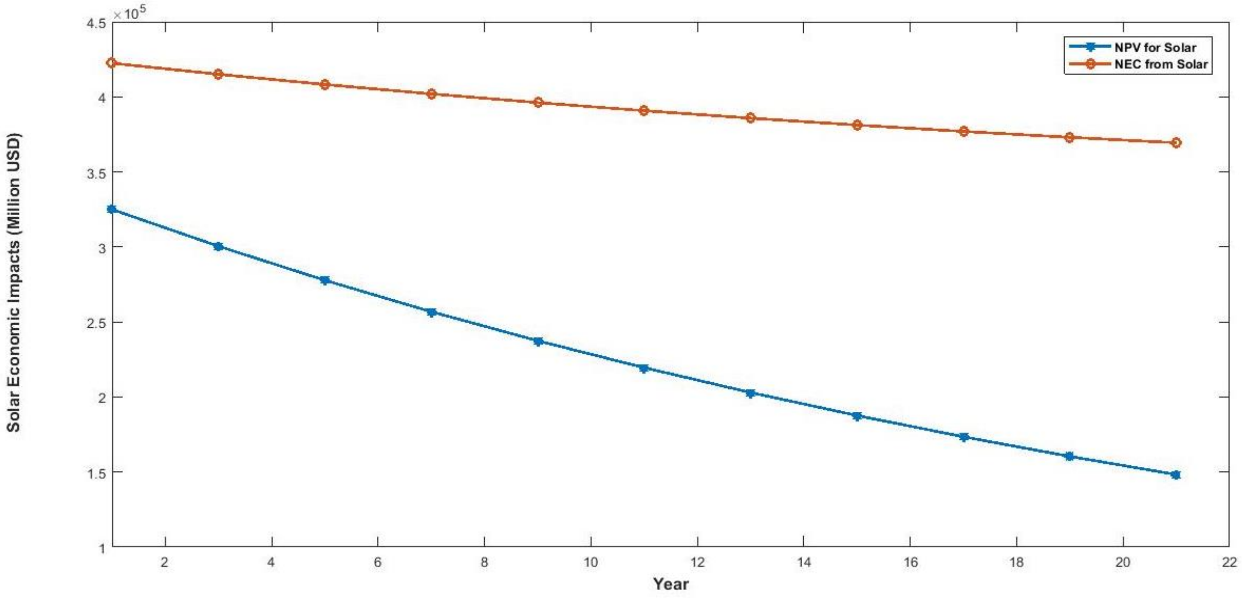

Figure 5.11: Solar Economic Impact (NPV and NEC)

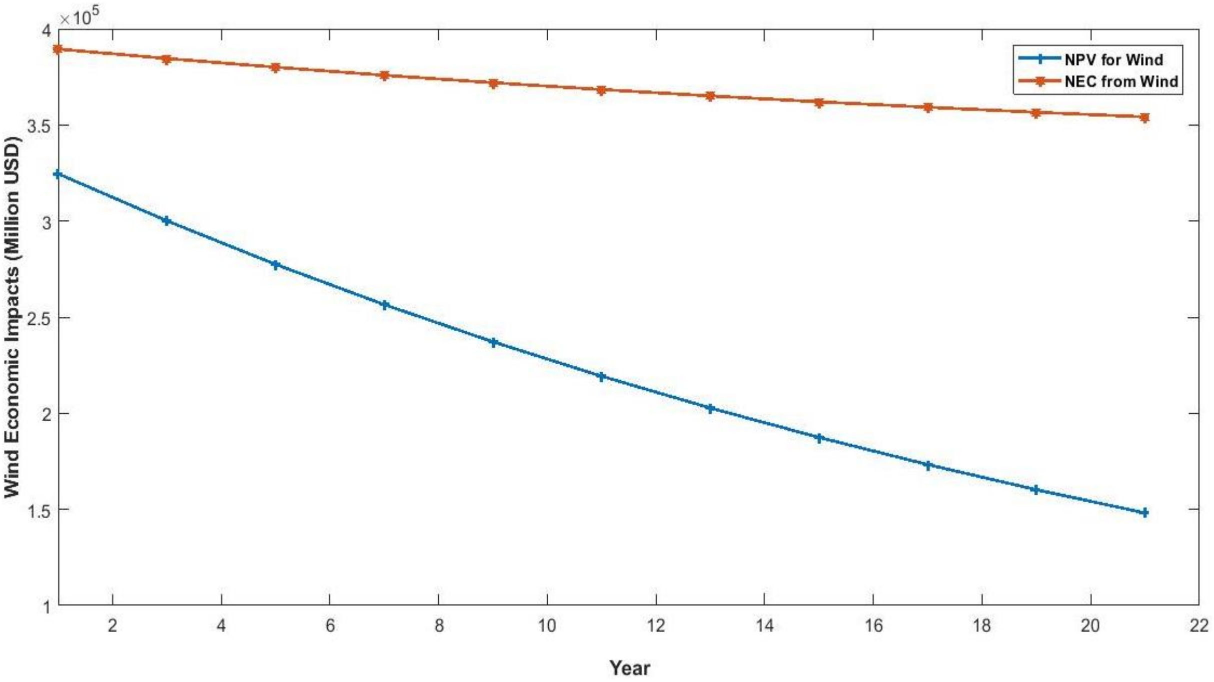

Figure 5.12: Wind Economic Impact (NPV and NEC)

For the same size of project (2.5MW), solar is seen to perform economically better than wind since returns from solar are slightly higher than that from wind. Putting other factors constant, solar is the most economically viable renewable source of energy for optimal utilization. However, this cannot be taken as a fact since other factors considered above are worth investigating before making any conclusion.

5.7 Chapter Conclusion

It can be concluded from this chapter that EEDMM model that was mathematically modeled in Chapter two is able to assist in decision making based on the initial cost of investment of RE, SIIDMM, HEDMM and Emissions impacts. The overall decision made by the EEDMM leads to the investigation of NEC over the lifespan of the project.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

This chapter gives the conclusion and recommendations based on the scope, findings and the challenges encountered.

6.1 Conclusion

EEDMM has been formulated for the first time and the simulated results were validated with 2.5MW wind and solar PV capacity of energy. The Social Impact on Investment Decision Making Model for Optimal Utilization was made and concluded that SIIDMM is only valid when it is positive. For a 2.5MW plant capacity, at least a probability of project outcome above 0.72 is required. This implies that between million USD 5.4 and million USD 7.8 should be planned for to cater for the social community needs for 21 years.

Besides, it concluded that during manufacturing, transportation, installation, operation and maintenance and decommissioning solar or wind plant, emissions are recorded which cause health and ecosystem effects. These also lead to increase in fuel costs. Hence, it proves that Solar and "*Wind Energy Sources are not clean and free"*. For a constant energy generation, an increase in nominal load increases the emissions level but reduces a change in increase in emissions. Solar and Wind, however, reduce the level of emissions when compared to the conventional thermal energy.

Based on the midpoint indicators for health, ecosystem, social and economics, EEDMM optimizes the endpoint scores in order to make decision on the validity of a project. The EEDMM chart is useful to the end user to aid in decision making once the EEDMM output is known.

Once the project passed the test and recommended for implementation, the cost benefit analysis is done based on NPV and NEC for the lifespan of the project. It is concluded that a 2.5MW plants has an average NPV of between 6% and 2.5% for the lifespan of the project. Similarly, NEC ranges averagely between 8% and 6% for the 21 years. Solar has better economic indicators than wind.

6.2 Recommendation

Based on the time constraint challenge and working within the scope, this thesis would not address all the unreported identified gaps. It is on this basis that we recommend the following for future works. These include but not limited to:

- Using a modified judgment matrix for decision making on social impacts for renewable energies for optimal utilization.
- Based on DALY, there is need to separate the formulation of Health and Ecosystem Effects for more accurate analysis of Endpoint Scores
- Further modification of the ReCiPe version to include political aspects as an area of protection. This is because the decisions to set up the RE technologies is reliant on the country's development policies and approval of the relevant authorities.
- Other RES (apart from wind and solar) should be investigated to determine social, health and ecosystem impacts they have to the environment. Furthermore, NPV and NEC should also be studied.
- EEDMM should be developed further to incorporate other economic and environmental factors beyond the once considered in the scope of this thesis.

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Appendix A: MATLAB Code Blocks

A1 New Initial Cost of Investment for Wind and Solar

```
%RESOURCE COST OPTIMIZATION  (1 THERMAL, 2 WIND AND 2 SOLAR GENERATORS)
clear all;%clears Workspace
clc;%clears command Window
%Storage File Name
opf=fopen('ICOI-WS’,'w+');

%GENERATOR VAIABLES 
no_units=4; %Number of units

%Exisitng cost, Indices and Sizes
Pdws1=input ('Please enter the value of variable cost (labor+materials)
for the 2MW existing wind and/or solar project (in million USD)= ');

%VARIABLE COST RANGES BETWEEN 3.0 TO 5.0 MILLION USD
Pdws2=input ('Please enter the value of fixed cost (capital equipment
cost) for the 2MW existing wind and/or solar project (in million USD)=
');

%FIXED COST RANGES BETWEEN 3.0 TO 5.0 MILLION USD
Pdws3=input ('Please enter the size of the proposed wind project (in
kWp)= ');

%THE SIZE RANGES BETWEEN 0 TO MAXIMUM
Pdws4=input ('Please enter the size of the proposed solar PV project (in
kWp)= ');

%THE SIZE RANGES BETWEEN 0 TO MAXIMUM

ICOI-WSexist=Pdws1+Pdws2;
ARnew=Pdws3+Pdws4;
ARexist=2000;

%GENERATION OF RANDOM NUMBERS
x= [0 1];x1=[0.1 0.2];x2=[0.3 0.4];x3=[0.5 0.6];x4=[0.7
0.8];x5=0.9;%PowerSizing exponent
RA= [100 1000]; %range for random numbers in wind unit 1
```

```
RC= [1 150]; %range for random numbers in pv solar unit 2(50 panels
max)
RF= [1 150]; %range for random numbers in pv solar unit 3
RK= [1 150]; %range for random numbers in pv solar unit 4
RL= [0 1000]; %range for random numbers in thermal unit 5


%COST INDEX VALUES
a2=[240.00 210.00 120.00 390.00 360.00]; %accounts for generation changes
a3=[1000 150 150 150 1000]; %accounts for plant operation

ICOI-WSnew=ICOI-WSexist*(1.04)*(ARnew/ARexist).^x;
ICOI-WSnew1=ICOI-WSexist*(1.04)*(ARnew/ARexist).^x1;
ICOI-WSnew2=ICOI-WSexist*(1.04)*(ARnew/ARexist).^x2;
ICOI-WSnew3=ICOI-WSexist*(1.04)*(ARnew/ARexist).^x3;
ICOI-WSnew4=ICOI-WSexist*(1.04)*(ARnew/ARexist).^x4;
ICOI-WSnew5=ICOI-WSexist*(1.04)*(ARnew/ARexist).^x5;


%GENERATOR LIMITS
pmax=[1000 150 150 150]; %maximum generation
pmin=[100 1 1 1]; %minimum generation


%POPULATION VARIABLES
nPop=60.0; %Population size
nAchive=60;
MaxIt=1000;%Maximum number of iterations.

%INITIAL POPULATION
igen= 0; %initializing generation counter
A= randi(RA, nPop, 1); %generates random numbers of size population
C= randi(RC, nPop, 1);
F= randi(RF, nPop, 1);
K= randi(RK, nPop, 1); 
L= randi(RL, nPop, 1);
M= randi (x, nPop, 1);
Pop= [1 2 3 4 5]; %forming initial population

%LOSS COEFFICIENTS
B= 0.45*[0.000218 0.000103 0.000009 -0.000010 0.000002
0.000103 0.000181 0.000004 -0.000015 0.000002
```

```
0.000009 0.000004 0.000417 -0.000131 -0.000153
-0.000010 -0.000015 -0.000131 0.000221 0.000094
0.000002 0.000002 -0.000153 0.000094 0.000243
0.000027 0.000030 -0.000107 0.000050 -0.000000];

%INCREMENTAL COST
alpha=a2;
beta=2*a3;
for i=1:no_units
IncrementalCost_min(i)=alpha(i)+beta(i)*pmin(i);
IncrementalCost_max(i)=alpha(i)+beta(i)*pmax(i);
end
IncrementalCost_min=min(IncrementalCost_min);
IncrementalCost_max=max(IncrementalCost_max);
IncrementalCost_min=IncrementalCost_min';
IncrementalCost_max=IncrementalCost_max';
for i=1:nPop
position(i)= unifrnd(IncrementalCost_min,IncrementalCost_max);
end

%INITIALIZING SPEA2 PARAMETERS
Crossover=zeros(1,nPop);
pareto_max=(IncrementalCost_max-IncrementalCost_min)/10;
for i=1:nPop
pareto(i)= unifrnd(-pareto_max,pareto_max);
end
S1=nPop/30;
S2=nAchive/30;
Rf=S1+S2;
F=2/abs(2-Rf-sqrt(Rf*Rf-4*Rf));
Mutation=0.0;
P=zeros(nPop,no_units);
tic;
for iter=1:MaxIt
for i=1:nPop
for k=1:no_units
Archive_new=0;
for j=1:no_units
if j~=k
```

```
Archive_new=Archive_new+B(k,j)*P(i,j);
end
end
end

%INEQUALITY CONSTRAINTS
Archive_new=2*Archive_new;
for j=1:no_units
Gen_min(j)=1-(alpha(j)/position(i))-Archive_new;
Gen_max(j)=(beta(j)/position(i))+(2*B(j,j));
if P(i,j)>pmax(j)
P(i,j)=pmax(j);
end
if P(i,j)<pmin(j)
P(i,j)=pmin(j);
end
end

%GENERATION CALCULATIONS
Pgen(i)=0.0;
for j=1:no_units
Pgen(i)=Pgen(i)+P(i,j);
end

%ERROR CALCULATIONS
error(i)=Pgen(i);
ArchiveBest_fitness(i)= 1.0/(100.0+abs(error(i)));
if Crossover(i)<ArchiveBest_fitness(i)
Crossover(i)=ArchiveBest_fitness(i);
Crossover_position(i)=position(i);
end

%SELECTION OF THE BEST OFFSPRING
if Mutation<Crossover(i)
Mutation=Crossover(i);
Mutation_position=Crossover_position(i);
end

%WEIGHTING FACTOR CALCULATION
Wmin=0.4;
```

```
Wmax=0.9;
W=Wmax-((Wmax-Wmin)*iter/MaxIt);
pareto(i)=F*(W*pareto(i)+S1*rand()*(Crossover_position(i)-
position(i))+S2*rand()*(Mutation_position-position(i)));

%NEW OFFSPRING UPDATING
if abs(pareto(i))>pareto_max
if pareto(i)<0.0
pareto(i)=-pareto_max;
end
if pareto(i)>0.0
pareto(i)=pareto_max;
end
end

%POSITION UPDATING
tposition=position(i)+pareto(i);
for k=1:no_units
tArchive_new=0;
for j=1:no_units
if j~=k
tArchive_new=tArchive_new+B(k,j)*P(i,j);
end
end
end

%CONTINUATION OF OPTIMIZATION LOOPING
tArchive_new=2*tArchive_new;
for j=1:no_units
Gen_min(j)=1-(alpha(j)/tposition)-tArchive_new;
Gen_max(j)=(beta(j)/tposition)+2*B(j,j);
tp(j)=Gen_min(j)/Gen_max(j);
if tp(j)>pmax(j)
tp(j)=pmax(j);
end
if tp(j)<pmin(j)
tp(j)=pmin(j);
end
end
```

```
tpgen=0.0;
for j=1:no_units, tpgen=tpgen+tp(j);
end

terror_line=tpgen;
Errorl(iter)=terror_line;

terror=tpgen;
Error(iter)=terror;

tArchiveBest_fitness= 1.0/(1.0+abs(terror));
if tArchiveBest_fitness>ArchiveBest_fitness(i)
position(i)=tposition;
Crossover(i)=tArchiveBest_fitness;
Crossover_position(i)=position(i);
end

if Mutation<Crossover(i)
Mutation=Crossover(i);
Mutation_position=Crossover_position(i);
end
end

%TERMINATION CRITERION
if abs(terror)<0.01
break;
end
end

runtime=toc;
fprintf(opf,'\n ICOI-WS USING SPEA2 \n');
fprintf(opf,'\n Problem converged in %d iterations\n',iter);
%fprintf(opf,'\n Optimal Lambda= %g\n',Mutation_position);
for j=1:no_units
fprintf(opf,'\n Pgen(%d)= %g kWp',j,tp(j));
end
for j=5
fprintf(opf,'\n Pgen(%d)= %g kW',j,(ARnew-sum(tp)));
end
fprintf(opf,'\n Total Power Generation = %g kW\n',ARnew);
%fprintf(opf,'\n Total Power Demand = %g MW',Pd);
```

```
 i
 i
%total_cost=0.0;
 i
 i
for ij=1
 i i i ifprintf(opf,'\n iICOI-WSnew(%d) i= imillion i$ i%g i',j,ICOI-WSnew(1));
end
for ij=2
 i i i ifprintf(opf,'\n iICOI-WSnew(%d) i= imillion i$ i%g i',j,ICOI-WSnew1(1));
end
for ij=3
 i i i ifprintf(opf,'\n iICOI-WSnew(%d) i= imillion i$ i%g i',j,ICOI-WSnew1(2));
end
for ij=4
 i i i ifprintf(opf,'\n iICOI-WSnew(%d) i= imillion i$ i%g i',j,ICOI-WSnew2(1));
end
for ij=5
 i i i ifprintf(opf,'\n iICOI-WSnew(%d) i= imillion i$ i%g i',j,ICOI-WSnew2(2));
end
for ij=6
 i i i ifprintf(opf,'\n iICOI-WSnew(%d) i= imillion i$ i%g i',j,ICOI-WSnew3(1));
end
for ij=7
 i i i ifprintf(opf,'\n iICOI-WSnew(%d) i= imillion i$ i%g i',j,ICOI-WSnew3(2));
end
for ij=8
 i i i ifprintf(opf,'\n iICOI-WSnew(%d) i= imillion i$ i%g i',j,ICOI-WSnew4(1));
end
for ij=9
 i i i ifprintf(opf,'\n iICOI-WSnew(%d) i= imillion i$ i%g i',j,ICOI-WSnew4(2));
end
for ij=10
 i i i ifprintf(opf,'\n iICOI-WSnew(%d) i= imillion i$ i%g i',j,ICOI-WSnew5);
end
for ij=11
 i i i ifprintf(opf,'\n iICOI-WSnew(%d) i= imillion i$ i%g i',j,ICOI-WSnew(2));
end
 i i i i
fprintf(opf,'\n icpu itime i= i%g isec.',runtime);
```

```
fclose('all');



%Plotting

t=0:0.1:1;
x=[5.00 5.11 5.23 5.35 5.47 5.59 5.72 5.85 5.98 6.11 6.25];
y=[5.20 5.32 5.44 5.56 5.68 5.81 5.94 6.08 6.21 6.36 6.50];
z=[5.60 5.73 5.86 5.98 6.12 6.26 6.40 6.55 6.69 6.85 7.00];

Ax=plot(t,x,t,y,t,z);


%Solar and wind Plots
x=0:1:10;
y=0:1:10;
z=0:1:10;

%Solar cost output
DATA_Sensitivity=[0 1.07 2.13 3.20 4.28 5.35 6.41 7.48 8.55 9.62 10.69
    0 1.11 2.22 3.33 4.44 5.56 6.67 7.78 8.89 10.00 11.12
    0 1.20 2.40 3.59 4.79 5.98 7.19 8.38 9.58 10.78 11.98];

%Wind cost output
z1=[
    0 1.12 2.24 3.35 4.47 5.59 6.71 7.83 8.94 10.06 11.18
    0 1.16 2.33 3.49 4.65 5.81 6.98 8.14 9.30 10.46 11.62
    0 1.25 2.50 3.75 5.01 6.26 7.51 8.77 10.02 11.27 12.52];

c=[1 1.04 1.12];
d=0:1:10;

figure
bar3(DATA_Sensitivity)
set(gca,'XTickLabel',{'0' '1' '2' '3' '4' '5' '6' '7' '8' '9' '10'})
set(gca,'YTickLabel',{'1' '1.04' '1.12'})
[X,Y] = meshgrid(1:size(DATA_Sensitivity,2), 1:size(DATA_Sensitivity,1));
text(X(:),Y(:), DATA_Sensitivity(:), num2str(DATA_Sensitivity(:)),
'HorizontalAlignment','center', 'VerticalAlignment','bottom')
xlabel('ICOI-WSexist (Million USD)')
ylabel('Cost Index Ratio')
zlabel('ICOI-WSnew (Million USD)')
```

```
figure
bar3(z1)
set(gca,'XTickLabel',{'0' '1' '2' '3' '4' '5' '6' '7' '8' '9' '10'})
set(gca,'YTickLabel',{'1' '1.04' '1.12'})
[X,Y] = meshgrid(1:size(z1,2), 1:size(z1,1));
text(X(:),Y(:), z1(:), num2str(z1(:)), 'HorizontalAlignment','center',
'VerticalAlignment','bottom')
xlabel('ICOI-WSexist (Million USD)')
ylabel('Cost Index Ratio')
zlabel('ICOI-WSnew (Million USD)')
```

A2 Social Impact on Investment Decision Making Model for Optimal Utilization

```
clc
clear all;
close all;
rng default
fileID = fopen('NEC.doc','w+');
opf=fopen('NEC.doc','w+');

%Initial Cost of Investment for Wind and Solar
ICOIw=[5.53 5.75 6.19];
ICOIs=[5.17 5.38 5.79];


%Exisitng cost, Indices and Sizes
Pdws1=input ('Please enter the value of variable cost (labor+materials)
for the 2MW existing wind and/or solar project (in million USD)= ');
%VARIABLE COST RANGES BETWEEN 3.0 TO 5.0 MILLION USD
Pdws2=input ('Please enter the value of fixed cost (capital equipment
cost) for the 2MW existing wind and/or solar project (in million USD)=
');
%FIXED COST RANGES BETWEEN 3.0 TO 5.0 MILLION USD
Pdws3=input ('Please enter the size of the proposed wind project (in
kWp)= ');
%THE SIZE RANGES BETWEEN 0 TO MAXIMUM
Pdws4=input ('Please enter the size of the proposed solar PV project (in
kWp)= ');
%THE SIZE RANGES BETWEEN 0 TO MAXIMUM
Expenses=input('Input the total expenses incurred in USD/Yr');
```

```
Project_Output=input('Input Project Output (USD/Yr)');
Philanthropic_Investment=input('Input Philanthropic Investment (USD/Yr)');


ICOI-WSexist=Pdws1+Pdws2;
ARnew=Pdws3+Pdws4;
ARexist=2000;

syms h

q=ICOI-WSexist*(1.0)*(ARnew/ARexist)^h;
ICOI-WSnew=subs(q, h, 0:0.1:1);
ICOI-WSnew1=double (ICOI-WSnew);

q2=ICOI-WSexist*(1.04)*(ARnew/ARexist)^h;
ICOI-WSnew4=subs(q2, h, 0:0.1:1);
ICOI-WSnew2=double (ICOI-WSnew4);

q3=ICOI-WSexist*(1.12)*(ARnew/ARexist)^h;
ICOI-WSnew5=subs(q3, h, 0:0.1:1);
ICOI-WSnew3=double (ICOI-WSnew5);

syms k
SIVs=(Project_Output*Philanthropic_Investment*k)/(Expenses);
SIVw=(8.99*11.62*k)/(13.48);
SIVnews=subs(SIVs, k, 0:0.1:1);
SIVneww=subs(SIVw, k, 0:0.1:1);
SIVnew1=double (SIVnews);
SIVnew2=double (SIVneww);

SIIDMMs1 =double ((SIVnew1(:) - ICOI-WSnew(1,4))/(ICOI-WSnew(1,4)));
SIIDMMs2 =double ((SIVnew1(:) - ICOI-WSnew4(1,4))/(ICOI-WSnew4(1,4)));
SIIDMMs3 =double ((SIVnew1(:) - ICOI-WSnew5(1,4))/(ICOI-WSnew5(1,4)));

SIIDMMw1 =double ((SIVnew2(:)- ICOI-WSnew(1,6))/(ICOI-WSnew(1,6)));
SIIDMMw2 =double ((SIVnew2(:)- ICOI-WSnew4(1,6))/(ICOI-WSnew4(1,6)));
SIIDMMw3 =double ((SIVnew2(:)- ICOI-WSnew5(1,6))/(ICOI-WSnew5(1,6)));

fprintf(opf,'\n SIV for a newly Proposed Solar PV Plant is Million USD
%g',SIVnew1);

fprintf(opf,'\n SIV for a newly Proposed Wind Plant is Million USD
%g',SIVnew2);

```

```
fprintf(opf,'\n SIIDMM for a newly Proposed Solar PV Plant (index ratio
1) is %g',SIIDMMs1);

fprintf(opf,'\n SIIDMM for a newly Proposed Solar PV Plant (index ratio
1.04) is %g',SIIDMMs2);

fprintf(opf,'\n SIIDMM for a newly Proposed Solar PV Plant (index ratio
1.12) is %g',SIIDMMs3);

fprintf(opf,'\n SIIDMM for a newly Proposed Wind Plant (index ratio 1)
is %g',SIIDMMw1);

fprintf(opf,'\n SIIDMM for a newly Proposed Wind Plant (index ratio
1.04) is %g',SIIDMMw2);

fprintf(opf,'\n SIIDMM for a newly Proposed Wind Plant (index ratio
1.12) is %g',SIIDMMw3);

m=0:0.1:1;
figure
plot(m, SIVnew1, m, SIVnew2); 
xlabel('Probability of Project Outcome')
ylabel('Social Impact on Investment (million USD)')
legend('Solar PV','Wind')

figure
plot(m, SIIDMMs1, m, SIIDMMs2, m, SIIDMMs3);
%hold on
%plot(m,SIIDMMs1(1),SIIDMMs2(1),SIIDMMs3(1), 'r*')
xlabel('Probability of Solar PV Project Outcome')
ylabel('SIIDMM')
legend('Cost Index Ratio 1','Cost Index Ratio 1.04','Cost Index Ratio
1.12')

figure
plot(m, SIIDMMw1, m, SIIDMMw2, m, SIIDMMw3); 
xlabel('Probability of Wind Project Outcome')
ylabel('SIIDMM')
legend('Cost Index Ratio 1','Cost Index Ratio 1.04','Cost Index Ratio
1.12')

fclose('all');
```

A3 Modified ReCiPe for Health and Ecosystem Endpoint Scores

```
%%CODE FOR THE MODIFIED RECIPE VERSION 
clear;
clc;
close all;
doc_name = 'midpoint_scores _for_endpoint_areas_of_protection.xlsx';
% Inter- Industry matrix A obtained from the Modified ReCipe database
A = [1 5 9; 12 1 13; 12.5 1 10];
% Adjusting the A matrix to remove -1s on diagonal
y11=[1.6059 6.1851 8.8549; 7.5389 27.8809 91.5034; 50.334 300.098
150.62323; 22.5611 39.5767 160.51502; 3.0026 3.0082 3.7301; 2.0099 2.0016
2.3054];
y22=[1.0053 1.1151 3.3055; 1.0020 1.0044 1.0045; 1.2103 1.4659 4.0158;
1.0011 1.0029 1.3563; 2.26335 2.90584 26.01588; 2.61 5.74 17.31];
diagAdj=diag(ones(length(A),1));
%A=A+diagAdj;
I = sparse(eye(size(A, 1)));
% Stresso matrix
S = [2 5 3.125; 3.700 2.020 0.5; 6.030 0.600 1.600];
% Calculating the total output vector
y=zeros(size(A,1),1);
y=sparse(y);
% Finding the total output flow vector
x=(I-A)\y;
% Find emissions and impacts due to final demand
e=S*x;
E=S*diag(x);
EI2Agg = 3.4295;
E_agg=E*EI2Agg;
% Calculate material flow matrix
Zi = A*x; %total material flow due to output flow, x
mat_agg = 7.65;
Zi_agg=mat_agg*Zi;
% Optimal emission at nominal load demand with cost constraint
optimal_emissions = 2.82322; %in ton/hr
% emissions with cost constraint at the nominal load
Pd = 2500;
```

```
% Process output
Gi = (A-I)*Pd*optimal_emissions;
% Aggregated Environmental effects
eGi = mtimes(S, Gi);
%Midpoint indicators
Ozone_depletion = [5.00E-07; 1.20E-06; 7.00E-07];
Human_toxicity = [2.50E-07; 1.10E-04; 2.10E-07];
Ionizing_radiation = [5.64E-05; 3.86E-03; 1.00E-03];
Particulate_matter_formation = [2.00E-01; 1.00E+00; 2.20E-01];
Photochemical_oxidation_formation = [8.10E-02; 2.36E-01; 1.15E-01];
Climate_Change = [8.70E+00; 3.10E+01; 1.06E+01];
Terrestrial_Ecotoxicity =[3.20E-04; 1.40E-01; 2.40E-04];
Terrestrial_acidification = [4.90E-01; 1.99E+00; 5.60E-01];
Marine_Freshwater_ecotoxicity =[ 2.20E-04; 1.60E-03; 4.70E-02];
Marine_Freshwater_eutrophication = [5.00E-02; 4.40E-01; 5.30E-02];
Land_occupation = [1.00E+00; 1.00E+00; 1.00E+00];
Land_transformation = [4.00E-01; 1.90E+00; 9.00E-01];
%Re sources used i.e. wind, hydro, solar and the thermal base
RE_ind = [2.5; 2.5; 2.5]*10^6;
%0.65 = WIND
%0.65 = SOLAR
%0.7 = THERMAL
%Calculating end point scores by applying, emissions, stressor, Inter-
%industry and Characterization matrices
filename = 'midpoint_scores _for_endpoint_areas_of_protection.xlsx';

%Health Endpoint Impacts
H1 = transpose(eGi)*Ozone_depletion;
xlswrite (filename,A,1,'B2:B5' );
H2 = eGi*Human_toxicity;
xlswrite (filename,A,1,'B6:B9' );
H3 =transpose(eGi)*Ionizing_radiation;
xlswrite (filename,A,1,'B10:B13' );
H4 = eGi*Particulate_matter_formation;
xlswrite (filename,A,1,'B14:B17' );
H5 = eGi*Photochemical_oxidation_formation;
xlswrite (filename,A,1,'B18:B21' );
H6 = eGi*Climate_Change;

```

```
%Ecosystems iEndpoint iImpacts
xlswrite i(filename,A,1,'B22:B25' i);
E1 i= ieGi*Terrestrial_Ecotoxicity;
xlswrite i(filename,A,1,'B26:B29' i);
E2 i= ieGi*Terrestrial_acidification;
xlswrite i(filename,A,1,'B30:B33' i);
E3 i= ieGi*Marine_Freshwater_ecotoxicity;
xlswrite i(filename,A,1,'B34:B37' i);
E4 i= ieGi*Marine_Freshwater_eutrophication;
xlswrite i(filename,A,1,'B38:B41' i);
E5 i= ieGi*Land_occupation;
xlswrite i(filename,A,1,'B42:B45' i);
E6 i= ieGi*Land_transformation;
 i
xlswrite i(filename,A,1,'B46:B49' i);
d i= i[H1 iRE_ind; iH2 iRE_ind; iH3 iRE_ind; iH4 iRE_ind; iH5 iRE_ind; iH6 iRE_ind;
iE1 iRE_ind; iE2 iRE_ind; iE3 iRE_ind; iE4 iRE_ind; iE5 iRE_ind; iE6 iRE_ind];
 i
%Plot iof ithe iresults
figure i(1)
bar i(y11, i'group');
legend i('Wind', i'Solar', i'Thermal');
ylabel('Health iEndpoint iScores i(kg/kWh)')
xlabel i('Midpoint iIndicators')
grid ion
set(gca, i'Xticklabel',{'H1', i'H2', i'H3','H4','H5','H6'})
 i
figure i(2)
bar(y22, i'group');
legend i('Wind', i'Solar', i'Thermal')
ylabel('Ecosystems iEndpoint iscores')
xlabel i('Midpoint iindicators')
grid ion
set i(gca,'XTicklabel',{'E1', i'E2', i'E3' i, i'E4', i'E5', i'E6'})
```

A4 Thermal, Solar and Wind Emissions

```
clc
clear all;
close all; 
rng default
fileID = fopen('OEFCCSW.doc','w+');
opf=fopen('OEFCCSW.doc','w+');
Pmin=[10 20 15 10 10];          %Minimum power generation in Mw
Pmax=[250 140 100 120 45];      %Maximum power generation in Mw
%POWER DEMAND
Pd=500;
%Pd=input ('Enter the Load demand in MW = ');
%Pd=[150;250;350;450;550]
%GENERATION OF RANDOM NUMBERS
G1= [10 250]; %range for random numbers in gen1
G2= [20 140]; %range for random numbers in gen2
G3= [15 100]; %range for random numbers in gen3
G4= [10 120]; %range for random numbers in gen4
G5= [10 45]; %range for random numbers in gen5
%Thermal cost coefficients
a=[0.020  0.0700 0.0900  0.02500 0.02500].'; 
b=[0.600  0.095  0.025   3.00000 3.00000].'; 
c=[60  45  30   0.0000  0.00000].'; 
e=[0 0 40 30 0].';
f=[0 0 0.008 0.009 0].'; 

%SO2 EMISSION COEFFICIENTS
aso2=[0.0005 0.0014 0.0010 0.0020 0.0013 0.0021];
bso2=[0.150 0.055 0.035 0.070 0.120 0.080];
cso2=[17.00 12.00 10.00 23.50 21.50 22.50];
dso2=[-90.00 -30.50 -80.00 -34.50 -19.75 25.60];
%NOx EMISSION COEFFICIENTS
anox=[0.0012 0.0004 0.0016 0.0012 0.0003 0.0014];
bnox=[0.0520 0.0450 0.0500 0.0700 0.0400 0.0240];
cnox=[18.50 12.00 13.00 17.50 8.50 15.50];
dnox=[-26.00 -35.00 -15.00 -74.00 -89.00 -75.00];
%CO2 EMISSION COEFFICIENTS
aco2=[0.0015 0.0014 0.0016 0.0012 0.0023 0.0014];
```

```
bco2=[0.0920 0.0250 0.0550 0.0100 0.0400 0.0800];
cco2=[14.0 12.5 13.5 13.5 21.0 22.0];
dco2=[-16.0 -93.5 -84.0 -24.5 -59.0 -70.0];
%POPULATION VARIABLES
nPop=100; %Population size
itermax=1000;%Maximum number of iterations.
%INITIAL POPULATION
%INITIAL POPULATION
igen= 0; %initializing generation counter
gen1= randi(G1,nPop, 1); %generates random numbers of size population
gen2= randi(G2, nPop, 1);
gen3= randi(G3, nPop, 1);
gen4= randi(G4, nPop, 1);
gen5= randi(G5, nPop, 1);
Pop= [1 2 3 4 5 6]; %forming initial population
%INCREMENTAL % SO2 EMISSION COEFFICIENTS
aso2=[0.0005 0.0014 0.0010 0.0020 0.0013 0.0021];
bso2=[0.150 0.055 0.035 0.070 0.120 0.080];
cso2=[17.00 12.00 10.00 23.50 21.50 22.50];
dso2=[-90.00 -30.50 -80.00 -34.50 -19.75 25.60];
%NOx EMISSION COEFFICIENTS
anox=[0.0012 0.0004 0.0016 0.0012 0.0003 0.0014];
bnox=[0.0520 0.0450 0.0500 0.0700 0.0400 0.0240];
cnox=[18.50 12.00 13.00 17.50 8.50 15.50];
dnox=[-26.00 -35.00 -15.00 -74.00 -89.00 -75.00];
%CO2 EMISSION COEFFICIENTS
aco2=[0.0015 0.0014 0.0016 0.0012 0.0023 0.0014];
bco2=[0.0920 0.0250 0.0550 0.0100 0.0400 0.0800];
cco2=[14.0 12.5 13.5 13.5 21.0 22.0];
dco2=[-16.0 -93.5 -84.0 -24.5 -59.0 -70.0];
%INITIAL POPULATION
igen= 0; %initializing generation counter
A= randi(G1, nPop, 1); %generates random numbers of size population
C= randi(G2, nPop, 1);
F= randi(G3, nPop, 1);
K= randi(G4, nPop, 1);
L= randi(G5, nPop, 1);
Pop= [1 2 3 4 5]; %forming initial population
```

```
% Emission coefficient
E=[0.0126 -0.90 22.983 0.00375 2.0
    0.0200 -0.10 25.313 0.01750 1.75
    0.0270 -0.01 25.505 0.0625 1.0
    0.0291 -0.005 24.900 0.00834 3.25
    0.0290 -0.004 24.700 0.02500 3.00];
%INCREMENTAL COST
no_units=5;
alpha=b;
beta=2*c;
for i=1:no_units
Lambda_min(i)=alpha(i)+beta(i)*Pmin(i);
Lambda_max(i)=alpha(i)+beta(i)*Pmax(i);
end
lambda_min=min(Lambda_min);
lambda_max=max(Lambda_max);
lambda_min=lambda_min';
lambda_max=lambda_max';

for i=1:nPop
part(i)= unifrnd(lambda_min,lambda_max);
end
%INITIALIZING MPSO PARAMETERS
Pbest=zeros(1,nPop);
vel_max=(lambda_max-lambda_min)/10;
for i=1:nPop
vel(i)= unifrnd(-vel_max,vel_max);
end
c1=2;
c2=2;
psi=c1+c2;
K=2/abs(2-psi-sqrt(psi*psi-4*psi));
Gbest=0.0;
P=zeros(nPop,no_units);
tic;
for iter=1:itermax
for i=1:nPop
for j=1:no_units
```

```
temp=0;
for ᵢj=1:no_units
if ᵢj~=j
temp=temp+E(j,j)*P(i,j);
end
end
end
end
end
%INEQUALITY ᵢCONSTRAINTS
temp=2*temp;
for ᵢj=1:no_units
Nr(j)=1-(alpha(j)/part(i))-temp;
Dr(j)=(beta(j)/part(i));
if ᵢP(i,j)>Pmax(j)
P(i,j)=Pmax(j);
end
if ᵢP(i,j)<Pmin(j)
P(i,j)=Pmin(j);
end
end
%GENERATION ᵢCALCULATIONS
Pgen(i)=0.0;
for ᵢj=1:no_units
Pgen(i)=Pgen(i)+P(i,j);
end
%ERROR ᵢCALCULATIONS
error(i)=Pgen(i)-Pd;
fit(i)= ᵢ1.0/(100.0+abs(error(i))/Pd);
if ᵢPbest(i)<fit(i)
Pbest(i)=fit(i);
Pbest_part(i)=part(i);
end
%PBEST ᵢAND ᵢGBEST ᵢCOMPARISON
if ᵢGbest<Pbest(i)
Gbest=Pbest(i);
Gbest_part=Pbest_part(i);
end
```

```
%WEIGHTING FACTOR CALCULATION
Wmin=0.4;
Wmax=0.9;
W=Wmax-((Wmax-Wmin)*iter/itermax);
vel(i)=K*(W*vel(i)+c1*rand()*(Pbest_part(i)-part(i))+c2*rand()*(Gbest_part-
part(i)));
%VELOCITY UPDATING
if abs(vel(i))>vel_max
if vel(i)<0.0
vel(i)=-vel_max;
end
if vel(i)>0.0
vel(i)=vel_max;
end
end
%POSITION UPDATING
tpart=part(i)+vel(i);
tpart=part(i)+vel(i);
for j=1:no_units
ttemp=0;
for j=1:no_units
if j~=j
ttemp=ttemp+E(j,j)*P(i,j);
end
end
end
%CONTINUATION OF OPTIMIZATION LOOPING
ttemp=2*ttemp;
for j=1:no_units
Nr(j)=1-(alpha(j)/tpart)-ttemp;
Dr(j)=(beta(j)/tpart)+2*E(j,j);
tp(j)=Nr(j)/Dr(j);
if tp(j)>Pmax(j)
tp(j)=Pmax(j);
end
if tp(j)<Pmin(j)
tp(j)=Pmin(j);
end
```

```
end
tP_loss=0.0;
for j=1:no_units
for j=1:no_units
tP_loss=tP_loss+(tp(j)*E(j,j)*tp(j));
end
end
tpgen=0.0;
for j=1:no_units, tpgen=tpgen+tp(j);
end
terror=tpgen-Pd-tP_loss;
Error(iter)=terror;
tfit= 1.0/(1.0+abs(terror)/Pd);
if tfit>fit(i)
part(i)=tpart;
Pbest(i)=tfit;
Pbest_part(i)=part(i);
end
if Gbest<Pbest(i)
Gbest=Pbest(i);
Gbest_part=Pbest_part(i);
end
%TERMINATION CRITERION
while abs(terror)<0.01
break;
end
runtime=toc;
% cost of wind generator where 8.542 is overgenerated power (a constant)
Cwj = 1.75; %initializing Wind Cost coefficient
Crwj = 3; %initializing Cost Coefficient due to overgeneration
Cpwj = 1.5; %initializing Cost Coefficient due to undergeneration
Wind_Fuel_Cost = (Cwj * a(j)*tp(j)*tp(j))+ (Crwj * 8.542)+ (Cpwj *
8.542);
% cost of solar generator where 8.542 is overgenerated power (a
constant)
Cpvj = 2.5; %initializing Solar Cost coefficient
Cppvi = 3; %initializing Cost Coefficient due to overgeneration
Crpvi = 1.5; %initializing Cost Coefficient due to undergeneration
```

```
Solar_Fuel_Cost = (Cpvj *a(j)*tp(j)*tp(j))+ (Cppvi * 8.542)+ (Crpvi * 8.542);
Thermal_Fuel_cost(j)=c(j)+b(j)*tp(j)+a(j)*tp(j)*tp(j)+abs(e(j)*sin(f(j)*(Pmin(j)-tp(j))));
for j=1
fprintf(opf,'\n Thermal Fuel cost of Gen.(%d)= %g $/Hr',j,Thermal_Fuel_cost(1));
end
for j=2
Thermal_Fuel_cost(2)=c(j)+b(j)*tp(j)+a(j)*tp(j)*tp(j)+abs(e(j)*sin(f(j)*(Pmin(j)-tp(j))));
end
for j=2
fprintf(opf,'\n Thermal Fuel cost of Gen.(%d)= %g $/Hr',j,Thermal_Fuel_cost(2));
end
for j=3
fprintf(opf,'\n Wind Fuel cost of Gen.(%d) = $ %g ',j,Wind_Fuel_Cost);
for j=4
fprintf(opf,'\n Wind Fuel cost of Gen.(%d) = $ %g ',j,Wind_Fuel_Cost);
end
end
for j=5
fprintf(opf,'\n Solar Fuel cost of Gen.(%d) = $ %g ',j,Solar_Fuel_Cost);
end
Total_Fuel_Cost=Thermal_Fuel_cost(3)+Thermal_Fuel_cost(4)+Wind_Fuel_Cost+Solar_Fuel_Cost;
total_cost=Total_Fuel_Cost;
fprintf(opf,'\n Total fuel cost= %g $/Hr\n',total_cost);
fprintf(opf,'\n cpu time = %g sec.',runtime);
%SO2 EMISSIONS
total_emission_so2=0.0;
for j=3
Thermal_Emission_so2(1)=dso2(j)+cso2(j)*tp(j)+bso2(j)*tp(j)*tp(j)+aso2(j)*tp(j)*tp(j)*tp(j);
end
for j=1
```

```
fprintf(opf,'\n ᵢThermal ᵢSO2 ᵢEmmission ᵢof ᵢGen.(%d)= ᵢ%g
ᵢkg/Hr',j,Thermal_Emission_so2(1));
end
for ᵢj=2
Thermal_Emission_so2(2)=dso2(j)+cso2(j)*tp(j)+bso2(j)*tp(j)*tp(j)+aso2(j)*tp(
j)*tp(j)*tp(j);
end
for ᵢj=2
fprintf(opf,'\n ᵢThermal ᵢSO2 ᵢEmmission ᵢof ᵢGen.(%d)= ᵢ%g
ᵢkg/Hr',j,Thermal_Emission_so2(2));
end
for ᵢj=3
Wind_Emission_so2(3)=(Cwj ᵢ* ᵢaso2(j)*tp(j)*tp(j))+ ᵢ(Crwj ᵢ* ᵢ8.542)+ ᵢ(Cpwj ᵢ*
ᵢ8.542);
end
for ᵢj=3
fprintf(opf,'\n ᵢWind ᵢSO2 ᵢEmmission ᵢof ᵢGen.(%d)= ᵢ%g
ᵢkg/Hr',j,Wind_Emission_so2(3));
end
for ᵢj=4
Wind_Emission_so2(5)=(Cwj ᵢ* ᵢaso2(j)*tp(j)*tp(j))+ ᵢ(Crwj ᵢ* ᵢ8.542)+ ᵢ(Cpwj ᵢ*
ᵢ8.542);
end
for ᵢj=4
fprintf(opf,'\n ᵢWind ᵢSO2 ᵢEmmission ᵢof ᵢGen.(%d)= ᵢ%g
ᵢkg/Hr',j,Wind_Emission_so2(4));
end
for ᵢj=5
Solar_Emission_so2(5)=(Cpvj ᵢ*aso2(j)*tp(j)*tp(j))+ ᵢ(Cppvi ᵢ* ᵢ8.542)+ ᵢ(Crpvi
ᵢ* ᵢ8.542);
end
for ᵢj=5
fprintf(opf,'\n ᵢSolar ᵢSO2 ᵢEmmission ᵢof ᵢGen.(%d)= ᵢ%g
ᵢkg/Hr',j,Solar_Emission_so2(5));
end
Total_EmissionRE_s02=Thermal_Emission_so2(1)+Thermal_Emission_so2(2)+Wind_Emi
ssion_so2(3);
total_emission_so2=total_emission_so2+Total_EmissionRE_s02;
```

```
fprintf(opf,'\n Total SO2 Emission = %g kg/Hr\n',total_emission_so2);
%NOx EMISSIONS
total_emission_nox=0.0;
Thermal_Emission_nox(j)=dnox(j)+cnox(j)*tp(j)+bnox(j)*tp(j)*tp(j)+anox(j)*tp(
j)*tp(j)*tp(j);
for j=1
fprintf(opf,'\n Thermal NOx Emmission of Gen.(%d)= %g
kg/Hr',j,Thermal_Emission_nox(1));
end
for j=2
Thermal_Emission_nox(2)=dnox(j)+cnox(j)*tp(j)+bnox(j)*tp(j)*tp(j)+anox(j)*tp(
j)*tp(j)*tp(j);
end
for j=2
fprintf(opf,'\n Thermal NOx Emmission of Gen.(%d)= %g
kg/Hr',j,Thermal_Emission_nox(2));
end
for j=3
Wind_Emission_nox(5)=(Cwj * anox(j)*tp(j)*tp(j))+ (Crwj * 8.542)+ (Cpwj *
8.542);
end
for j=3
fprintf(opf,'\n Wind NOx Emmission of Gen.(%d)= %g
kg/Hr',j,Wind_Emission_nox(5));
end
for j=4
Wind_Emission_nox(5)=(Cwj * anox(j)*tp(j)*tp(j))+ (Crwj * 8.542)+ (Cpwj *
8.542);
end
for j=4
fprintf(opf,'\n Wind NOx Emmission of Gen.(%d)= %g
kg/Hr',j,Wind_Emission_nox(4));
end
for j=5
Solar_Emission_nox(5)=(Cpvj *anox(j)*tp(j)*tp(j))+ (Cppvi * 8.542)+ (Crpvi
* 8.542);
end
for j=5
```

```
fprintf(opf,'\n Solar NOx Emmission of Gen.(%d)= %g
kg/Hr',j,Solar_Emission_nox(5));
end
Total_EmissionRE_nox=Thermal_Emission_nox(1)+Thermal_Emission_nox(2)+Wind_Emi
ssion_nox(3)+Wind_Emission_nox(4)+Solar_Emission_nox(5);
total_emission_nox=total_emission_nox+Total_EmissionRE_nox;
fprintf(opf,'\n Total NOx Emission = %g kg/Hr\n',total_emission_nox);
%CO2 EMISSIONS
for j=1
Thermal_Emission_co2(3)=dco2(j)+cco2(j)*tp(j)+bco2(j)*tp(j)*tp(j)+aco2(j)*tp(
j)*tp(j)*tp(j);
end
for j=1
fprintf(opf,'\n Thermal CO2 Emmission of Gen.(%d)= %g
kg/Hr',j,Thermal_Emission_co2(3));
end
for j=2
Thermal_Emission_co2(4)=dco2(j)+cco2(j)*tp(j)+bco2(j)*tp(j)*tp(j)+aco2(j)*tp(
j)*tp(j)*tp(j);
end
for j=2
fprintf(opf,'\n Thermal CO2 Emmission of Gen.(%d)= %g
kg/Hr',j,Thermal_Emission_co2(2));
end
for j=3
Wind_Emission_co2(3)=(Cwj * aco2(j)*tp(j)*tp(j))+ (Crwj * 8.542)+ (Cpwj *
8.542);
end
for j=3
fprintf(opf,'\n Wind CO2 Emmission of Gen.(%d)= %g
kg/Hr',j,Wind_Emission_co2(3));
end
for j=4
Wind_Emission_co2(4)=(Cwj * aco2(j)*tp(j)*tp(j))+ (Crwj * 8.542)+ (Cpwj *
8.542);
end
for j=4
```

```
fprintf(opf,'\n Wind CO2 Emmission of Gen.(%d)= %g
kg/Hr',j,Wind_Emission_co2(4));
end
for j=5
Solar_Emission_co2(5)=(Cpvj *aco2(j)*tp(j)*tp(j))+ (Cppvi * 8.542)+ (Crpvi
* 8.542);
end
for j=5
fprintf(opf,'\n Solar CO2 Emmission of Gen.(%d)= %g
kg/Hr',j,Solar_Emission_co2(5));
end
Total_EmissionRE_c02=Thermal_Emission_co2(1)+Thermal_Emission_co2(2)+Wind_Emi
ssion_co2(4)+Solar_Emission_co2(5);
total_emission_co2=Total_EmissionRE_c02;
fprintf(opf,'\n Total CO2 Emission = %g kg/Hr\n',total_emission_co2);
Total_Thermal_Emission=total_emission_so2+total_emission_nox+total_emission_c
o2;
fprintf(opf,'\n Total Emissions = %g kg/Hr\n',Total_Thermal_Emission);
Total_Wind_Emissions=Wind_Emission_co2(3)+Wind_Emission_so2(4);
Total_Solar_Emissions=Solar_Emission_co2(5)+Solar_Emission_so2(5)+Solar_Emiss
ion_nox(5);
k=[1.00 0.90 0.70 0.50 0.30 0.10 0.00];
% Economic Cost with emission ece using weighing factor k
ece=((1-
k)*(Total_Thermal_Emission)+(Total_Wind_Emissions+Total_Solar_Emissions))+(k*
total_cost);
fprintf(opf,'\n ECE = %g $/Hr\n',ece);

wind=[0.4865 0.5101 0.5387];
solar=[0.1543 0.2749 0.3968];
CO2=[0.91000 0.91667 0.92347];
SO2=[0.00694 0.01361 0.02041];
NOx=[0.00422 0.01089 0.01769];
Thermal_Total=[0.9212 0.9412 0.9616];

figure
y=[wind(1,1) solar(1,1) CO2(1,1) SO2(1,1) NOx(1,1) Thermal_Total(1,1);
wind(1,2) solar(1,2) CO2(1,2) SO2(1,2) NOx(1,2) Thermal_Total(1,2);
wind(1,3) solar(1,3) CO2(1,3) SO2(1,3) NOx(1,3) Thermal_Total(1,3)];
```

```
bar(y, 'group');
legend ('Wind', 'Solar', 'CO2', 'SO2', 'NOx', 'Thermal_Total')
ylabel('Emissions (kg/kWh)')
grid on
set (gca,'XTicklabel',{'75%NL', 'NL', '125%NL'})
```

A5 EEDMM

```
clc
clear all;
close all; 
rng default
fileID = fopen('NEC.doc','w+');
opf=fopen('NEC.doc','w+');

%Initial Cost of Investment for Wind and Solar 
ICOIw=[5.53 5.75 6.19];
ICOIs=[5.17 5.38 5.79];


%Exisitng cost, Indices and Sizes
Pdws1=input ('Please enter the value of variable cost (labor+materials)
for the 2MW existing wind and/or solar project (in million USD)= ');
%VARIABLE COST RANGES BETWEEN 3.0 TO 5.0 MILLION USD
Pdws2=input ('Please enter the value of fixed cost (capital equipment
cost) for the 2MW existing wind and/or solar project (in million USD)=
');
%FIXED COST RANGES BETWEEN 3.0 TO 5.0 MILLION USD
Pdws3=input ('Please enter the size of the proposed wind project (in
kWp)= ');
%THE SIZE RANGES BETWEEN 0 TO MAXIMUM
Pdws4=input ('Please enter the size of the proposed solar PV project (in
kWp)= ');
%THE SIZE RANGES BETWEEN 0 TO MAXIMUM
Expenses=input('Input the total expenses incurred in USD/Yr');
Project_Output=input('Input Project Output (USD/Yr)');
Philanthropic_Investment=input('Input Philanthropic Investment (USD/Yr)');


ICOI-WSexist=Pdws1+Pdws2;
ARnew=Pdws3+Pdws4;
ARexist=2000;
```

```
%GENERATION OF RANDOM NUMBERS
x= [0 1];x1=[0.1 0.2];x2=[0.3 0.4];x3=[0.5 0.6];x4=[0.7
0.8];x5=0.9;%PowerSizing exponent
RA= [100 1000]; %range for random numbers in wind unit 1
RC= [1 150]; %range for random numbers in pv solar unit 2(50 panels
max)
RF= [1 150]; %range for random numbers in pv solar unit 3
RK= [1 150]; %range for random numbers in pv solar unit 4
RL= [0 1000]; %range for random numbers in thermal unit 5

%COST INDEX VALUES
a2=[240.00 210.00 120.00 390.00 360.00]; %accounts for generation changes
a3=[1000 150 150 150 1000]; %accounts for plant operation

syms h

q=ICOI-WSexist*(1.04)*(ARnew/ARexist)^h;
ICOI-WSnew=subs(q, h, 0:0.1:1);
%ICOI-WSnew1=ICOI-WSexist*(1.04)*(ARnew/ARexist).^x1;
%ICOI-WSnew2=ICOI-WSexist*(1.04)*(ARnew/ARexist).^x2;
%ICOI-WSnew3=ICOI-WSexist*(1.04)*(ARnew/ARexist).^x3;
%ICOI-WSnew4=ICOI-WSexist*(1.04)*(ARnew/ARexist).^x4;
%ICOI-WSnew5=ICOI-WSexist*(1.04)*(ARnew/ARexist).^x5;

syms k
SIV=(Project_Output*Philanthropic_Investment*k)/(1000000*ICOI-
WSnew(:,1)+(Project_Output+Philanthropic_Investment));
SIVnew=subs(SIV, k, 0.5:0.05:1);
SIVnew1=double (SIVnew);

Pmin=[1.5 1.5 1.5];                 %Minimum power generation in Mw
Pmax=[2 2 2];           %Maximum power generation in Mw
%POWER DEMAND
Pd=2000000;
%Pd=input ('Enter the Load demand in MW = ');
%Pd=[150;250;350;450;550]
%GENERATION OF RANDOM NUMBERS
G1= [1 2]; %range for random numbers in gen1
G2= [1 2]; %range for random numbers in gen2
G3= [1 2]; %range for random numbers in gen3
```

```
%G4= [10 120]; %range for random numbers in gen4
%G5= [10 45]; %range for random numbers in gen5

%Thermal cost coefficients
a=0.02500; 
b=3.00000; 
c=60; 
e=40;
f=0.008; 

%SO2 EMISSION COEFFICIENTS
aso2=0.0014;
bso2=0.150;
cso2=17.00;
dso2=-90.00;

%NOx EMISSION COEFFICIENTS
anox=0.0012;
bnox=0.0520;
cnox=18.50;
dnox=-26.00;

%CO2 EMISSION COEFFICIENTS
aco2=0.0015;
bco2=0.0920;
cco2=14.0;
dco2=-16.0;

%POPULATION VARIABLES
nPop=100; %Population size
itermax=1000;%Maximum number of iterations.

%INITIAL POPULATION
igen= 0; %initializing generation counter
gen1= randi(G1,nPop, 1); %generates random numbers of size population
gen2= randi(G2, nPop, 1);
gen3= randi(G3, nPop, 1);
%gen4= randi(G4, nPop, 1);
%gen5= randi(G5, nPop, 1);

Pop= [1 2 3]; %forming initial population
```

```
 %INITIAL POPULATION
igen= 0; %initializing generation counter
A= randi(G1, nPop, 1); %generates random numbers of size population
C= randi(G2, nPop, 1);
F= randi(G3, nPop, 1);
%K= randi(G4, nPop, 1);
%L= randi(G5, nPop, 1);
Pop= [1 2 3]; %forming initial population

% Emission coefficient
E=[0.0126 -0.90 22.983
     0.0200 -0.10 25.313
     0.0270 -0.01 25.505
     0.0291 -0.005 24.900
     0.0290 -0.004 24.700];

%INCREMENTAL COST
no_units=3;
alpha=b;
beta=2*c;
for i=1:no_units
Lambda_min(i)=alpha+beta*Pmin(i);
Lambda_max(i)=alpha+beta*Pmax(i);
end
lambda_min=min(Lambda_min);
lambda_max=max(Lambda_max);
lambda_min=lambda_min';
lambda_max=lambda_max';

for i=1:nPop
part(i)= unifrnd(lambda_min,lambda_max);
end

%INITIALIZING MPSO PARAMETERS
Pbest=zeros(1,nPop);
vel_max=(lambda_max-lambda_min)/10;
for i=1:nPop
vel(i)= unifrnd(-vel_max,vel_max);
end
c1=2;
```

```
c2=2;
psi=c1+c2;
K=2/abs(2-psi-sqrt(psi*psi-4*psi));
Gbest=0.0;
P=zeros(nPop,no_units);
tic;
for iter=1:itermax
for i=1:nPop
for j=1:no_units
temp=0;
for j=1:no_units
if j~=j
temp=temp+E(j,j)*P(i,j);
end
end
end
end
end

%INEQUALITY CONSTRAINTS
temp=2*temp;
for j=1:no_units
Nr(j)=1-(alpha/part(i))-temp;
Dr(j)=(beta/part(i));
if P(i,j)>Pmax(j)
P(i,j)=Pmax(j);
end
if P(i,j)<Pmin(j)
P(i,j)=Pmin(j);
end
end

%GENERATION CALCULATIONS
Pgen(i)=0.0;
for j=1:no_units
Pgen(i)=Pgen(i)+P(i,j);
end

%ERROR CALCULATIONS
```

```
error(i)=Pgen(i)-Pd;
fit(i)= i1.0/(100.0+abs(error(i))/Pd);
if iPbest(i)<fit(i)
Pbest(i)=fit(i);
Pbest_part(i)=part(i);
end
 i
%PBEST iAND iGBEST iCOMPARISON
if iGbest<Pbest(i)
Gbest=Pbest(i);
Gbest_part=Pbest_part(i);
end
%WEIGHTING iFACTOR iCALCULATION
Wmin=0.4;
Wmax=0.9;
W=Wmax-((Wmax-Wmin)*iter/itermax);
vel(i)=K*(W*vel(i)+c1*rand()*(Pbest_part(i)-part(i))+c2*rand()*(Gbest_part-
part(i)));
 i
%VELOCITY iUPDATING
if iabs(vel(i))>vel_max
if ivel(i)<0.0
vel(i)=-vel_max;
end
if ivel(i)>0.0
vel(i)=vel_max;
end
end
 i
%POSITION iUPDATING
tpart=part(i)+vel(i);
tpart=part(i)+vel(i);
for ij=1:no_units
ttemp=0;
for ij=1:no_units
if ij~=j
ttemp=ttemp+E(j,j)*P(i,j);
end
end
```

```
end
 ᵢ
%CONTINUATION ᵢOF ᵢOPTIMIZATION ᵢLOOPING
ttemp=2*ttemp;
for ᵢj=1:no_units
Nr(j)=1-(alpha/tpart)-ttemp;
Dr(j)=(beta/tpart)+2*E(j,j);
tp(j)=Nr(j)/Dr(j);
if ᵢtp(j)>Pmax(j)
tp(j)=Pmax(j);
end
if ᵢtp(j)<Pmin(j)
tp(j)=Pmin(j);
end
end
tP_loss=0.0;
for ᵢj=1:no_units
for ᵢj=1:no_units
tP_loss=tP_loss+(tp(j)*E(j,j)*tp(j));
end
end
tpgen=0.0;
for ᵢj=1:no_units, ᵢtpgen=tpgen+tp(j);
end
terror=tpgen-Pd-tP_loss;
Error(iter)=terror;
tfit= ᵢ1.0/(1.0+abs(terror)/Pd);
if ᵢtfit>fit(i)
part(i)=tpart;
Pbest(i)=tfit;
Pbest_part(i)=part(i);
end
if ᵢGbest<Pbest(i)
Gbest=Pbest(i);
Gbest_part=Pbest_part(i);
end
%TERMINATION ᵢCRITERION
while ᵢabs(terror)<0.01
```

```
break;
end
runtime=toc;

% cost of wind generator where 8.542 is overgenerated power (a constant)
Cwj = 1.75; %initializing Wind Cost coefficient
Crwj = 3; %initializing Cost Coefficient due to overgeneration
Cpwj = 1.5; %initializing Cost Coefficient due to undergeneration
Wind_Fuel_Cost = (Cwj * a*tp(j)*tp(j))+ (Crwj * 8.542)+ (Cpwj * 8.542);

% cost of solar generator where 8.542 is overgenerated power (a
constant)
Cpvj = 2.5; %initializing Solar Cost coefficient
Cppvi = 3; %initializing Cost Coefficient due to overgeneration
Crpvi = 1.5; %initializing Cost Coefficient due to undergeneration
Solar_Fuel_Cost = (Cpvj *a*tp(j)*tp(j))+ (Cppvi * 8.542)+ (Crpvi *
8.542);

% Inter- Industry matrix A obtained from the Modified ReCipe database
A = [1 5 9; 12 1 13; 12.5 1 10];
% Adjusting the A matrix to remove -1s on diagonal
diagAdj=diag(ones(length(A),1));
%A=A+diagAdj;
I = sparse(eye(size(A, 1)));
% Stresso matrix
S = [2 5 3.125; 3.700 2.020 0.5; 6.030 0.600 1.600];
% Calculating the total output vector
y=zeros(size(A,1),1);
y=sparse(y);
% Finding the total output flow vector
x=(I-A)\y;
% Find emissions and impacts due to final demand
e=S*x;
E=S*diag(x);
EI2Agg = 3.4295;
E_agg=E*EI2Agg;
% Calculate material flow matrix
Zi = A*x; %total material flow due to output flow, x
mat_agg = 7.65;
```

```
Zi_agg=mat_agg*Zi;
% Optimal emission at nominal load demand with cost constraint
optimal_emissions = 2.82322; %in ton/hr
% emissions with cost constraint at the nominal load
Pd = 2*10^6;
% Process output
Gi = (A-I)*Pd*optimal_emissions;
% Aggregated Environmental effects
eGi = mtimes(S, Gi);
%Midpoint indicators
Ozone_depletion = [ 5.00E-02; 1.20E-01; 7.00E-02];
Human_toxicity = [2.20E-04; 1.10E-01; 2.10E-04];
Ionizing_radiation = [5.64E-01; 1.00E+01; 3.86E-02];
Particulate_matter_formation = [2.00E-01; 1.00E+00; 2.20E-01];
Photochemical_oxidation_formation = [8.10E-02; 2.36E-01; 1.15E-01];
Climate_Change = [8.70E+00; 3.10E+01; 1.06E+01];
Terrestrial_Ecotoxicity =[3.20E-04; 1.40E-01; 2.40E-04];
Terrestrial_acidification = [4.90E-01; 1.99E+00; 5.60E-01];
Marine_Freshwater_ecotoxicity =[ 2.20E-04; 1.60E-03; 4.70E-02];
Marine_Freshwater_eutrophication = [5.00E-02; 4.40E-01; 5.30E-02];
Land_occupation = [1.00E+00; 1.00E+00; 1.00E+00];
Land_transformation = [4.00E-01; 1.90E+00; 9.00E-01];
%Re sources used i.e. wind, hydro, solar and the thermal base
RE_ind = [0.65; 0.65; 0.7]*10^6;
%0.65 = WIND
%0.65 = SOLAR
%0.7 = THERMAL
%Calculating end point scores by applying, emissions, stressor, Inter-
%industry and Characterization matrices
filename = 'midpoint_scores _for_endpoint_areas_of_protection.xlsx';

%Health Endpoint Impacts
H1 = eGi*Ozone_depletion;
xlswrite (filename,A,1,'B2:B5' );
H2 = eGi*Human_toxicity;
xlswrite (filename,A,1,'B6:B9' );
H3 = eGi*Ionizing_radiation;
xlswrite (filename,A,1,'B10:B13' );
```

```
H4 = eGi*Particulate_matter_formation;
xlswrite (filename,A,1,'B14:B17' );
H5 = eGi*Photochemical_oxidation_formation;
xlswrite (filename,A,1,'B18:B21' );
H6 = eGi*Climate_Change;

%Ecosystems Endpoint Impacts
xlswrite (filename,A,1,'B22:B25' );
E1 = eGi*Terrestrial_Ecotoxicity;
xlswrite (filename,A,1,'B26:B29' );
E2 = eGi*Terrestrial_acidification;
xlswrite (filename,A,1,'B30:B33' );
E3 = eGi*Marine_Freshwater_ecotoxicity;
xlswrite (filename,A,1,'B34:B37' );
E4 = eGi*Marine_Freshwater_eutrophication;
xlswrite (filename,A,1,'B38:B41' );
E5 = eGi*Land_occupation;
xlswrite (filename,A,1,'B42:B45' );
E6 = eGi*Land_transformation;


%SO2 EMISSIONS
total_emission_so2=0.0;
for j=1
Thermal_Emission_so2=dso2(j)+cso2(j)*tp(j)+bso2(j)*tp(j)*tp(j)+aso2(j)*tp(j)*
tp(j)*tp(j);
end
for j=2
Wind_Emission_so2=(Cwj * aso2*tp(j)*tp(j))+ (Crwj * 8.542)+ (Cpwj *
8.542);
end
for j=3
Solar_Emission_so2=(Cpvj *aso2*tp(j)*tp(j))+ (Cppvi * 8.542)+ (Crpvi *
8.542);
end

Total_Emission_s02=Thermal_Emission_so2+Wind_Emission_so2+Solar_Emission_so2;

%NOx EMISSIONS
total_emission_nox=0.0;
```

```
for ij=1
Thermal_Emission_nox=dnox+cnox*tp(j)+bnox*tp(j)*tp(j)+anox(j)*tp(j)*tp(j)*tp(
j);
end
for ij=2
Wind_Emission_nox=(Cwj i* ianox*tp(j)*tp(j))+ i(Crwj i* i8.542)+ i(Cpwj i*
i8.542);
end
for ij=3
Solar_Emission_nox=(Cpvj i*anox*tp(j)*tp(j))+ i(Cppvi i* i8.542)+ i(Crpvi i*
i8.542);
end
 i
Total_Emission_nox=Thermal_Emission_nox+Wind_Emission_nox+Solar_Emission_nox;
 i
%CO2 iEMISSIONS
for ij=1
Thermal_Emission_co2=dco2(j)+cco2(j)*tp(j)+bco2(j)*tp(j)*tp(j)+aco2(j)*tp(j)*
tp(j)*tp(j);
end
for ij=2
Wind_Emission_co2=(Cwj i* iaco2*tp(j)*tp(j))+ i(Crwj i* i8.542)+ i(Cpwj i*
i8.542);
end
for ij=3
Solar_Emission_co2=(Cpvj i*aco2*tp(j)*tp(j))+ i(Cppvi i* i8.542)+ i(Crpvi i*
i8.542);
end
 i
Total_Emission_c02=Thermal_Emission_co2+Wind_Emission_co2+Solar_Emission_co2;
 i
Total_Thermal_Emission=Thermal_Emission_so2+Thermal_Emission_nox+Thermal_Emis
sion_co2;
 i
Total_Wind_Emissions=Wind_Emission_co2+Wind_Emission_so2+Wind_Emission_nox;
 i
Total_Solar_Emissions=Solar_Emission_co2+Solar_Emission_so2+Solar_Emission_no
x;
 i
SIIDMM i=double i((SIVnew1(1,1)- i1000*(ICOI-WSnew(1,1)))/1000*(ICOI-
WSnew(1,1)));
```

```
HEDMMs i=
i(H1(1,1)+H2(1,1)+H3(1,1)+H4(1,1)+H5(1,1)+H6(1,1)+E1(1,1)+E2(1,1)+E3(1,1)+E4(1
,1)+E5(1,1)+E6(1,1))/10^10;
HEDMMw i=
i(H1(2,1)+H2(2,1)+H3(2,1)+H4(2,1)+H5(2,1)+H6(2,1)+E1(2,1)+E2(2,1)+E3(2,1)+E4(2
,1)+E5(2,1)+E6(2,1))/10^10;
HEDMM i= iHEDMMs+HEDMMw;
 i
syms ia
OEFCCSW i= i(Total_Solar_Emissions+Total_Wind_Emissions)*a;
OEFCCSWnew i=double i(subs i(OEFCCSW, ia, i0:0.1:1));
 i
syms ib
Resource=b*ICOI-WSnew(1,1)*10;
BICOI-WSnew=double i(subs i(Resource, ib, i0.1:0.1:1.1));
 i
EEDMM i= iOEFCCSWnew i+((1-SIIDMM)+HEDMM)+BICOI-WSnew;

r0 i= i100 i; i i% iinner iradius
r1 i= i200. i; i i i% iouter iradius
r2= i300.;
r3= i400.;
% icircles
th i= ilinspace(0,2*pi) i;
x0 i= ir0*sin(th) i; iy0 i= ir0*cos(th) i;
x1 i= ir1*sin(th) i; iy1 i= ir1*cos(th) i;
x2 i= ir2*sin(th) i; iy2 i= ir2*cos(th) i;
x3 i= ir3*sin(th) i; iy3 i= ir1*cos(th) i;
plot(x0,y0,x1,y1,x2,y2,x3,y3,'r') i;
hold ion
plot(x1,y1,'r') i;
hold ion
plot(x2,y2,'r') i;
hold ion
plot(x3,y3,'r') i;
%%generate irandom inumbers
x i= i[x1 iNaN ifliplr(x0)] i;
y i= i[y1 iNaN ifliplr(y0)] i;
a i= i-1;
```

```
b = 1;
count = 0 ;
n = 0 ;   % number of pints lying inside 
while count==0
    r = (b-a).*rand(1,2) + a;
    idx = inpolygon(r(1),r(2),x,y) ;
    if idx
        plot(r(1),r(2),'.g')
        n = n+1 ;
    else
        plot(r(1),r(2),'.b')
    end
    drawnow
end
fclose('all');
```

A6 NPV and Net-Economic Contributions

```
clc
clear all;
close all; 
rng default
fileID = fopen('NEC.doc','w+');

opf=fopen('NEC.doc','w+');

 
%Initial Cost of Investment for Wind and Solar 
ICOIw=[5.53 5.75 6.19];
ICOIs=[5.17 5.38 5.79];
 
 
%Exisitng cost, Indices and Sizes
Pdws1=input ('Please enter the value of variable cost (labor+materials)
for the 2MW existing wind and/or solar project (in million USD)= ');
%VARIABLE COST RANGES BETWEEN 3.0 TO 5.0 MILLION USD
Pdws2=input ('Please enter the value of fixed cost (capital equipment
cost) for the 2MW existing wind and/or solar project (in million USD)=
');
```

```
%FIXED COST RANGES BETWEEN 3.0 TO 5.0 MILLION USD
Pdws3=input ('Please enter the size of the proposed wind project (in
kWp)= ');

%THE SIZE RANGES BETWEEN 0 TO MAXIMUM
Pdws4=input ('Please enter the size of the proposed solar PV project (in
kWp)= ');

%THE SIZE RANGES BETWEEN 0 TO MAXIMUM
Expenses=input('Input the total expenses incurred in USD/Yr');
Project_Output=input('Input Project Output (USD/Yr)');
Philanthropic_Investment=input('Input Philanthropic Investment (USD/Yr)');


ICOI-WSexist=Pdws1+Pdws2;
ARnew=Pdws3+Pdws4;
ARexist=2000;


%GENERATION OF RANDOM NUMBERS
x= [0 1];x1=[0.1 0.2];x2=[0.3 0.4];x3=[0.5 0.6];x4=[0.7
0.8];x5=0.9;%PowerSizing exponent

RA= [100 1000]; %range for random numbers in wind unit 1
RC= [1 150]; %range for random numbers in pv solar unit 2(50 panels
max)
RF= [1 150]; %range for random numbers in pv solar unit 3
RK= [1 150]; %range for random numbers in pv solar unit 4
RL= [0 1000]; %range for random numbers in thermal unit 5

%COST INDEX VALUES
a2=[240.00 210.00 120.00 390.00 360.00]; %accounts for generation changes
a3=[1000 150 150 150 1000]; %accounts for plant operation


syms h

q=ICOI-WSexist*(1.0)*(ARnew/ARexist)^h;
ICOI-WSnew=subs(q, h, 0:0.1:1);
ICOI-WSnew1=double (ICOI-WSnew);
```

```

q2=ICOI-WSexist*(1.04)*(ARnew/ARexist)^h;
ICOI-WSnew4=subs(q2, h, 0:0.1:1);
ICOI-WSnew2=double (ICOI-WSnew4);

q3=ICOI-WSexist*(1.12)*(ARnew/ARexist)^h;
ICOI-WSnew5=subs(q3, h, 0:0.1:1);
ICOI-WSnew3=double (ICOI-WSnew5);


syms k
SIVs=(Project_Output*Philanthropic_Investment*k)/(Expenses);
SIVw=(8.99*11.62*k)/(13.48);
SIVnews=subs(SIVs, k, 0:0.1:1);
SIVneww=subs(SIVw, k, 0:0.1:1);
SIVnew1=double (SIVnews);
SIVnew2=double (SIVneww);

Pmin=[1.5 1.5 1.5];          %Minimum power generation in Mw
Pmax=[2.5 2.5 2.5];       %Maximum power generation in Mw

%POWER DEMAND
Pd=2000000;
%Pd=input ('Enter the Load demand in MW = ');
%Pd=[150;250;350;450;550]

%GENERATION OF RANDOM NUMBERS
G1= [1 3]; %range for random numbers in gen1
G2= [1 3]; %range for random numbers in gen2
G3= [1 3]; %range for random numbers in gen3
%G4= [10 120]; %range for random numbers in gen4
%G5= [10 45]; %range for random numbers in gen5


%Thermal cost coefficients
a=0.02500; 
b=3.00000; 
c=60; 
e=40;
f=0.008; 
```

```
 i
%SO2 iEMISSION iCOEFFICIENTS
aso2=0.0014;
bso2=0.150;
cso2=17.00;
dso2=-90.00;

 i
%NOx iEMISSION iCOEFFICIENTS
anox=0.0012;
bnox=0.0520;
cnox=18.50;
dnox=-26.00;

 i
%CO2 iEMISSION iCOEFFICIENTS
aco2=0.0015;
bco2=0.0920;
cco2=14.0;
dco2=-16.0;

 i
%POPULATION iVARIABLES
nPop=100; i%Population isize
itermax=1000;%Maximum inumber iof iiterations.

 i
%INITIAL iPOPULATION
igen= i0; i%initializing igeneration icounter
gen1= irandi(G1,nPop, i1); i%generates irandom inumbers iof isize ipopulation
gen2= irandi(G2, inPop, i1);
gen3= irandi(G3, inPop, i1);
%gen4= irandi(G4, inPop, i1);
%gen5= irandi(G5, inPop, i1);

 i
Pop= i[1 i2 i3]; i%forming iinitial ipopulation
 i
 i
 i
```

```
%INITIAL POPULATION
igen= 0; %initializing generation counter
A= randi(G1, nPop, 1); %generates random numbers of size population
C= randi(G2, nPop, 1);
F= randi(G3, nPop, 1);
%K= randi(G4, nPop, 1);
%L= randi(G5, nPop, 1);
Pop= [1 2 3]; %forming initial population


% Emission coefficient
E=[0.0126 -0.90 22.983
    0.0200 -0.10 25.313
    0.0270 -0.01 25.505
    0.0291 -0.005 24.900
    0.0290 -0.004 24.700];

%INCREMENTAL COST
no_units=3;
alpha=b;
beta=2*c;
for i=1:no_units
Lambda_min(i)=alpha+beta*Pmin(i);
Lambda_max(i)=alpha+beta*Pmax(i);
end
lambda_min=min(Lambda_min);
lambda_max=max(Lambda_max);
lambda_min=lambda_min';
lambda_max=lambda_max';

for i=1:nPop
part(i)= unifrnd(lambda_min,lambda_max);
end



%INITIALIZING MPSO PARAMETERS
Pbest=zeros(1,nPop);
vel_max=(lambda_max-lambda_min)/10;
for i=1:nPop
vel(i)= unifrnd(-vel_max,vel_max);
```

```
end
c1=2;
c2=2;
psi=c1+c2;
K=2/abs(2-psi-sqrt(psi*psi-4*psi));
Gbest=0.0;
P=zeros(nPop,no_units);
tic;
for iter=1:itermax
for i=1:nPop
for j=1:no_units
temp=0;
for j=1:no_units
if j~=j
temp=temp+E(j,j)*P(i,j);
end
end
end
end
end


%INEQUALITY CONSTRAINTS
temp=2*temp;
for j=1:no_units
Nr(j)=1-(alpha/part(i))-temp;
Dr(j)=(beta/part(i));
if P(i,j)>Pmax(j)
P(i,j)=Pmax(j);
end
if P(i,j)<Pmin(j)
P(i,j)=Pmin(j);
end
end


%GENERATION CALCULATIONS
Pgen(i)=0.0;
for j=1:no_units
```

```
Pgen(i)=Pgen(i)+P(i,j);
End

%ERROR CALCULATIONS
error(i)=Pgen(i)-Pd;
fit(i)= 1.0/(100.0+abs(error(i))/Pd);
if Pbest(i)<fit(i)
Pbest(i)=fit(i);
Pbest_part(i)=part(i);
End

%PBEST AND GBEST COMPARISON
if Gbest<Pbest(i)
Gbest=Pbest(i);
Gbest_part=Pbest_part(i);
End

%WEIGHTING FACTOR CALCULATION
Wmin=0.4;
Wmax=0.9;
W=Wmax-((Wmax-Wmin)*iter/itermax);
vel(i)=K*(W*vel(i)+c1*rand()*(Pbest_part(i)-part(i))+c2*rand()*(Gbest_part-
part(i)));

%VELOCITY UPDATING
if abs(vel(i))>vel_max
if vel(i)<0.0
vel(i)=-vel_max;
end
if vel(i)>0.0
vel(i)=vel_max;
end
end

%POSITION UPDATING
```

```
tpart=part(i)+vel(i);
tpart=part(i)+vel(i);
for j=1:no_units
ttemp=0;
for j=1:no_units
if j~=j
ttemp=ttemp+E(j,j)*P(i,j);
end
end
end


%CONTINUATION OF OPTIMIZATION LOOPING
ttemp=2*ttemp;
for j=1:no_units
Nr(j)=1-(alpha/tpart)-ttemp;
Dr(j)=(beta/tpart)+2*E(j,j);
tp(j)=Nr(j)/Dr(j);
if tp(j)>Pmax(j)
tp(j)=Pmax(j);
end
if tp(j)<Pmin(j)
tp(j)=Pmin(j);
end
end
tP_loss=0.0;
for j=1:no_units
for j=1:no_units
tP_loss=tP_loss+(tp(j)*E(j,j)*tp(j));
end
end
tpgen=0.0;
for j=1:no_units, tpgen=tpgen+tp(j);
end
terror=tpgen-Pd-tP_loss;
Error(iter)=terror;
tfit= 1.0/(1.0+abs(terror)/Pd);
if tfit>fit(i)
```

```
part(i)=tpart;
Pbest(i)=tfit;
Pbest_part(i)=part(i);
end
if Gbest<Pbest(i)
Gbest=Pbest(i);
Gbest_part=Pbest_part(i);
end

%TERMINATION CRITERION
while abs(terror)<0.01
break;
end

runtime=toc;

% cost of wind generator where 8.542 is overgenerated power (a constant)
Cwj = 1.75; %initializing Wind Cost coefficient
Crwj = 3; %initializing Cost Coefficient due to overgeneration
Cpwj = 1.5; %initializing Cost Coefficient due to undergeneration
Wind_Fuel_Cost = (Cwj * a*tp(j)*tp(j))+ (Crwj * 8.542)+ (Cpwj * 8.542);

% cost of solar generator where 8.542 is overgenerated power (a
constant)
Cpvj = 2.5; %initializing Solar Cost coefficient
Cppvi = 3; %initializing Cost Coefficient due to overgeneration
Crpvi = 1.5; %initializing Cost Coefficient due to undergeneration
Solar_Fuel_Cost = (Cpvj *a*tp(j)*tp(j))+ (Cppvi * 8.542)+ (Crpvi *
8.542);


syms t
z = 365*24*(Solar_Fuel_Cost)/(1.04)^t;
d= 365*24*(Wind_Fuel_Cost)/(1.04)^t;
NPVs = subs(z, t, 1:2:21);
NPVw = subs(d, t, 1:2:21);

NPVs1 = double(NPVs-5.56002);
NPVw1 = double(NPVw-5.81378);
```

```
NECs = (NPVs1(:,1) - (Solar_Fuel_Cost+Expenses))+ SIVnew1+(0.3*NPVs1);
NECw = (NPVw1(:,1) - (Wind_Fuel_Cost+Expenses))+ SIVnew2+(0.2*NPVw1);
NECt=NECs+NECw;


fprintf(opf,'\n Net Present Value for Solar = %g USD/Yr\n',NPVs1);
fprintf(opf,'\n Net Present Value for Wind = %g USD/Yr\n',NPVw1);

fprintf(opf,'\n Net Economic Contribution for Solar = %g USD/Yr\n',NECs);
fprintf(opf,'\n Net Economic Contribution for Wind = %g USD/Yr\n',NECw);
fprintf(opf,'\n Total Net Economic Contribution = %g USD/Yr\n',NECt);

figure (1)
y=1:2:21;
plot(y,NPVs1,y,NECs);
xlabel('Year')
ylabel('Solar Economic Impacts (Million USD)')
legend('NPV for Solar','NEC from Solar')

figure (2)
y=1:2:21;
plot(y,NPVw1,y,NECw);
xlabel('Year')
ylabel('Wind Economic Impacts (Million USD)')
legend('NPV for Wind','NEC from Wind')
```

Appendix B: Simulation Results Data

Table B1: Initial Cost of Investment Data

	Range	**wind**	**solar**
Powersizing Exponential	[0 – 1]	0.5	0.3
Cost Index Ratios	1 – 1.12	1.0 1.04 1.12	1.0 1.04 1.12
Existing Initial cost of investment (million USD)	4.95 – 5.15	5	5
Size of Existing Plant (MW)	1 - 80	2	2
Proposed Plant size (MW)		2.5	2.5

Table B2: SIIDMM Data

	Solar (Million USD)	**Wind (Million USD)**
Project Outcome	8.60	8.99
Philanthropic Investment	11.12	11.62
Project Total Cost	11.903	13.48
Probability of the Project Outcome	[0 – 1]	[0 – 1]

Table B3: HEDMM Data

	Solar	**Wind**	**Thermal**
Inter-industry Matrix	[1 12 12.5]	[5 1 1]	[12.5 13 10]
Stresso Matrix	[2.0 3.7 6.03]	[5.0 2.02 0.6]	[3.125 0.5 1.6]
Ozone Depletion	5.00E-02	1.20E-01	7.00E-02
Human Toxicity	2.20E-04	1.10E-01	2.10E-04
Ionizing Radiation	5.64E-01	1.00E+01	3.86E-02
Particulate Matter Formation	2.00E-01	1.00E+00	2.20E-01
Photochemical Oxidation Formation	8.10E-02	2.36E-01	1.15E-01
Climate Change	8.70E+00	3.10E+01	1.06E+01

	Solar	**Wind**	**Thermal**
Terrestrial Ecotoxicity	3.20E-04	1.40E-01	2.40E-04
Terrestrial Acidification	4.90E-01	1.99E+00	5.60E-01
Marine Freshwater Eco-toxicity	2.20E-04	1.60E-03	4.70E-02
Marine Freshwater Eutrophication	5.00E-02	4.40E-01	5.30E-02
Land Occupation	1.00E+00	1.00E+00	1.00E+00
Land Transformation	4.00E-01	1.90E+00	9.00E-01

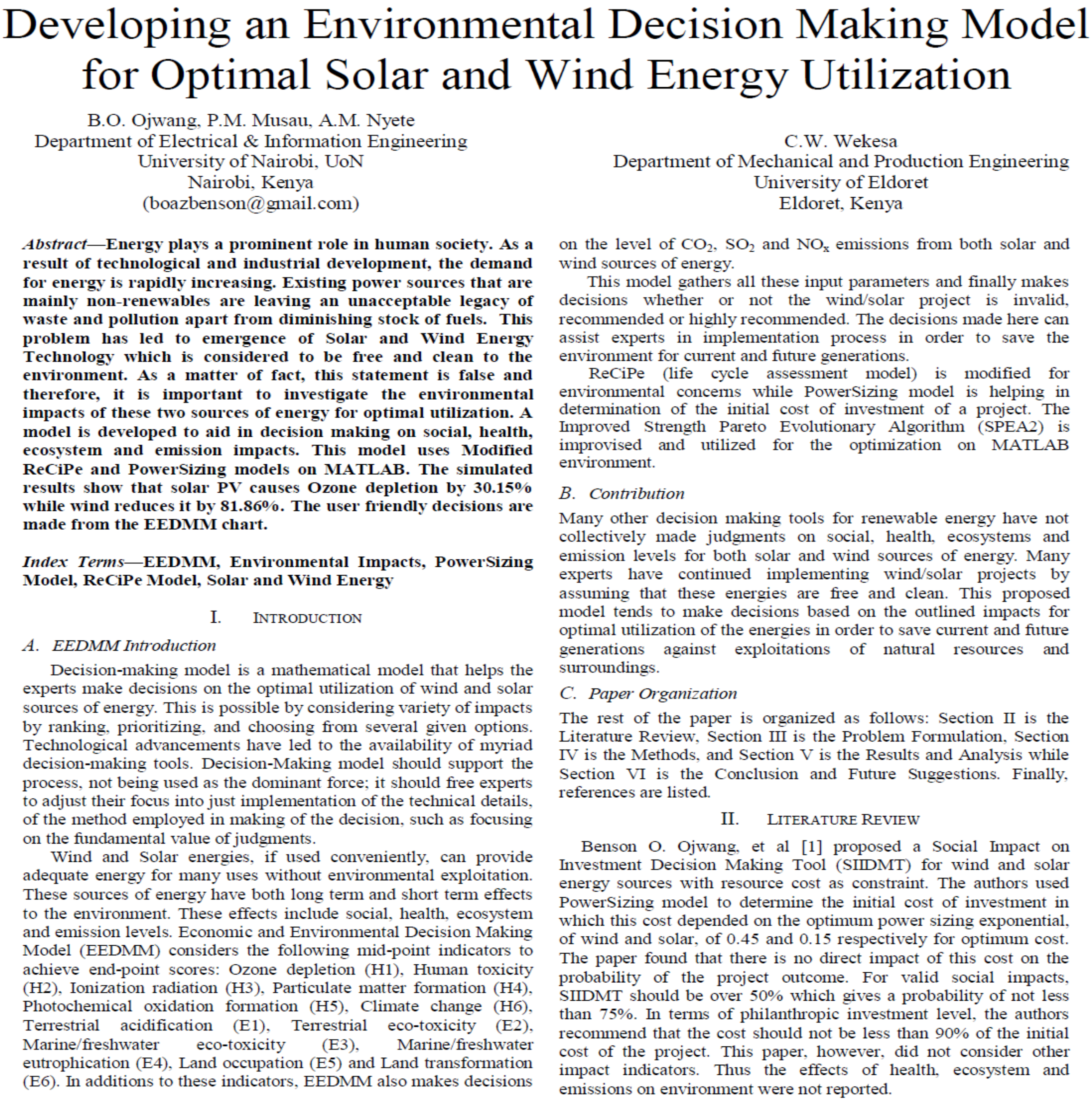
Table B4: Emissions Coefficients

		Solar	**Wind**	**Thermal**
Cost Coefficient	**a**	0.020	0.0700	0.0900
	b	0.600	0.095	0.025
	c	30	45	60
	e	0	0	40
	f	0	0	0.008
SO_2 Emission Coefficients	**a**	0.0005	0.0014	0.0010
	b	0.035	0.055	0.150
	c	10.00	12.00	17.00
	d	-80.00	-30.50	-90.00
NO_x Emission Coefficients	**a**	0.0016	0.0004	0.0012
	b	0.0500	0.0450	0.0520
	c	13.00	12.00	18.50
	d	-15.00	-35.00	-26.00
CO_2 Emission Coefficients	**a**	0.0016	0.0014	0.0015
	b	0.0550	0.0250	0.0920
	c	13.5	12.5	14.0
	d	-84.0	-93.5	-16.0

Appendix C: Author’s Publication

C1: IEEE PES/IAS PowerAfrica Conference 2020

Benson O. Ojwang;Peter M. Musau;Cyrus W. Wabuge;Abraham M. Nyete, “Developing an Environmental Decision Making Model for Optimal Solar and Wind Energy Utilization,” 2020 IEEE PES/IAS PowerAfrica, 12 October 2020



Developing an Environmental Decision Making Model for Optimal Solar and Wind Energy Utilization

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Abstract—**Energy plays a prominent role in human society. As a result of technological and industrial development, the demand for energy is rapidly increasing. Existing power sources that are mainly non-renewables are leaving an unacceptable legacy of waste and pollution apart from diminishing stock of fuels. This problem has led to emergence of Solar and Wind Energy Technology which is considered to be free and clean to the environment. As a matter of fact, this statement is false and therefore, it is important to investigate the environmental impacts of these two sources of energy for optimal utilization. A model is developed to aid in decision making on social, health, ecosystem and emission impacts. This model uses Modified ReCiPe and PowerSizing models on MATLAB. The simulated results show that solar PV causes Ozone depletion by 30.15% while wind reduces it by 81.86%. The user friendly decisions are made from the EEDMM chart.**

Index Terms—**EEDMM, Environmental Impacts, PowerSizing Model, ReCiPe Model, Solar and Wind Energy**

I. INTRODUCTION

A. *EEDMM Introduction*

Decision-making model is a mathematical model that helps the experts make decisions on the optimal utilization of wind and solar sources of energy. This is possible by considering variety of impacts by ranking, prioritizing, and choosing from several given options. Technological advancements have led to the availability of myriad decision-making tools. Decision-Making model should support the process, not being used as the dominant force; it should free experts to adjust their focus into just implementation of the technical details, of the method employed in making of the decision, such as focusing on the fundamental value of judgments.

Wind and Solar energies, if used conveniently, can provide adequate energy for many uses without environmental exploitation. These sources of energy have both long term and short term effects to the environment. These effects include social, health, ecosystem and emission levels. Economic and Environmental Decision Making Model (EEDMM) considers the following mid-point indicators to achieve end-point scores: Ozone depletion (H1), Human toxicity (H2), Ionization radiation (H3), Particulate matter formation (H4), Photochemical oxidation formation (H5), Climate change (H6), Terrestrial acidification (E1), Terrestrial eco-toxicity (E2), Marine/freshwater eco-toxicity (E3), Marine/freshwater eutrophication (E4), Land occupation (E5) and Land transformation (E6). In additions to these indicators, EEDMM also makes decisions on the level of CO_2, SO_2 and NO_x emissions from both solar and wind sources of energy.

This model gathers all these input parameters and finally makes decisions whether or not the wind/solar project is invalid, recommended or highly recommended. The decisions made here can assist experts in implementation process in order to save the environment for current and future generations.

ReCiPe (life cycle assessment model) is modified for environmental concerns while PowerSizing model is helping in determination of the initial cost of investment of a project. The Improved Strength Pareto Evolutionary Algorithm (SPEA2) is improvised and utilized for the optimization on MATLAB environment.

B. *Contribution*

Many other decision making tools for renewable energy have not collectively made judgments on social, health, ecosystems and emission levels for both solar and wind sources of energy. Many experts have continued implementing wind/solar projects by assuming that these energies are free and clean. This proposed model tends to make decisions based on the outlined impacts for optimal utilization of the energies in order to save current and future generations against exploitations of natural resources and surroundings.

C. *Paper Organization*

The rest of the paper is organized as follows: Section II is the Literature Review, Section III is the Problem Formulation, Section IV is the Methods, and Section V is the Results and Analysis while Section VI is the Conclusion and Future Suggestions. Finally, references are listed.

II. LITERATURE REVIEW

Benson O. Ojwang, et al [1] proposed a Social Impact on Investment Decision Making Tool (SIIDMT) for wind and solar energy sources with resource cost as constraint. The authors used PowerSizing model to determine the initial cost of investment in which this cost depended on the optimum power sizing exponential, of wind and solar, of 0.45 and 0.15 respectively for optimum cost. The paper found that there is no direct impact of this cost on the probability of the project outcome. For valid social impacts, SIIDMT should be over 50% which gives a probability of not less than 75%. In terms of philanthropic investment level, the authors recommend that the cost should not be less than 90% of the initial cost of the project. This paper, however, did not consider other impact indicators. Thus the effects of health, ecosystem and emissions on environment were not reported.

Moses Peter Musau, et al (2017) [2] proposed an Environmental Decision Making Tool for Renewable Energy (EDMTRE) with the resources cost as constraints. The authors used the midpoint indicators of the Modified ReCiPe version 1.3 model to indicate the negative environmental impacts while the more accurate cubic cost function was used to model the positive impacts on health and ecosystem. In addition to health and ecosystem, the proposed research also looked into reduction of emission. It was concluded that, with resource cost as a constraint, the determination of optimal environmental benefits is accurate. The findings indicate that the adverse effects of wind are four times less than those of solar. However, no research has been done on resource cost using the end-point indicator and no social aspect has been considered in the development of EDMTRE.

Mohamed Habib Sellami, et al (2014) [3] developed a thermo-economic cost model that was used to determine the environmental impact assessment on wind farms in Tunisia that use a biogas reactor that is energized using energy from wind and yeast with the capacity to generate 242.6MW and 123.27×10^6 kJ/day respectively. It was determined that from the wind farms, an area of $152{,}604\text{m}^2$ wind turbines was required to generate 2.6GWh electrical energy with the cost of wind energy being \$2939.4. The research found that every week an average of 216 birds were found dead in the area occupied by the wind farms. The research, however, could not look into other wind environmental impacts like life-cycle global warming, value of land, value of wildlife and the economic value of use of natural resources (wind).

Dawit Diriba Guta (2014) [4] modeled, using the ordinary least squares method, the use and impact on the environment of charcoal and wood fuel in Ethiopia and as a consequence recommended the reduction in cost of other renewable energies so as to reduce the reliance on wood based biodegradable fuels. The consumption of these fuels has led to deforestation of 14000 – 20000 hectare estimated forest cover loss per annum and this has greatly contributed to soil erosion. The conclusion was made by advocating the initialization of policy to control and subsidize other RES like biogas other than relying on the known traditional biomass. However, the study did not look into the economic effects such as fuel cost as well as the effects on the ecosystem and environmental pollution.

Table 1 shows some of the selected reviewed tools on decision making on health, ecosystem and emissions for solar and wind energy sources.

The possible gaps, from table 1, clearly indicate that there is need to have a very robust tool for making decisions on solar and wind energy sources based on the impacts they have on the environment. This paper only proposes a mathematical model for decision making.

III. PROBLEM FORMULATION

Formulation starts by the decision on the possible initial cost of investment for a new solar/wind project. This formulation considers variable cost (labor, direct materials) and fixed cost (capital equipment cost).

$$\mathrm{ICOI}-\mathrm{WS}_{\mathrm{new}}=\frac{\mathrm{CI}_t}{\mathrm{CI}_n}\left(\frac{\mathrm{AR}_{\mathrm{new}}}{\mathrm{AR}_{\mathrm{exist}}}\right)^x \mathrm{ICOI}-\mathrm{WS}_{\mathrm{exist}} \qquad (1)$$

Where, $\mathrm{ICOI}-\mathrm{WS}_{\mathrm{new}}$ is the optimized new resource cost (\$) for wind and/or solar PV, CI_t is cost index value today, CI_n is the cost index value n years ago, $\mathrm{AR}_{\mathrm{new}}$ is the amount of new resources (kWp), $\mathrm{AR}_{\mathrm{exist}}$ is the amount of existing resources (kWp), $x = [0\ 1]$ is the PowerSizing exponent provided by resource manufacturer and $\mathrm{ICOI}-\mathrm{WS}_{\mathrm{exist}}$ is the estimated existing resource cost. This equation (1) is modified from PowerSizing Model.

Table 1: Review of Tools and the Gaps

Ref	Tool	Content	Possible Gaps
[5]	Homer Energy	• Designing, modeling and analysis of renewable energy systems by considering wind speed, solar irradiation and load profile. • Optimization of renewable energy system based on the lowest TNPC	• Only considers CO_2 emissions in its analysis of RE systems • Does not consider social impacts directly • Does not consider health impacts directly
[6]	ETAP®	• Monitoring, controlling and optimization of the performance of power generation and transmission using a suite of programs. • Evaluation of real time data for reliability, security and performance of an electrical system. • Checking and controlling of the environmental emission levels for electrical systems. • Forecasting of load and planning of power generation schedule.	• The model does not address the social impacts of RE directly. • ETAP® does not make decisions on health impacts due to RE systems.
[7]	GTAP	• Calculating the amount of energy and carbon emissions based on fuel usage.	• No health impact is optimized by the tool
[8] [9]	LCC	• Looking for effectiveness of energy consumption efficiency and reduction of CO_2 emissions.	• Only considers economic impacts of a project. No social and health impacts are tackled directly. • Considers only CO_2 emissions which are not the only emissions in the ecosystem.
[10]	WASP	• Finding the optimal generation capacity of various methods of power being employed to find the optimal generation capacity accounting for fuel availability constraint. • Optimization tool for energy generation planning. • Time placing environmental emissions like CO2 in its centrality for the reduction.	• The tool does not directly address the social and health impacts caused by the solar and wind energies.

With this cost in place, we can therefore go ahead and make decisions on social impacts on investment as formulated in [1]. This model identifies the effectiveness of capital and other resources utilization of a project towards creating value for the community in terms of environmental, social and economic impacts. In measuring the social impacts on investment, the following elements were considered; cost of resources invested ($\mathrm{ICOI} - \mathrm{WS}_{\mathrm{new}}$), project outputs ($P_O$), that is, final products including trained human resource within the community, outcomes in terms of improved standards of living or new jobs created within the community and net impact to the community resulting from the project.

$$SIIDMMOU = \frac{SIV - (\mathrm{ICOI} - \mathrm{WS}_{\mathrm{new}})}{(\mathrm{ICOI} - \mathrm{WS}_{\mathrm{new}})}\ X\ 100\% \qquad (2)$$

Where $SIIDMMOU$ is the social impact on investment (%) and SIV is the social impact value given by equation (3).

$$SIV = \frac{P_O X P\{P_O\} X P_I}{P_C} \qquad (3)$$

With P_O being project outcome ($), $P\{P_O\}$is the probability of the project outcome, P_I is the philanthropic investment ($) and P_C is the project total cost ($).

After making decisions on the social impacts on investment, we then model health and ecosystem model for optimal utilization of these energies. This is formulated in [2] as:

$$HEDMMOU = Ce(E_i) \qquad (4)$$

Where $HEDMMOU$ is the Health and Ecosystem Decision Making Model for the environment, C is the characterization factor and $e(E_i)$ is the environmental impact based on stressor matrix S, that is,

$$e(E_i) = S(E_i) \qquad (5)$$

The next step is to make decision on the emission levels. An objective function for minimization of emissions is formulated in [2] as:

$$E(P_{j,3}) = \alpha_{3,j}P_{t,j}^3 + \alpha_{2,j}P_{t,j}^2 + \alpha_{1,j}P_{t,j}^1 + \alpha_{0,j} + \gamma_{3,j}e^{(\lambda_{3,j}\ P_j)} + \gamma_{2,j} \qquad (6)$$

In which $E(P_{j,3})$ = EMII (Emissions Minimization Impact Index) in tones per hour. The cost implication of EMII can be computed using environmental cost factor. $\gamma_{3,j}$, $\gamma_{2,j}$ and $\lambda_{3,j}$ are factors of emission as result of ramping effect of the jth unit whereas $\alpha_{0,j}$, $\alpha_{1,j}$, $\alpha_{2,j}$ and $\alpha_{3,j}$ are the coefficients of the emissions of the jth unit. CO_2, NO_X and SO_2 are the 3 main emissions that are factored.

OEFCCSW objective function is formulated as:

$$\mathrm{OEFCCSW} = E(P_{j,3}) = \sum_{j=1}^{L} E(P_{1,t,s}, P_{2,s,t}, P_{3,t,s}) \qquad (7)$$

Where L= total number of renewable energy sources (solar PV and wind) and thermal

$$L = PV + W + T \qquad (8)$$

In which PV =number of solar generators, W= number of wind turbines and T = number of thermal generators in the power system.

Objective function

Finally, this model is formulated, EEDMMM, (from equations (1), (2), (4) and (7)) by minimizing the overall objective function as:

$$minimize\left\{\left[[(1 - SIIDMMOU) + Ce(E_i)] + hE(P_{j,3})\right] + \beta(\mathrm{ICOI} - \mathrm{WS}_{\mathrm{new}})\right\} \qquad (9)$$

Where h is the negative and positive impacts' weighting factor for solar and wind renewable whereas β is the weighting factor on the resource cost function in relation to the environmental impacts.

Subject to:

$$0 < SIIDMMOU \leq SIIDMMOU^{max} \qquad (10)$$

$$\mathrm{ICOI} - \mathrm{WS}_{\mathrm{new}} \geq \mathrm{ICOI} - \mathrm{WS}_{\mathrm{exist}} \text{ if } CI_t > CI_n \text{ for } \mathrm{AR}_{\mathrm{new}} \geq \mathrm{AR}_{\mathrm{exist}} \qquad (11)$$

$$\beta(\mathrm{ICOI} - \mathrm{WS}_{\mathrm{new}}) \leq EEDMM \leq \{\beta(\mathrm{ICOI} - \mathrm{WS}_{\mathrm{new}}) + SIIDMMOU_{min} + Ce(E_i)_{max} + hE(P_{j,3})_{max}\} \qquad (12)$$

IV. METHODS

Modified ReCiPe 1.3 mid-point indicators are used to get the end-point scores for the environmental impacts from solar and wind. The optimization of the problem is done using Improved Strength Pareto Evolutionary Algorithm (SPEA2).

Modified ReCiPe 1.3

ReCiPe is one of the available life cycle assessment models. A life cycle assessment refers to the factual assessing of the life span of equipment through its useful years in terms of sustainability. It looks at the inputs and outputs of the equipment as well as the effect of social and economic decisions to the life of infrastructure. The aspects considered are production, distribution, operation and the disposal at the end of useful life. Phases of LCA are [11] – [14]:

i. Goal and Scope – defines reasons for executing LCA, determines the scope and then defines the product and operation boundaries.
ii. Inventory Analysis – defines the environmental inputs and outputs such as energy and raw materials emitted as well as the waste streams.
iii. Impact Assessment – Here the environmental impact is determined.
iv. Interpretation – The conclusions are well substantiated and shared with decision makers for the final decision to be made.

Midpoint level characterization

At this level characterization is done using equation (13) [12]:

$$I_m = \sum_j Q_{m,j} m_j \qquad (13)$$

Where I_m *is* the indicator outcome for category *m* midpoint impact, $Q_{m,j}$ the factor of characterization which links intervention *j* with category *m* midpoint impact and m_j is the magnitude of intervention.

Endpoint level characterization

At this level, there are 2 ways in obtaining characterization. The first one involves intervention devoid of intermediate points [13] and is calculated as:

$$I_e = \sum_j Q_{e,j} m_j \qquad (14)$$

Where I_e *is* the indicator outcome for category *e* endpoint impact, $Q_{e,j}$ is the factor of characterization which links intervention *j* with category *e* midpoint impact and m_j the magnitude of interventionQ_{ei}.

The 2nd way starts from the intermediate midpoints [13]. The formula is:

$$I_e = \sum_{im} Q_{eim} m_{im} \qquad (15)$$

Where m_{im} *is* the indicator outcome for category *im* midpoint impact, Q_{eim} is the factor of characterization which links category *im* midpoint impact with category *e* endpoint impact and I_e is the indicator outcome for category *e* endpoint impact.

The inputs for this ReCiPe model are raw materials used, land used, and waste materials such as VOS (Value of Solar), CFCs, PAH (Polycyclic Aromatic Hydrocarbon), cadmium(Cd) , phenyl (P) and emissions from combustion of fuel such as CO_2, NO_2 and SO_2 [13].

Table 2 shows the mapping of the problem formulated in equation (9) to SPEA2 [16].

V. RESULTS AND ANALYSIS

A 2.5MW size of solar and wind projects were considered to aid in the determination of the new initial cost of investment of solar/wind project. The results are shown in Table 3.

Table 2: Mapping of the Problem to SPEA2

Method Parameter	EEDMM
Population, P_t (input)	Mid-point indicators
Individuals, i (input)	ICOI-WS, SIIDMMOU, HEDMMOU and OEFCCSW
Archive, A_t (output)	Objective function EEDMM
Crossover	Updates emissions and negative environmental and economic impacts at each iteration
Mutation	Updates emissions and positive environmental and economic impacts at each iteration
New Archive, A_{t+1}	Newly acquired EEDMM
Distance sought, σ_i^k	PowerSizing Exponential x

Results and Analysis cont…

Table 3: 2.5MW Initial Cost of Investment

Source of Energy	ICOI-WSnew for CIR = 1	ICOI-WSnew for CIR = 1.04	ICOI-WSnew for CIR = 1.12
Solar	5.34617	5.56002	5.98771
Wind	5.59017	5.81378	6.26099

Table 3 shows that as the cost index ratio increases, the initial costs of investment also increase. Therefore, a better decision needs to be made on when the investment should be initiated. An elaborate decision making 3D graph is shown in Figure 1.

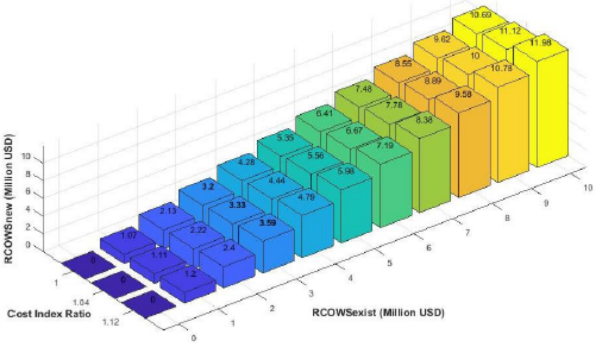

Figure 1: Plot of ICOI-WSnew versus ICOI-WSexist for varying Cost Index Ratios for Optimal Solar/Wind Utilization

From Figures 1, the existing cost of investment increase, as the percentage changes remain slightly constant at 20%. This work, however, uses the results here to determine SIIDMOU as formulated in equation (2).

As elaborate illustrations from [1], Table 4 illustrates the results for SIV and SIIDMOU for Solar Energy Project.

According to the decisions made based on social impacts like level of philanthropic investments, project outcome and total project cost, from Table 4, the SIIDMMOU is only valid when it is positive, that is, greater than 0. For instance, it was observed that the valid SIIDMMOU is reached upon when the probability outcomes are 0.72, 0.75 and 0.81 for cost index ratios 1, 1.04 and 1.12 respectively. The highest SIIDMMOU is 0.4 (the best) and the lowest is -1 (the worst) for a 2.5MW renewable energy project. After knowing the probability of project outcome, the decision is made and settles on the best probability project outcome.

Table 4: Solar PV SIV and SIIDMOU

P(P_o)	CIR = 1		CIR = 1.04		CIR = 1.12	
	SIV (million USD)	SIIDMMOU	SIV (million USD)	SIIDMMOU	SIV (million USD)	SIIDMMOU
0	0	-1.0000	0	-1.0000	0	-1.0000
0.1	0.7412	-0.8614	0.7412	-0.8667	0.7412	-0.8762
0.2	1.4823	-0.7227	1.4823	-0.7334	1.4823	-0.7524
0.3	2.2235	-0.5841	2.2235	-0.6001	2.2235	-0.6287
0.4	2.9646	-0.4455	2.9646	-0.4668	2.9646	-0.5049
0.5	3.7058	-0.3068	3.7058	-0.3335	3.7058	-0.3811
0.6	4.4470	-0.1682	4.4470	-0.2002	4.4470	-0.2573
0.7	5.1881	-0.0296	5.1881	-0.0669	5.1881	-0.1335
0.8	5.9293	0.1091	5.9293	0.0664	5.9293	-0.0098
0.9	6.6704	0.2477	6.6704	0.1997	6.6704	0.1140
1.0	7.4416	0.3863	7.4416	0.3330	7.4416	0.2378

Once this decision is reached upon, the Social Impact Value (in million USD) is determined. This equates the social impacts to monetary value. This assists investors to allocate optimum costs for social responsibilities of a project to the community – both direct and indirect responsibilities. When valid SIIDMMOU is ignored, there would be lack of employment opportunities, displacement of the local community and poor infrastructural development.

Once the decision on SIV has been made, there is need to investigate Health and Ecosystem Impacts. Here, Modified ReCiPe 1.3 with mid-point indicators is used to determine the end-point results.

Health Impacts

Table 5 shows the end-point results for different health mid-point indicators. Thermal has been used as a conventional energy source.

Table 5: Health Endpoint Scores

Midpoint Indicator	Endpoint Scores (kg/kWh)		
	Wind	Solar	Thermal
Ozone Depletion, H1	1.6059	6.1851	8.8549
Human Toxicity, H2	7.5389	27.8809	91.5034
Ionization Radiation, H3	50.3340	300.098	150.623
Particulate Matter Formation, H4	22.5611	39.5767	160.515
Photochemical Oxidation Formation, H5	3.0026	3.0082	3.7301
Climate Change, H6	2.0099	2.0016	2.3054

From Table 5, the graph was plotted as depicted in Figure 2. The mid-point indicators for Human Health that were considered include: H1 – Ozone depletion, H2 - Human Toxicity, H3 – Ionization Radiation, H4 – Particulate Matter Formation, H5 – Photochemical Oxidant formation and H6 – Climate change.

From Figure 2, it is observed that the use of wind reduces H1 by 81.86% and use of Solar increases H1 by only 30.15%. From the ReCiPe model, ozone depletion is related to NO_x. Solar, in comparison to wind, has larger negative contribution to ozone depletion because of the Chemicals used in PV cells such as Nitrogen trifluoride and sulfur hexafluoride that are used in the production of the solar cells. Use of wind reduces H2 by 91.76% while Solar reduces H2 by 62.04%, and Hydropower reduces H2 by 69.53%. Human toxicity effects result from exposure to fine particles, tropospheric ozone and ionizing radiation. Wind reduces H3 by 66.58% and solar increases H3 by 99.24%.

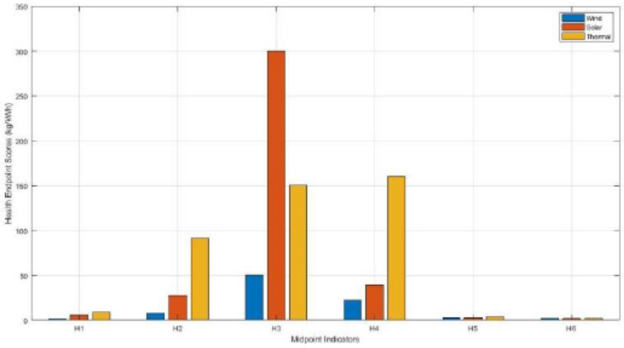

Figure 2: Health End Point Scores for 2.5MW project

Using the conventional reservoir thermal power, solar contributes the highest to ionizing radiation. This is because only about 15% of the light absorbed from the sun by the solar panel is turned into electricity. The rest is re-radiated as heat which significantly contributes to ionizing radiation. Wind reduces H4 by 85.94% as Solar reduces H4 by 75.34%. As in the case of global warming, solar has the highest negative contribution to particulate matter formation compared to. Wind reduces H5 by 19.50% while Solar reduces H5 by 19.35%. Generally, the deployment of RE reduces photochemical oxidant formation significantly. Wind reduces H6 by 12.82% while Solar reduces H6 by 13.17%. Of the RE energies, solar has the highest CO_2 emissions that is linked to climate change and global warming in the ReCiPe model. Solar PV makes a significant impact to global warming due to the energy-intensive silicon purification process where fossil fuels are combusted.

Ecosystem Impacts

These impacts are shown in Table 5.

Table 5: Ecosystem Endpoint Scores

Midpoint Indicator	Endpoint Scores		
	Wind	Solar	Thermal
Terrestrial Acidification, E1	1.0053	1.1151	3.3055
Terrestrial Eco-toxicity, E2	0.0020	0.0044	0.0045
Marine/Freshwater Eco-toxicity, E3	1.2103	1.4659	4.0158
Marine/Freshwater Eutrophication, E4	1.0011	1.0029	1.3563
Land Occupation, E5	2.2634	2.9058	26.0159
Land Transformation, E6	2.6100	5.7400	17.3100

From Table 5, it is observed that wind reduces E1 by 69.58% while Solar reduces E1 by 66.26%. Terrestrial acidification is closely associated with SO_2. Of the two REs studied, solar has higher SO_2 emissions than wind. Solar PV has a notable impact due to the use of fossil fuels used in the manufacturing process of the PV cells. Wind reduces E2 by 55.56 and solar reduces it by 2.22%. Solar has higher negative contribution to terrestrial Eco-toxicity. This is because of use of chemicals in photovoltaic (PV) cells in the manufacturing facility, the installation site, and the disposal or recycling facility and the accidental release of heat transfer fluids (water and oil) from parabolic trough and central receiver systems that cause health hazards and contribute to the release of toxic substances. Wind reduces E4 by 26.18% as opposed to solar which reduces E4 by 26.06%. Wind reduces E5 by 91.30% while solar by 88.83%. Land occupation encompasses both agricultural and urban land. The situation with land occupation sometime leads to eviction of people to pave way for the construction of these RES of Energies. There is Land degradation and habitat loss when large scale solar facilities are set up compared to wind sources of energy. Wind reduces E6 by 84.92% and solar reduces the land transformation by 66.83%. The Solar PV panels set up has a negative value for land transformation due to the fact that the technologies flood significant areas of land, which is frequently wilderness, or natural land, prior to the project being implemented. The result would be true and significantly larger for the larger capacity technology, which would lead to extinction of vegetation and soil erosion.

Emissions

Table 6 shows optimized emissions from solar, wind and thermal sources of energy.

Table 6: Optimized Emissions from Thermal, Wind and Solar Energy Sources

Source	Main type of emission	75% Nominal Load (kg/kWh)		Nominal Load (kg/kWh)		125%Nominal Load (kg/kWh)	
Wind	Carcinogenic		0.487		0.510		0.539
Solar	Carcinogenic		0.154		0.275		0.397
Thermal	CO_2	0.9100	0.921	0.9167	0.941	0.9234	0.962
	SO_2	0.0069		0.0136		0.0204	
	NO_x	0.0042		0.0109		0.0177	

From Table 6, it can be observed that wind reduces the level of emissions from noise, dust, CO_2, SO_2 and NO_x by 47.19% for 75%NL, 45.80% for 100%NL and 43.97% for 125%NL cumulatively. Similarly, solar reduces the level of emissions by 83.25% for 75%NL, 70.79% for 100%NL and 58.74% for 125%NL. The trend shows that as the nominal load increases, the percentage emissions changes keep on decreasing although the overall level of emissions per unit energy will be increased. These behaviors are due to the fact that as the load increases with constant generation, there is overloading of the system hence increase in friction would cause the emissions of gases due to overheating and wear and tear.

Once the initial cost of investment is determined and the social impact on investment decision is made as well as the health and ecosystem impacts and emissions are analyzed, a decision is then made by optimizing all the considered factors together. Here the EEDMM comes to play.

EEDMM

The decisions are made based on whether the cost of investment is inadequate, adequate or too high, the social impact on investment is valid or invalid and whether or not the health and ecosystem impacts and emissions are favorable. The simulated results from the EEDMM are shown in Table 7.

It can be observed that as the cost index ratios increase, the EEDMM is also increasing. This is due to the fact that the initial cost of investment will increase as well as Social Impact Value (SIV) which leads to higher project outcome.

Table 7: EEDMM Results for 2.5MW RE with different Cost Index Ratios

Instances	CIRs		
	1	1.04	1.12
1	1.5000	1.5200	1.5600
2	41.0873	41.1327	41.2222
2	80.6746	80.7453	80.8843
4	120.2620	120.3580	120.5465

Instances	CIRs		
	1	1.04	1.12
5	159.8493	159.9706	160.2087
6	199.4366	199.5833	199.8709
7	239.0239	239.1959	239.5330
8	278.6112	278.8086	279.1952
9	318.1986	318.4212	318.8574
10	357.7859	358.0339	358.5196
11	397.3732	397.6465	398.1817

Based on these, some decisions have to be made on the Social Impacts, Health Impacts, Ecosystem Impacts and Emissions for optimum conditions leading to overall decision on whether the project is invalid, recommended or highly recommended. These are summarized in Table 8.

Table 8: EEDMM Decisions based on the Output Results

EEDMM	Social Impacts	Health Impacts	Ecosystem Impacts	Emissions	Resource Cost	Overall Decision
0 – 100	Invalid	Unfavorable	Unfavorable	Unfavorable	Inadequate	Invalid Project
101 – 200	Invalid	Unfavorable	Unfavorable	Unfavorable	Adequate	Invalid Project
201 – 300	Invalid	Favorable	Favorable	Favorable	Adequate	Recommended
300 – 400	Valid	Slightly Favorable	Slightly Favorable	Favorable	Adequate	Highly recommended
>400	Valid	Unfavorable	Unfavorable	Unfavorable	Too high	Invalid Project

The results from Table 8 are represented as a chart in Figure 3. This chart is referred to as EEDMM chart that is useful to the end user for decision making once the output from EEDMM is known.

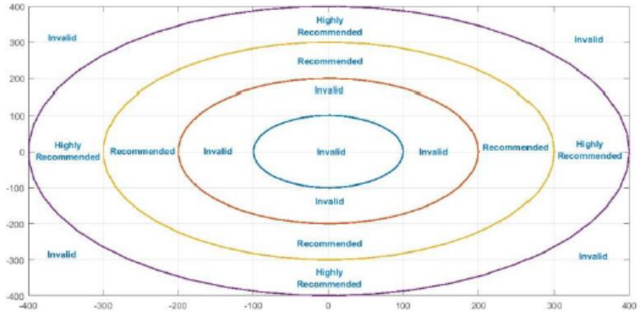

Figure 3: EEDMM Chart

VI. CONCLUSION AND FUTURE SUGGESTIONS

EEDMM has been formulated for the first time and the simulated results were validated with 2.5MW wind and solar PV capacity of energy. The Social Impact on Investment Decision Making Model for Optimal Utilization was made and concluded that SIIDMMOU is only valid when it is positive. For a 2.5MW plant capacity, at least a probability of project outcome above 0.72 is required. It is also concluded that during manufacturing, transportation, installation, operation and maintenance and decommissioning solar or wind plant, emissions are recorded which cause health and ecosystem effects. These also lead to increase in fuel costs. Hence, it proves that Solar and "*Wind Energy Sources are not clean and free*". For a constant energy generation, an increase in nominal load increases the emissions level but reduces a change in increase in emissions. Solar and Wind, however, reduce the level of emissions when compared to the conventional thermal energy. Based on the midpoint indicators for health, ecosystem, social and economics, EEDMM optimizes the endpoint scores in order to make decision on the validity of a project. The EEDMM chart is useful to the end user in decision making once the EEDMM output is known.

Further works need to be done from this proposed model to come up with a robust tool that could make decisions based on the environmental (health, ecosystem, social and emissions) and technical impacts besides economic impacts. Further modification of the ReCiPe version to include political aspects as an area of protection is proposed. This is because the decisions to set up the RE technologies is reliant on the country's development policies and approval of the relevant authorities.

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Implementation of Solar and Wind Technology based on Social Impact on Investment Decision Making Tool

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***Abstract*— Since the start of the new millennium, Renewable Energy Technology has been considered harmless, clean and free. On the other hand, Non-Renewable Energy Sources are perceived as the only hostile technology to the environment without focusing on the detrimental effect of Renewable Energy Sources. It is, therefore, important to evaluate the social impacts of solar and wind technologies and decide on the net social benefit before utilization. This will ensure sustainable utilization while maintaining the quality and availability of natural resources for current and future generations. For a suitable decision from the proposed tool, there is need to interrelate resource cost and social effects of solar and wind technology to the environmental and economic impacts. This will improve the judgment on whether or not to deploy the technology depending on the net social benefit to the community. The tool is developed using Modified PowerSizing model and simulated based on the proposed Improved Strength Pareto Evolutionary Algorithm on MATLAB environment. The proposed results for this research hope to demonstrate the social impacts of solar and wind technologies and effectively make the decision on the viability of deploying the technology as per the Environmental Impact Assessment regulations provided by UNEP in the 2018 – 2021 medium term strategy. In conclusion, the proposed Social Impact on Investment Decision Making Tool (SIIDMT) will be useful in providing prior advice to the technical team on whether or not the implementation of the solar and/or wind should be carried out. A valid SIIDMT should be more than or equal to 50 percent.**

Keywords—Social Impacts, Solar-and-Wind Energy, SIIDMT, Power Sizing Model, SPEA2

I. INTRODUCTION

Conservation of natural resources necessitates a better utilization in the current world. According to oxford dictionary, utilization can be defined as an effective and practical action of using something. Environmentally friendly and economical energy implementation of Renewable Energy (RE) employment is decided properly by selection of type of energy, which suitably utilizes the air, water, land and energy resources. Before taking action, especially concerning wind and solar energies, a detailed study of the social impacts and resource costs, with fuel costs as the constraints, should be conducted.

In order to identify the effects, negative and positive impacts on environment, people and property, this paper considers a critical examination of Environmental Impact Assessment (EIA) [1] [18]. A well outlined scope and terms of reference are made before carrying out the proposed research. Gathering of baseline information is conducted and an implementation decision is reached at the final stage. This processes necessitates a decision making tool to achieve compact results.

Other than exploring the social impacts, the instructor resource, that is, the Social Impact on Investment Decision Making Tool (SIIDMT), advices the relevant authorities and experts on the decisions made about the social issues. On the other hand, aspects of materials and energy resources are explored by Modified Power Sizing Model. The proposed tool, that is, SIIDMT, makes decisions for the concerned parties and energy experts.

The proposed SPEA2 (Improved Strength Pareto Evolutionary Algorithm) is improvised and utilized for the optimization.

A. Contribution

Due to the notion that wind and solar as renewable energies, are freely available, there has been a rapid growth in the development and utilization of the two RE generation technologies, as compared to non-renewable and other renewable energy technologies. This growth has generally disregarded social impacts while rampantly implementing and utilizing these technologies. In order to aid in this decision making before RE utilization, the SIIMDT is required. Apart from availing the resources to future generations, the tool will ensure proper utilization of human and natural resources, once it is deployed.

B. Paper Organization

The remaining part of the paper is organized as follows: Section II is the Literature Review, Section III carries the Problem Formulation, Section IV is the Proposed Methodology, Section V is the Presentation of Results and Analysis, while Section VI is the Conclusion and Recommendations for further work. Finally, there is a list of references used.

II. LITERATURE REVIEW

Moses Peter Musau, et al (2017) [2] proposed an Environmental Decision Making Tool for Renewable Energy (EDMTRE) with the resources cost as constraints. The authors used the midpoint indicators of the Modified ReCiPe version 1.3 model to indicate the negative environmental impacts while the more accurate cubic cost function was used to model the positive impacts on health and ecosystem. In addition to health and ecosystem, the proposed research also looked into reduction of emission. It was concluded that, with resource cost as a constraint, the determination of optimal environmental benefits is accurate. The findings indicate that the adverse effects of wind are four times less than those of solar. However, no research has been done on resource cost using the end-point indicator and no social aspect has been considered in the development of EDMTRE.

P.A. Leicester, et al (2013) [3] used the Bayesian Network, to develop a socioeconomic and environmental tool for modelling solar PV to reduce the deficits in the energy needs of England. The network predicted the energy generation levels per unit area estimating levels of Carbon (IV) Oxide reduction; based on the solar PV technology used. The project involved home based solar PV installations in England. Though the project met the needs of the energy sector by installing the PV cells on the rooftops, the installations meant the environmental impact was never determined as the small-scale installations never helped determine if any birds would be killed and how many, the effect on the ecosystem, were the PV cells installed on a broad solar farm and also the scaling of the land needed to generate a given amount of solar energy. It also could not determine the number of employment opportunities that would, in the long term, be created were a solar farm been the option implemented.

A.K. Akella, et al (2009) [4] employed the Renewable Energy Technologies such as biomass; used municipal waste in India to generate electricity, solar PV, wind and small hydroelectric power generation. The authors determined socioeconomic and environmental impact of these energy sources through the determination on the levels of CO_2 emission from each of the sources for a given size of a renewable energy power plant. The study however fell short of determining the cost of land as a direct impact of setting up RE power plants and also the impact on the ecosystem by these RE power plants.

E. Ariel Bergmann, et al (2007) [5] studied the effect of the choice policy in Scotland on the use of a preferable source of energy by people against anticipated socioeconomic and environmental effects of Renewable Energy Technologies. As a consequence, an extra £53.71 is paid by the community per hour to curb effects on the ecosystem such as wildlife deaths and the loss of land's aesthetic value as a result of the use of a wind turbine. However, the issue of resource costs of renewable energy technologies in Scotland was not addressed as it was not within the scope of the study.

Positive and Negative Social Effects of Wind and Solar [6 – 12]

Positive: Wind farms are normally set up in areas outside densely populated zones such on hilltops and other raised grounds thus do not disrupt the social order or displace the population.

The wind farms provide a lot of employment opportunities during the stage of setting them up as well as when it is running and during maintenance.

Some of the wind farms become tourist attraction zones and thus open up the areas to greater investment and also integrate the local community and tourists.

The installation of solar farms results in creation of employment for many people both in solar cells industries as well as at the solar farms themselves. This improves their quality of life and spurs economic growth

Negative: Setting up the wind farms leads at times to destruction of recreational sites as they are normally on hilltops used for hiking. They are also archaeological sites thus it leads to destruction of historical artifacts and historical areas.

People living on hilly areas are displaced and migrated leading to congestion and social disputes.

There is displacement of people to pave way for solar farms thus disrupting social order.

Power Sizing Model

Renewable energy economic analysis refers to the analysis of the cost of power generation using renewable energy and the economic benefits that it gives to its users relative to other sources of energy. Depending on the size of the intended renewable energy project, provided the energy resources are sufficient, the estimates may be detailed or semi-detailed but the economic benefits, as analyzed, should be more than the cost of setting up the project in totality else the project would be rendered economically unviable.

Using the PowerSizing model, the cost of setting up a power plant can be determined by determining the cost of equipment and the scale of the size of the desired power plant non-linearly using the PowerSizing exponent, x, since the size of power plant to generate twice the amount of electrical power must not necessarily be twice the size of the other power plant. The PowerSizing model formula is [13]:

$$\frac{Cost\ of\ Equipment\ A}{Cost\ of\ EquipmentB} = \left(\frac{Size\ of\ Equipment\ A}{Size\ of\ Equipment\ B}\right)^{X} \quad (1)$$

Where $0 < X < 1$ is the PowerSizing exponent provided by equipment manufacturer while A is the equipment in the new power plant whose cost is being estimated and B is the equipment in the old power plant used as a point of reference. The units for the size of equipment should be the same. If the cost of an equipment known was about n years ago, the current cost can be determined as follows using the cost index:

$$\frac{equipment\ cost\ today}{equipment\ cost\ n\ years\ ago} = \frac{cost\ index\ value\ today}{cost\ index\ value\ n\ years\ ago} \quad (2)$$

III. PROBLEM FORMULATION

First there is need to determine the Initial Cost of Investment (ICOI). This formulation considers variable cost (labor, direct materials) and fixed cost (capital equipment cost), which is given by equation (3), modified from equations (1) and (2).

$$\mathrm{ICOI}_{\mathrm{new}} = \frac{\mathrm{CI_t}}{\mathrm{CI_n}}\left(\frac{\mathrm{AR_{new}}}{\mathrm{AR_{exist}}}\right)^{x} \mathrm{ICOI}_{\mathrm{exist}} \quad (3)$$

Where, $\mathrm{ICOI}_{\mathrm{new}}$ is the optimized new initial cost of investment ($) for wind and/or solar PV, $\mathrm{CI_t}$ is cost index value today, $\mathrm{CI_n}$ is the cost index value n years ago, $\mathrm{AR_{new}}$ is the amount of new resources (kWp), $\mathrm{AR_{exist}}$ is the amount of existing resources (kWp), $x = [0\ 1]$ is the PowerSizing exponent provided by resource manufacturer and $\mathrm{ICOI_{exist}}$ is the estimated existing initial cost of investment.

Using the ICOI calculated, we go ahead to develop the SIIDMT. SIIDMT is a tool that identifies the effectiveness of capital and other resources utilization of a project towards creating value for the community in terms of environmental, social and economic impacts. In measuring SIIDMT, the following elements are considered: cost of resources invested, project outputs, that is, final products including trained human resource within the community, outcomes in terms of improved standards of living or new jobs created within the community and net impact to the community resulting from the project.

The SIIDMT is formulated as:

$$SIIDMT = \frac{SIV - ICOI}{ICOI} \; X \; 100\% \tag{4}$$

Where; $SIIDMT$ is the social impact on investment (%), $ICOI$ is the initial cost of investment ($) and SIV is the social impact value given by equation (5).

$$SIV = \frac{P_O X P\{P_O\} X P_I}{P_C} \tag{5}$$

With P_O being project outcome ($), $P\{P_O\}$ is the probability of the project outcome, P_I is the philanthropic investment ($) and P_C is the project total cost ($).

This tool is subject to solar and wind fuel constraints [2, 14 - 15]

$$SCF \geq F(pv_{ji}) + F_{pv,p,i}(pv_{ji,avg} - pv_{ji}) + F_{pv,ri}(pv_{j,i} - pv_{j,i,avg}) \tag{6}$$

In which SCF is the solar cost function, $F(pv_{j,i})$ = representation of solar irradiance cost constraint in a weighted cost function, $F_{pv,ri}(pv_{ji} - pv_{ji,avg})$ = cost requirement for penalty reserve since the scheduled solar power is more than available power and $F_{pv,p,i}(pv_{j,i,avg} - pv_{j,i})$ = penalty cost for failure of consuming the total solar PV available.

Where, $F(W_{j,i})$ is the j^th^ wind generator scheduled output for the i^th^ hour, $F_{W,ri}(W_{ji} - W_{ji,avg})$ is the cost requirement for penalty reserve since the scheduled wind energy is more than available energy and $F_{W,p,i}(W_{j,i,avg} - W_{j,i})$ is the penalty cost of failing to consume the total wind energy available.

$$WCF \geq F(W_{ji}) + F_{W,pi}(W_{ji,avg} - W_{ji}) + F_{W,ri}(W_{ji} - W_{ji,avg}) \tag{7}$$

Where, WCF is the wind cost function, $F(W_{j,i})$ is the jth wind generator scheduled output for the ith hour, $F_{W,ri}(W_{ji} - W_{ji,avg})$ is the cost requirement for penalty reserve since the scheduled wind energy is more than available energy and $F_{W,p,i}(W_{j,i,avg} - W_{j,i})$ is the penalty cost of failing to consume the total wind energy available.

$$TCF = \left\{a_{0i} + \sum_{j=1}^{L=3} a_{j,i} P_{ti}^{j} + \varepsilon_i\right\} + \left|r_i \sin g_i\left(P_i^{min} - P_i\right)\right| \tag{8}$$

Where TCF is the thermal cost function, P_i^{min} is minimum generation bound for ith unit, r_i, a_{0i}, $a_{j,i}$, and g_i are the coefficients of the cost in the unit ith and ε_i is the ith equation error.

Where $SIIDMT^{max}$ is the maximum Social Impacts on Investment which should be 100%. Ideally, this can only be achieved when the Initial Cost of Investment is twice the Social Impact Value.

Other constraints include:

$$0 < SIIDMT \leq SIIDMT^{max} \tag{9}$$

Where $SIIDMT^{max}$ is the maximum Social Impacts on Investment which should be 100%. Ideally, this can only be achieved when the Initial Cost of Investment is twice the Social Impact Value.

$$\begin{gathered} \mathrm{ICOI}_{\mathrm{new}} \geq \mathrm{ICOI}_{\mathrm{exist}} \text{ if } CI_t > CI_n \\ \text{for } \mathrm{AR}_{\mathrm{new}} \geq \mathrm{AR}_{\mathrm{exist}} \end{gathered} \tag{10}$$

In order to minimize the resource cost, the new resource cost (variable and fixed) should be less than the existing resource cost for the same size of projects in line with fuel cost constraints.

IV. PROPOSED METHOD

This research proposes Improved Strength Pareto Evolutionary Algorithm (SPEA2). The Strength Pareto Evolutionary Algorithm is useful in optimizing both negative and positive social effects and improving the solution from it. The uncertainties of Wind and Solar are also considered.

SPEA2 is an extension of SPEA which is an Evolutionary and a Multiple Objective Optimization Algorithm. The SPEA has an objective of locating and maintaining a front of non-dominant set of Pareto Optimal solutions. The achievement of this is realized by using the evolutionary process (which explores the search space) and a selection process. The selection process uses a combination of the level in which candidate solution is dominated and the density of the Parent front estimation as an assigned fitness. A population of candidates and an Archive of the non-dominant set are separately maintained. This provides a form of superiority (elitism) [16].

As opposed to SPEA, SPEA2 has an improved scheme of fitness assignment. In this scheme, each individual is taken into consideration to know the number of individuals it dominates or dominate it. Besides, there is incorporation of the nearest neighbour density estimation method. This allows for the guidance of the process of searching to be more precise. Finally, SPEA2 employs a new archive truncation techniques where the boundary preservation results is guaranteed. However, this algorithm only considers the minimized distance to the optimal front [16].

Fitness Assignment: Each individual ***j*** is taken into account to know the individual numbers it dominates or dominate it. The quantity of solutions dominated by particular individual ***j*** in the population ***P_n*** and the archive ***A*** is assigned a value of strength ***S(j)*** given by [16]:

$$S(j) = |\{i \mid i \in P_n \cup A \wedge j \succ i\}| \tag{11}$$

Where |.| is the cardinal of a set, ∪ is the multiset union and ≻ is the Pareto dominance relation.

Based on the values of ***S(j)***, the individual ***j*** raw fitness ***R_f(j)*** is given by:

$$R_f(j) = \sum_{i \in P_n \cup A, i \succ j} S(i) \tag{12}$$

This implies that the dominators strengths determine the raw fitness in both ***P_n*** and ***A.*** Note that the minimization of $R_f(j)$ is to be done. For $R_f(j) = 0$ then the correspondence is taken to be a non-dominated individual and if $R_f(j) = high\ value$ then it implies that ***j*** is dominated by big number of individuals which in turn leads to dominance of many individuals. However, the raw fitness may fail if the domination of each other by the most individuals do not occur.

This problem can be solved by the additional density information.

Density Estimation, k: This is useful to discriminate between individuals with similar raw fitness values. For particular individual ***j,*** the distances involving total individuals, ***i*** in ***A*** and ***P_n*** are computed and kept in the list. The list is then classified in ascending order for the *t-th* element to give the distance sought, σ_j^t.

t is assigned to be the square-root of the sample size,

$$t = \sqrt{M + \overline{M}} \tag{13}$$

followed by the calculation of the density ***D(j)*** for the corresponding ***j*** as:

$$D(j) = \frac{1}{\sigma_j^t + 2} \tag{14}$$

At the end, the fitness ***F(j)*** is then calculated as the sum of the density and the raw fitness, that is,

$$F(j) = R_f(j) + D(j) \tag{15}$$

Run Time: The density estimator $(O(N^2 logN))$ dominates the run time of fitness assignment procedure. ***$R_f(j)$*** and ***D(j)*** is of complexity of $O(N^2)$ with $N = M + \overline{M}$.

Mating Selection: The search of Pareto-optimal front is guided by the mating selection where the individuals for offspring production are selected by assignment of a pool of fitness values and individuals ***i.*** This procedure for filling the mating pool is usually randomized.

Environmental Selection: This selection decides on which individuals to keep during the process of evolution. Here deterministic selection is mostly used. In this selection, there are two cases:

i. When there is constant quantity of individuals, over time, in the archive.

ii. When the boundary conditions cannot be removed due to truncation method *(Archive Truncation).*

To get the ***new generation (offspring or new archive)*** from the individuals, ***i,*** and investigate the above two cases, the following equation is used:

$$New\ Archive, A_{n+1} = \{j | j \in P_n + A_n \wedge F(j) < 1\} \tag{16}$$

When $New\ Archive, A_{n+1} = A_n = power\ output\ A$, then there is completion of the environmental selection (case i).

When $New\ Archive, A_{n+1} < A_n$ (too small archive), then there is copying of the best $A_n - |A_{n+1}|$ dominated individuals from the previous population and archive to the new archive.

When $New\ Archive, A_{n+1} > A_n$ (too large archive), then there is invocation of procedural archive truncation. This iteratively takes away individuals from A_{n+1} until $New\ Archive, A_{n+1} = A_n$. This is achieved by taking the individual with shortest distance to another individual chosen at every stage. The tie is broken by choosing the 2nd smallest distance if there are many individuals with the least distance and so forth.

Based on the existing ICOI, using the equation 3, the optimum new ICOI is plotted as shown in Figure 1. Different cost index ratios of 1, 1.04 and 1.12 have been considered. For instance, if the existing initial cost of wind project was 5 million US dollars, the proposed new project of the same size should cost averagely million USD 5.53, 5.75 and 6.19 for cost index ratios of 1.0, 1.04 and 1.12 respectively. This implies to a percentage increase of 10.6, 15.0 and 23.8 for the cost index ratios 1.0, 1.04 and 1.12 in that order.

TABLE 1: PARAMETER MAPPING THE SIIMDT PROBLEM

SPEA2 Parameter	**Mapping to the SIIMDT Problem**
Population, P_t (input)	Project total cost ($)
Individuals, i (input)	Initial cost of investment ($) Philanthropic Investment ($)
Archive, A_t (output)	Social Impact on Investment (%)
Crossover	Link between social impact value and initial cost of investment
Mutation	Link between project total cost, philanthropic investment and project total outcome
New Archive, A_{t+1}	Newly acquired Social Impact on Investment (%)
Distance sought, σ_i^k	Probability of the project outcome [0 1]

V. SIMULATED RESULTS

A. *Initial Cost of Investment*

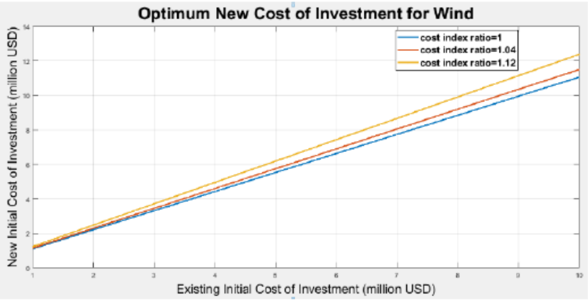

FIGURE 1: A GRAPH SHOWING OPTIMUM NEW COST OF INVESMENT FOR WIND COMPARED TO THE EXISTING COST OF INVESTMENT OF THE SAME POWER CAPACITY

Based on the existing ICOI, using the equation 3, the optimum new ICOI is plotted as shown in Figure 1. Different cost index ratios of 1, 1.04 and 1.12 have been considered. For instance, if the existing initial cost of wind project was 5 million US dollars, the proposed new project of the same size should cost averagely million USD 5.53, 5.75 and 6.19 for cost index ratios of 1.0, 1.04 and 1.12 respectively. This implies to a percentage increase of 10.6, 15.0 and 23.8 for the cost index ratios 1.0, 1.04 and 1.12 in that order.

For an investor who wants to minimize the initial cost of investment, it is advisable to invest when the inflation rate is minimum in a country, that is, when the cost index ratio is averagely 1.0 and the new cost of investment should not exceed 110.6% of the existing value of the project. Figure 1 shows the decisions that can be made on new cost based on different values of existing wind projects.

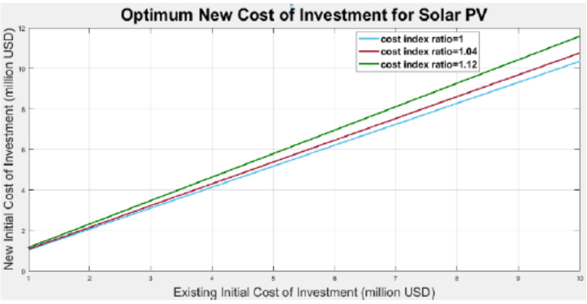

FIGURE 2: A GRAPH SHOWING OPTIMUM NEW COST OF INVESMENT FOR SOLAR PV COMPARED TO THE EXISTING COST OF INVESTMENT OF THE SAME POWER CAPACITY

Similarly, the above analysis from Figure 1 can be extended to Figure 2. For a 5 million US dollars existing project, the new initial cost of investment on solar PV project is 5.17, 5.38 and 5.79 for cost index ratios of 1.0, 1.04 and 1.12 respectively. This relates to increase of 3.4%, 7.6% and 15.8% against cost index ratios respectively. Again, here, the best option is 3.4% for cost index of 1.0.

Figure 3 shows the changes in new initial cost of investment for different cost index ratios for wind.

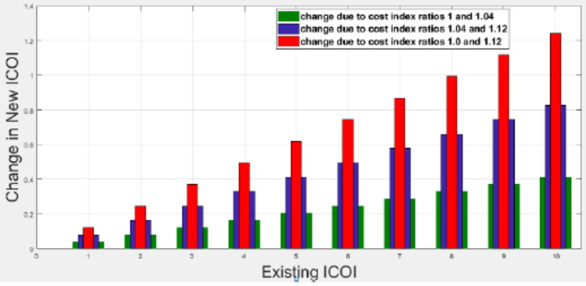

FIGURE 3: CHANGE IN NEW INITIAL COST OF INVESTMENT FOR COST INDEX RATIOS OF 1, 1.04 AND 1.12

From Figure 3, as the value of existing initial cost of investment increases, the change in value of the new initial cost of investment also increases with respect to increase in cost index ratios. Even though the trend is depicted as an increment with increase in wind costs, the percentage changes remain averagely constant as 10.50, 15.00 and 23.75% for the cost index ratios of 1.0, 1.04 and 1.12 respectively.

After making decisions on the new initial costs of investment, the cost are used to work out the Social Impact on Investment in order to make the final decision whether or not to implement the project. Here, the values of million USD 5.53, 5.75 and 6.19 for Wind project and million USD 5.17, 5.38 and 5.79 for solar PV project are used. The figures for SIIDMT are depicted in the following part *B*.

B. Social Impact on Investment Decision Making Tool (SIIDMT)

From the values of new ICOI of wind project stated above, the social impact on investment is simulated. It is observed that these investment costs have no effect on social impacts therefore we have just picked million USD 5.53 for illustration and analysis of SIIDMT. The graph of SIIDMT against probability of project outcome is shown in figure 4.

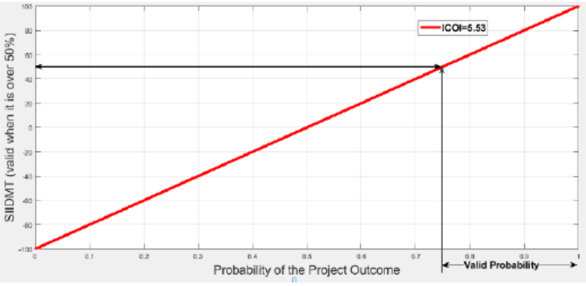

FIGURE 4: A GRAPH OF SOCIAL IMPACT ON INVESTMENT DECISION MAKING TOOL VERSUS THE PROBABILITY OF PROJECT OUTCOME

For a project to be valid as a project that is having positive impact to the community, at least the positive social impact on investment should be 50 percent. This implies that, from Figure 4, the probability of the project outcome should not be less than 0.75. This shows that at least the community should benefit directly from the project 75 percent more than other people who may be directly involved in the project.

Once the decision has been made on the portion of project outcome that should be felt directly by the community, then there is need to know the value of philanthropic investment before assigning this value to various investments like school support, hospital support, setting up of recreational facilities among others. This, here, we call it indirect community support from the project. The decision on indirect community support is illustrated in Figure 5.

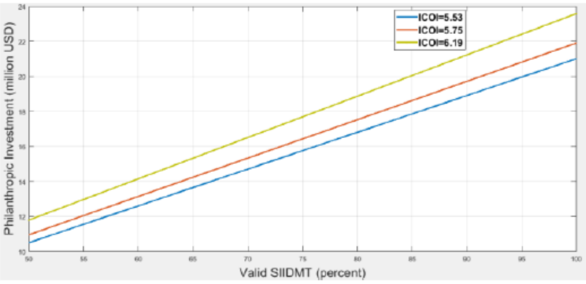

FIGURE 5: A GRAPH SHOWING PHILANTHROPIC INVESTMENT BASED ON VALID SIIDMT

From Figure 5, the value of philanthropic investment is evidently affected by the initial cost of investment. Large investments will require an investor to hugely invest philanthropically. The minimum cumulative amount to be philanthropically invested is million USD 10.50, 10.95 and 11.79 and the maximum amount is twice the minimum amount (21.00, 21.90 and 23.58) for optimum new initial cost of investment of million USD 5.53, 5.75 and 6.19 respectively. The valid minimum cumulative value of philanthropic investment is therefore at least 90 percent more than the initial cost of investment and should not exceed 380 percent of the initial cost of the project.

VI. CONCLUSION

Before putting a wind or solar project, the investor need to consider the following:

i. Optimum initial cost of investment based on the existing cost of investment. This cost is optimized based on the best choice of power sizing exponential. For wind is it 0.45 and solar PV it is 0.15.

ii. The optimum initial cost of investment is used to calculate the social impact on investment but it has no effect on the direct impact of the project to the community, that is, the probability of project outcome. The valid SIIDMT is above 50 percent which is given by probability of project outcome of 0.75.

iii. Once the SIIDMT passed the valid test, an indirect project impact (philanthropic investment) is investigated. This cost should be cumulatively more than 90 percent of the ICOI but not exceeding 380 percent of ICOI.

Further works need to investigate emission levels of these two technologies (solar PV and wind) and consider the impacts these sources of energy have on health and ecosystem. From emission level, social impacts, health and ecosystem effects, a net economic value of the project need to be investigated and an overall tool should be modelled.

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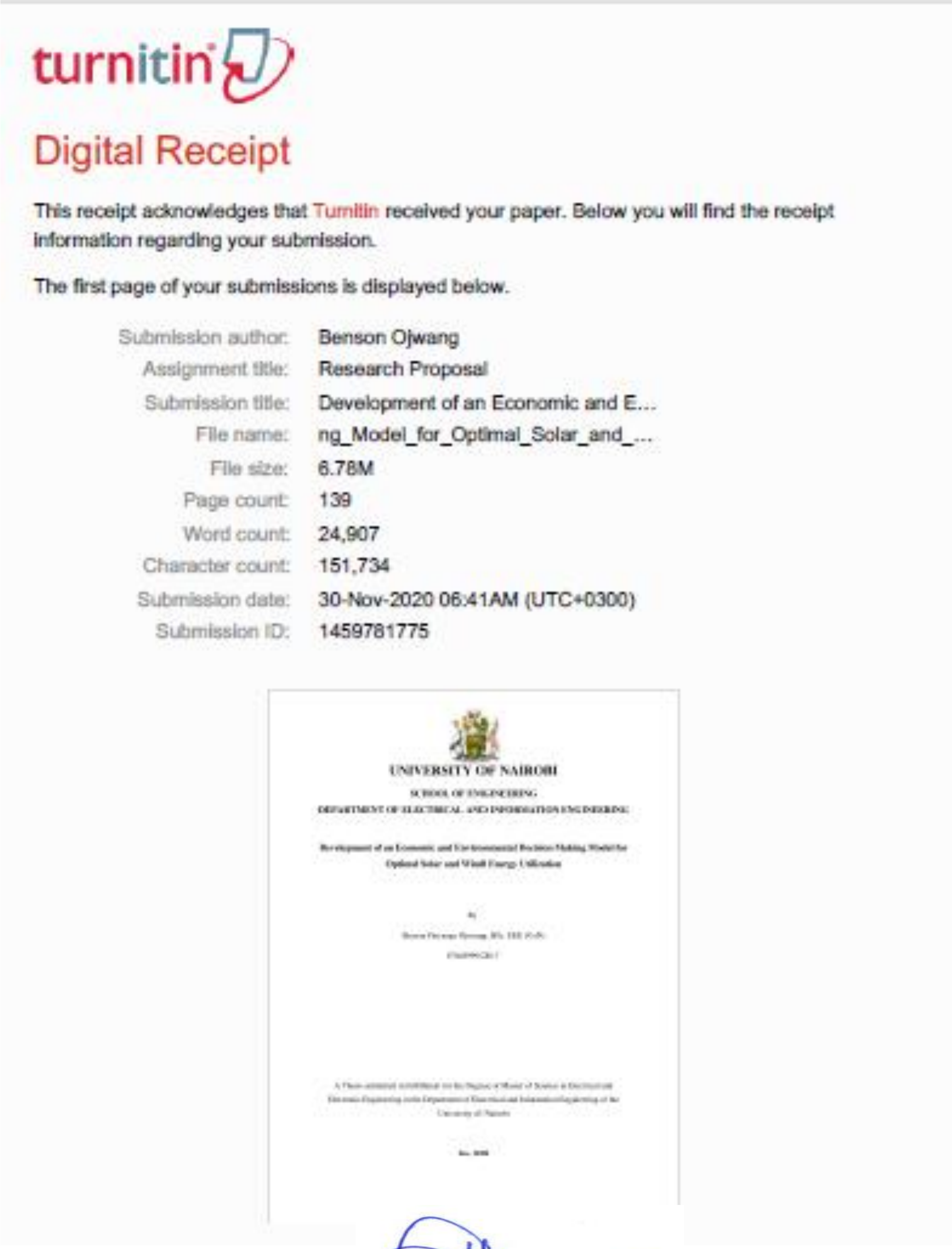

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