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LIFE CYCLE EXERGY ANALYSIS ON WIND FARM IN ETHIOPIA

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ABSTRACT

Aim of the study is Life Cycle Exergy Analysis (LCExA) is as indicator of sustainability measure for wind farm found in Ethiopia. The method employed contains three phases: Identification of goal and scope of the study, life cycle inventory of the system and calculation of Exergy of in and out of the materials and energy flow into the system. ExROI of the wind farm varies between 18 and 22 depending on the different scenarios taken in the system. The material Exergy of the wind farm contributes 22% from total Exergy of the system which has no share in ordinary life cycle analysis. Disposal contributes 13% of the total system considering recycling of materials, which has no share in ordinary life cycle analysis. Emissions and Waste (37%) have contribution to the total input Exergy. Most of the input Exergy goes to manufacturing of wind turbine (72%) and the rest takes 28% from the total input Exergy of the system. Special contribution of this study is analyzing the impact of waste and emission on the total Exergy flow of the system. In the study, recycling of materials is considered as output Exergy of the system. Exergetic method can reveal the sustainability of wind farm that appears to be sustainable in the way that it gives back many times more energy than it uses during the life cycle of the farm.

INTRODUCTION

Wind energy technology for electricity generation is one of the most appreciated, reliable and interesting technology among the list of renewable energy sources that the world has today. Ethiopian Government has planned for the country to be in list of middle income countries by 2025. This target can be achieved with a goal of electricity Production, estimated to be, 1700 MW, at the end of 2020 (GTP II, 2014). Among this during the same time frame, wind energy is expected to have a contribution of 1000MW power generation capacity, estimated to have 5.8% share in the total electricity production of the country. In the first growth and transformation plan of the government of Ethiopia there are three wind farms Installed in the country, namely Ashegoda (120Mw), Adama I (51Mw), and Adama II (151Mw) (EEPCo, 2015) and now there are wind project underway in different parts of the country like Ayisha (300Mw) which is north of Somalia region near to Djibouti and also Mosobo (300Mw) north of the country (EEPCo, 2015) That will increase electricity production from wind energy by 5.8% at end of GTP II. This total installed capacity of 1000MW, to be realized at the end of 2020, will make the country a leader in Africa to generate such amount of electricity production from renewable energy technology. The Ethiopian topography, specially found in the northern, eastern and central regions of the country, characterized by climate and landscape very suitable for further explotation of renewable energy. However renewable energy sources are often presented as very ‘‘clean’’ energy , not considering the environmental impacts related to during their manufacture(Ardente *et al*. (2005). For instance the production of renewable plants of the renewable plants, like every production process, entails a consumption of energy and natural resources as well as release of pollutants (Goralczyk, 2003). Following the energy demand in a country because of the double digit growth construction of energy supply systems from renewable energy sources Should be considered in policy and planning in the coming years of the transformation plan.

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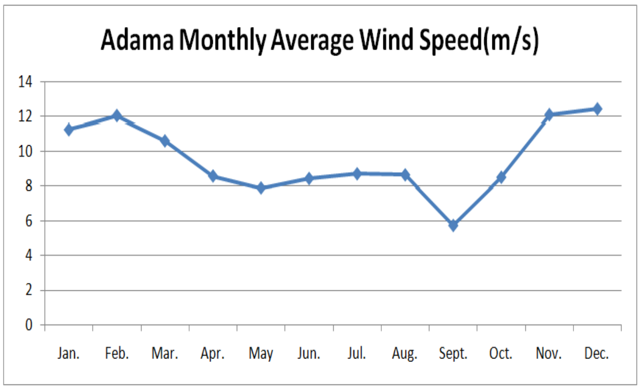
The life cycle Exergy analysis of wind farms explains therefore a way to address the issue of a large scale implementation and installation of wind farm in Ethiopia, to identify the steps with the greatest impacts and with the largest improvement potentials. Accordingly, this research work aims to evaluate the life cycle Exergy analysis of wind electricity production at Adama I Wind farm located near to Adama city which is 95kms away from Addis Ababa, the capital city of the country. This wind farm incorporated 34 Generators, each with a single unit capacity of 1500 kW, which makes up a total of 51 MW electricity production capacity. The main objective of this research is to assess Life Cycle Exergy Analysis as indicator of sustainability measure for wind electricity Systems, and to bring the Exergy concept to the world as a new light to sustainability measure of renewable energy in particular wind.

MATERIALS AND METHODS

The location under investigation is Adama I wind farm, 08″32′41”N, 39″13′48”E 1824-1976m. Wind potential of the location is studied in Adama I wind farm report. As it is clearly shown in the Where is Figure 1 rom my master copy and from Adama I wind farm report, wind energy potential is promising. Figure 1 shows the monthly average wind speed at a height of 65m. At a certain height, Z, the wind speed increases according to Equation 1. It has been calculated that average annual wind speeds is 9.56m/s .



$V(Z).\ln\left[\frac{Zr}{Zo}\right] = V(Zr).\ln\left[\frac{Z}{Zo}\right]$……….……..Equation 1

Where: Z_r is the reference height
Z_o is the roughness length

Materials: Materials used in the analysis are standard literature, different software’s like HOMER and online Exergy calculator (EXERGOECOLOGY). Besides, Adama I wind farm feasibility, technical and financial Report is used. HOMER software is used for the analysis. HOMER is a micro power design tool developed in 1992 to simulate and optimize stand-alone and grid-connected power systems. Exergy values of different elements are found from standard literature, Due to the absence of any previously published Exergies of different components, the study used the only Exergy calculator developed by ExergecologyGroup (Exergoecology, 2015). The calculator is based on Szarguts references environment and the methodology described in Szargut *et al*., (2005).

Scope of the Study

In the study, the stages involved in the analysis of life cycle of the wind farm includes: manufacturing, Transportation, installation, decommission, operation and maintenance.

Life Cycle Inventory

Life Cycle Inventory is to perform the actual inventory of inputs and outputs of mass and Energy to the systems, i.e. Exergy, throughout the life cycle.
Relevant data of the materials and processes related to the process were collected and accessed.

Data Analysis

Data is analyzed using different software’s and standard literature. HOMER is used for calculation of electricity output for wind farm for 20 years. EXERGOECOLOGY software is used for calculation of exergy values of chemical elements and compounds used in the manufacturing of various parts of the wind farm.

RESULTS

Phase One: Scope and Goal

The study has investigated the following Life-Cycle Stages: such as manufacturing of wind turbines and other plant’s components (cables, transformers…), construction of building structures and auxiliary facilities (lay-bays, foundation, cable trenches, path connectors, etc.), operation and maintenance, transportations used during each phase and in the future disposal of the plant..

Phase Two: Life Cycle Inventory

Manufacturing of Wind Turbine: The analysis of the manufacturing step started from the detail survey of systems components. Materials has been assessed on the basis of supplier’s handbooks and Adama I wind farm feasibility, Technical and financial Reports (Adama, 2009). The wind farm components consist mainly of materials utilized for manufacturing of wind generator, turbines as explained in the Table 1.

Table 1. Material used for construction of Adama I wind farm

S. No	Material	Mass(kg)
1	Steel	6446580
2	Cast Iron	49208
3	Glass Reinforced Plastic	40590
4	Copper	7576
5	Paints	3189
6	Lubricant Oils	910
7	Aluminum	697
8	PVC	533
9	Bronze	41

Building Works (Civil Work)

Building works includes all the structure and facilities produced locally as support to the plant. Table 2 describes material used for civil work for Adama I wind farm. These materials are explained in different sections of Adama I wind farmReports (Adama, 2009):

Table 2. Materials used for building works for Adama I wind farm

S. No	Materials	Mass(kg)
1	Aggregate Quarrying	86832000
2	Local Soils and Stone	41333976
3	Steel	1800000
4	Polypropylene	460
5	HDPE	45532
6	PolyButadiene	20564
7	Aluminum	33156
8	Copper	11572
9	PVC	75728
10	Sand	11209116
11	Concrete	7800000

Material for Transformer

Basic materials used for construction of the transformer are still and Copper other materials used for manufacturing of the transformer are listed in the Table 3.

Table 3. Material used for manufacturing of Transformer for Adama I wind farm

S. No	Materials	Amount	Unit
1	Steel	97920	Kg
2	Aluminum	8940	Kg
3	Copper	22770	Kg
4	Polyamide Injection Molded	4850	Kg
5	Polyester	3000	Kg
6	Polyethylene, HD	1500	Kg
7	Paint	1500	Kg
8	Transformer Oil(Vegetable)	60010	Kg

Material for Replaced Part of Transformer

Parts of Transformers and invertors are replaced every 10 years for proper functioning of the system. 15 % of Still, Aluminium and Copper from transformer and invertors are replaced as indicated in the Table 4.

Table 4. Material used for manufacturing of Transformer for Adama I wind farm

S. No	Materials	Amount	Unit
1	Steel	97920	Kg
2	Aluminum	8940	Kg
3	Copper	22770	Kg

Material to Be Substituted for Transformer

Materials substituted during the maintenance of transformers and invertors for the whole farm are explained in the Table 5. Steel and copper plays a crucial role in the maintenance period.

Table 5. Material to be substituted for transformer for Adama I wind farm

S. No	Materials	Amount	Unit
1	Steels	97920	Kg
2	Aluminum	8940	Kg
3	Copper	22770	Kg
4	Polyamide Injection Molded	4850	Kg
5	Polyester	3000	Kg
6	Polyethylene, HD	1500	Kg
7	Paint	1500	Kg
8	Transformer Oil(Vegetable)	60010	kg

Waste during manufacturing of Turbines

There are various types of wastes during the manufacturing of wind turbine components. These materials are explained as shown in the Table 6.

Waste Materials during Maintenance

There are some materials replaced during maintenance period of the farm like one blade is replaced from every turbine from useful life time and also 15 % of generator equipment is replaced by new parts(Adama, 2009).
Hence there are waste Steel, Aluminum, and Copper to be recycled. As indicated in the Table 7 waste materials to be recycled.

Table 6. Waste during the manufacturing of turbines for Adama I wind farm

S. No	Materials	Amount	Unit
1	Particulates	50200	Kg
2	Suspended solids	7110000	Kg
3	Dissolved Solids	18900	Kg
4	Mineral and Debris	11500000	Kg
5	Ash	863000	Kg
6	Oil and Lubricants	7730	Kg

Table 7. Materials collected during maintenance to be recycled from Adama I wind farm

S. No	Material	Amount	Unit
1	Steel	432420	Kg
2	Aluminum	12440	Kg
3	Copper	8542	Kg

Emission during Manufacturing of Turbines

The study calculated the various types of emissions and wastes during the construction of Adama I wind farm and the manufacturing of its wind turbine and other parts. As indicated in the Table 8 most of the emissions found to be gases.

Table 8. Emission during the Manufacture of Adama I Wind Farm

S. No	Materials	Amount	Unit
1	CO_2	106000	Kg
2	CO	72900	Kg
3	SO_x	63600	Kg
4	NO_x	41700	Kg
5	VOC	449	Kg
6	N_2O	1.3	Kg
7	Cl^-	63700	Kg
8	COD	3090	Kg
9	$SO4^{-2}$	4020	Kg
10	BOD	124	Kg
11	AO_x	2.78	Kg

Emission from Eco profile of Electricity

The study also recorded, calculated and forecasted the types of emissions and waste, during electricity production of Adama I wind farm, for useful life time of the plant as indicated inTable 9.

Table 9. Emission due to Ecoprofile of Adama I wind farm

S. No	Emission	Emission/kwh	Total Emission(kg)
1	Global warming potential	14.8gCO_2/kwh	23324800
2	Ozone depletion potential	6.59E-7gCFC_{11}/kwh	1.038584
3	Acidification	3.62E-3molH+/kwh	11410
4	Photochemical Ozone creation potential	1.61E-2gC_2H_4/kwh	253736
5	Eutrophication	0.35gO_2/kwh	551600
6	Inert wastes	154.2mg/kwh	24301920
7	Special wastes	1.2mg/kwh	189120

Recycled Materials as Output from maintenance

There are materials to be recycled during maintenance of the farm. These materials Come out of transformers, invertors and blade of the turbine. As explained in the Table 10, the study calculated the amount of recycled materials at the end of decommissioning and maintenance period.

Table 10. Materials collected during maintenance period and at the end of useful life of the plant for recycling from Adama I wind farm

S. No	Materials	Amount	Unit
1	Steel	3648251	kg
2	Aluminum	13541	kg
3	Copper	7659	kg

Rest of Life Cycle

The energy consumption for components manufacturing, for transportation from plant gate to site, for onsite installation, for operation and maintenance, and for decommissioning phase are adapted and extrapolated from Ardente *et al*., (2008) as indicated in the Table 11.

Phase Three*:* Exergy Calculation

Exergy inputs

Exergy input are Exergy of material for manufacturing of turbine, Exergy of building materials, Exergy of wastes and emissions and Exergy of materials used for replacements during life time of the farm. As indicated in the Table 12exergy for different use are explained and described.

Exergy of the Rest of the Life Cycle

The Exergy used for the rest of the life cycle is adapted and approximated from Italian wind farm. These is based on Ardente's analysis and estimation of exergy value according to the global requirement (Ardente et al., 2008). One can refer the result from Table 13.

Table 11. Percentage of Total Energy use adapted from Ardente *et al*., (2008) for Adama I wind farm

	Components Manufacture	Transports	Onsite Installation	Operation and Maintenance	End of Life
Percentage of Total Energy	16.4%	6.5%	0.2%	6.4%	1.7%
Energy(TJ)	62.76	24.87	0.77	24.49	6.5

Table 12. In put Exergy to the Adama I wind farm

S. No	Exergy for Different Use	Material Exergy(TJ)	Fuel Exergy(TJ)	Exergy(TJ)
1	Exergy of Materials for Turbine	24.59	95.11	119.72
2	Exergy of Building Materials	33.66	69.82	103.48
3	Exergy of Wastes	0	173	173
4	Exergy of Emission	36.86	0	36.86
5	Exergy of Transformers	4.02	8.22	12.24
6	Exergy of Materials for Replacement	1.48	5.98	7.46
	Total	100.61	352.13	452.74

Table 13. Percentage of total energy use adapted from Ardente *et al*., (2008) for Adama I wind farm

	Components Manufacture	Transports	Onsite Installation	Operation and Maintenance	End of Life	Total
Percentage of Total Energy	16.4%	6.5%	0.2%	6.4%	1.7%	31.2%
Exergy(TJ)	62.76	24.88	0.7654	24.49	6.50	119.4

Table 14. TotalIn put Exergy to the Adama I wind farm

S. No	Exergy for Different Use	Material Exergy(TJ)	Fuel Exergy(TJ)	Exergy(TJ)
1	Exergy of Materials for Turbine	24.59	95.11	119.72
2	Exergy of Building Materials	33.66	69.82	103.48
3	Exergy of Wastes	0	173	173
4	Exergy of Emission	36.86	0	36.86
5	Exergy of Transformers	4.02	8.22	12.24
6	Exergy of Materials for Replacement	1.48	5.98	7.46
7	Exergy for Components Manufacture	0	62.76	62.76
8	Exergy of Transports	0	24.88	24.88
9	Exergy of Onsite Installation	0	0.76	0.77
10	Exergy for Operation and Maintenance	0	24.49	24.49
11	End of Life, Dismantling and Decommissioning	0	6.5	6.5
	Total	96.59	500.16	596.75

Table 15. Scenario of Electricity outputs by varying the Capacity Factor for Adama I wind farm

S. No	Scenario	Capacity Factor	Electricity(TJ)	Exergy(TJ)
1	Scenario 1	0.3	9650	9650
2	Scenario 2	0.36	11580	11580
3	Scenario 3	0.4	12640	12640

Table 16. Materials wasted during the maintenance period for Adama I wind farm

S. No	Material	Mass(kg)	Material Exergy(TJ)	Fuel Exergy(TJ)	Total Exergy(TJ)
1	Steel	432420	0.676872	2.12629	3.403162
2	Aluminum	12440	0.80784	3.0538	4.06164
3	Copper	7659	0.67823	1.1254	1.80367
	Total		1.484712	5.98009	7.464802

Figure 17. Exergy of Recycled Materials for Adama I wind farm

S. No	Material	Material Exergy(TJ)	Fuel Exergy(TJ)	Total Exergy(TJ)
1	Steel from turbine	20.89	84.12	105.01
2	Aluminum from turbine	0.003	0.0225	0.0255
3	Copper from turbine	0.098	0.0637	0.1617
4	Steel from Recycled during Maintenance	1.432	5.77	7.202
	Total	22.423	89.9762	112.3992

Table 18. Output Exergy to the Adama I wind farm

S. No	Exergy from Different Source	Material Exergy (TJ)	Fuel Exergy (TJ)	Exergy (TJ)
1	Exergy of Wind Turbine Electricity Production	0	12640	12640
2	Exergy of Recycled Materials	23.91	95.96	119.85
	Total	23.91	12736	12760

Table 19. Variation of ExROI by using different Capacity Factor for Adama I wind farm

Scenario	CF	Exergy(TJ)	ExROI
I	0.3	9650	18
II	0.36	11580	20
III	0.4	12640	22

Table 20. Comparison of Exergy input and output to Installed Capacity for Adama I wind farm

Type of Farm	Instal. Capa. (Mw)	Total Ex.in (TJ)	Total Ex. Out (TJ)	Ex. input to Instal. (TJ/Mw/yr)	Ex. out to Instal. (TJ/Mw/yr)
wind	51	609	11580	0.60	11.11

Total Exergy Input

Exergy input Includes Exergy of materials for manufacturing of turbine, Exergy of building materials, Exergy of wastes and emissions, Exergy of materials used for replacements during life time of the farm, Exergy for manufacturing of components, Exergy of transport, Exergy of onsite installation, Exergy of operation and Maintenance and Exergy for decommissioning. Table 14 explains and describes various input Exergies for the wind farm.

Exergy Outputs

Exergy of Wind Turbine Electricity Production

The capacity factor for Adama I wind farm is taken to be 0.36 which gives an annual electrical energy production of 643.4 TJ for the entire wind farm for one year. This is equal to a production of 378.4 TJ of electrical energy produced by one wind turbine in 20 years. Electricity production of Adama I wind farm according to different scenario is indicated in Table 15.

Exergy of Recycling

During maintenance of Adama I wind farm, the Exergy of waste materials for recycling materials comprised of one blade from each tower and 15% of generator and invertor parts and accessories in the useful life time of the plant. The calculated wastes from all turbines are indicated in Table 16.

Exergy of Materials from Dismantling Wind Farm for Recycling

At the end of its life cycle, there are various types of waste materials from the farm.Among these, some of the materials can be recycled. Exergy values of these materials, as calculated in the study, are indicated in Table 17. These Exergy is taken as exergy of output of the system.

Total Exergy Output of the System

Exergy output of the system comprises of electricity production during the useful life time of the farm and recycled materials. As indicated in Table 18.

Scenario taken for wind farm

The scenario taken in the analysis of electricity production of the farm for 20 years is given in the Table 19. Depending of the capacity Factor of the plant the output of the farm varies greatly. The study found that the output of the farm varies greatly depending on the capacity factor of the plant which has an implication on ExROI.

Comparison of Exergy input and output to Installed Capacity

It is important to compare the farm exergy input and Exergy output with respect to the installed capacity. This study revealed that the Exergy output to the installed capacity out numbers and out weights the Exergy input to installed capacity as indicated in Table 20.

DISCUSSION

Every detailed calculation is made based on the inventory of the Adama I wind farm construction manual. For analysis of Exergy values of different compounds the study employed online Exergy and made references to published articles. In this study Exergy of material production is mainly the components of the turbine and parts on the civil work, is based on the masses in Adama I wind farm handbooks. But few materials are approximated from different literature such as Ardente et al., (2008). The road construction to the wind farm site has no any share on in the analysis since this infrastructure is built not for wind farm but as the main road to Addis Ababa.

Among the materials needed to manufacture Adama I wind farm, as presented in Table 1 and 2, small amount of the total iron material cast iron while most of it Steel. Hence, Exergy value of cast iron is approximated as Exergy of steel, Exergy of aggregate, local soils and stones are approximated as Exergy of sand and aggregate quarrying is approximated as rock during material Exergy calculation. Material Exergy for sand and rock is taken from Finnveeden and Ostlund (1997). In this paper it is adapted, assumed and approximated that the fuel Exergy use would be the same as the global energy requirement 382.7 TJ as indicated in Ardente et al., (2008) which is fairly good estimate.The basic and most interesting difference between ordinary life cycle assessment and LCExA is that the material Exergy has no any role in life cycle assessment even though it has big share on the total Exergy amounting to 22 %. The material Exergy of the concrete holds a great impact on the whole calculation and also rocks makes up of great contribution to the total Exergy of the wind farm. Fuel Exergy is not included in the analysis due to lack of available data. In many of the reviewed literature for the study the fuel Exergy has no any place in the analysis. In the analysis above the material Exergy counted is counted to be 22 % of the total Exergy which indicates ExROI variation in the life time. The resulting of the ExROI only by having fuel Exergy is 26, but with using Total Exergy (fuel + material) the ExROI is 22. An important aspect of this research is that it considered recycled materials as an output of Exergetic system.

According to Stiller (1999) it is well explained that material made of waste (recycled) part has many advantages over the product made out of the waste secondary materials. The calculation of Exergy demand for electrical energy mix in this paper is adapted from European average electrical energy generation mix which is used as energy demand of 3.1 MJ per MJ electricity (ECA, 2010). The total Exergy return on investment of the wind farm lies on the range of 18 to 22 based on the different scenario taken on capacity Factor of the plants as varies from 0.3 to 0.4. This is consistent with areport fromDavidsson S. (2011). Every possible scenario in this study reveals that the sustainability of Adama I wind farm.
Those Exergy return values indicate that a wind farm has a net Exergy output to the system and is sustainable as indicated by the result of the research. Changing the capacity factor from 0.3-0.4 has an influence on the output Exergy value of the system. Hence this result depends on several factors and parameters on the study of sustainability of the wind farm.The wind turbine decommissioning is a life-cycle phase not completely predictable in the context of Adama I wind farm in Ethiopia. Since the wind farm is currently producing electricity actual available data on decommissioning could not be found. Therefore the study assumed disposal on the basis of other research works. Materials replaced during the maintenance period are considered to be Exergy input, and these materials are additional materials for the wind farm to operate with full potential. One blade is replaced from each of the tower, and 15 % of generator part is replaced by new materials in life time of the farm.

The basic and most interesting difference between ordinary life cycle assessment and LCEA is that the material Exergy has no any role in life cycle assessment even though it has big share. For instance, the material Exergy is found to be 22 %.The material Exergy of the concrete holds a great impact on the whole calculation and also rocks makes up of great contribution to the total Exergy of the wind farm. The recycled material has a share about 13 % of the total in put Exergy to the wind farm systems. This has no any share on ordinary life cycle analysis. Emission and wastes contributes 37 % from the total input Exergy to the wind farm systems.The Exergy needed for the manufacturing of components of the wind farm is given the Table 12. The amount of energy invested in manufacturing of parts turbines(Rotor blades, nacelle parts, and transformer) is calculated as 62.76 TJ. Since Ethiopia is an inland country, all the required mass and goods of the wind farm are produced in china and delivered to adjustment port. Then after these materials are transported by trucks and long vehicles to Adama city where they are assembled by a company found near the city, at Adama I wind farm site.Hence in this study the calculated transportation Exergy includes the fuel consumed during the delivery and transportation of the goods.However since materials like cement and steel for foundation of the towers and other plant components such as cable plastics and steel are produced inside the country using local materials, it reduces extra fuel Exergy need. As adapted and extrapolated from Ardente et al., (2008), the amount of energy invested for transportation is calculated as 24.88 TJ. The wind farm needs different types of machines for online installation like Cranes, Bulldozers, Graders for installation of the tower and earth work. The Exergy needed for this task 0.77 TJ as adapted from Ardente et al., (2008).

This study considered Exergetic wastes counted in the inflowof the system. As it has also suggested by several researchers, such as Sciubba E. and Wall G. (2007) and Ayres R. U. et al., (1998), Exergy can be used to measure the potential harm in emissions. According to Stiller (1999) it is well explained that materials made of waste (recycled) parts have many advantages over the product made out of the waste (secondary materials). Recycling of materials is beneficiary to minimize environmental impact during the production process. However in most of the literature reviewed for this study most assessments do not give emphasis to this importance of recycling materials in the system. Issues with regard to recycling of materials are one of the interestingparts of in the analysis of this study. Accordingly it was observed that one benefits of recycling materials is that it encourages construction of renewable energy power plants. In addition it has also an advantage over the total material input to reduce while comparing the Exergetic flow in to the system. This study counted and calculated the Exergy values of evergy material in the analysis unlike Vestaset al., (2011) who excluded materials under 1 % of the cumulative mass of all the inputs and outputs in the inventory. Exergy Return On Investment indicates that Adama I wind farm gives back more energy than it uses during the useful life time of the farm. This reveals that these types of project are sustainable for the production of clean and reliable energy to the country. In the analysis, it is found out that the ExROI is 18-22 using different scenarios. From this result, one can conclude that life cycle Exergy analysis is a good indicator of the sustainability of renewable energy resources. Sustainability of renewable energy sources can be assessed using Exergetic life cycle approach. These methods are getting common in the evaluation of the systems currently with some complex calculation to the values of Exergy value of materials (Davidsson, 2011).

Conclusion

Life cycle exergyanalysis(LCExA) is important to evaluate world's future energy systems to make sure that we are supporting as much net Exergy as possible so as to create a more sustainable energy production for society. Material Exergy of the wind farm, which has a 22% share of the total exergy, has no place in the ordinary life cycle analysis. This value implies that LCExA is important than other types of life cycle analysis. ExROI of the wind farm varies between 18 and 22 depending on the different scenarios taken in the system. Disposal, considering recycling of materials, contributes 13% of the total input exergy of the system. Emissions and waste have 37%contribution to the total input exergy of the wind farm. In the study is found out that ExROI is 20 at a capacity factor of 0.36 which also varies as capacity factor of the turbine vary. Exergy return on investment indicates that the wind farm gives back more energy than it uses during its useful life time. This reveals that such types of projects are sustainable for the production of clean and reliable energy in the country.

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