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Energy Audit of a Solar Panel Manufacturing Plant: A Case Study of NASENI Solar Panel Plant, Karshi, Abuja

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Abstract

The obvious high cost of energy poses an unfavourable effect on the cost of production of goods and services. A method that can be used to identify and quantify how energy is being used as well as wasted in a plant is called energy audit. This study conducted an energy audit on NASENI solar panel manufacturing plant, in Karshi, Abuja, Nigeria. Various data such as the power rating capacities of the different machines, monthly diesel and electricity consumption of the solar manufacturing plant for the years 2019 and 2020, and monthly production output in kilogramme for these years were collected and analysed. The data revealed that among the process machines used in the production of solar panels, the solar panel laminating machine has the highest energy consumption, accounting for 49.87% of the total electrical energy. It was observed that fuel energy expended in operating the generator had the highest energy use accounting for approximately 96% of the total energy used. The process machines consumed 587,387.11kwh/year of diesel as against 62,847.49kwh/year which is the evaluated energy requirement of the process machines in 2019. Similarly, the manufacturing plant consumed 592,116Kwh/year of diesel as against 62,337.4Kwh/year in 2020. Also, the company operated below installed capacity to separately produce three categories namely: 37,500 for category 1A, 42,858 for category 1B and 93,750 solar panels per year for category 1C that could generate 7.5MW of electricity. In 2019, 10,945 of 1A, 10,535 of 1B and 14,200 of 1C that could generate 5.169MW of electricity was produced, while in 2020, 10,6687 of 1A, 11,230 of 1B and 15,238 of 1C that could generate 5.318MW of electricity was produced. This study revealed that energy was not efficiently utilized in NASENI and recommendations for efficient usage were proposed.

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1. Introduction

Energy audit is paramount in developing an energy management program. It enables companies and institutions to determine where and how energy is being used. This audit program gives a holistic view of an understanding of the specific energy, using patterns of a facility. Energy audit helps in monitoring variations such as energy cost, availability and reliability of supply of energy, decide on appropriate energy mix, identify energy conservation technologies and retrofit for energy conservation equipment. According to Saidur and Mekhilef [1], a method that can be used to identify and quantify how energy is being used as well as wasted in a plant is an energy audit. In Aliu et al [2], it was reported that many production industries are faced with challenges of utilizing energy efficiently. Hence, for industries to utilize energy efficiently, a proper energy audit should be carried out on its production processes. Sarkar [3] stated that in industries, there are three major factors responsible for production expenses; this include energy (electrical and thermal), labour and material.

According to Nicole [4], energy cost is a significant factor in economic activity and at par with factors of production like capital, land and labour. Hence, energy conservation measure which simply means using less energy for the same level of service or production output cannot be over-emphasized. The solar panel manufacturing plant is an energy intensive industry. Oyedepo and Aremu [5] opined that the energy input demand starts from the testing and sorting of the solar cells at a temperature of 26^{o}C and followed by the single and string soldering of the solar cell at a temperature of 200^{o} [6]. The challenge before an energy auditor is to increase energy efficiency or at least maintain the physical/economic situation at a reduced level of energy consumption [7].

Several studies have been published on energy audit and energy analysis for different industries [8][9][10][11][12]. Energy use performances and energy efficiencies of the industry have also been studied via various surveys in different countries [13][14]. However current literature does not show any study that has identified and quantified estimates of the energy usage in the National Agency for Science and Engineering Infrastructure (NASENI) Solar Panel Plant, Karshi, Abuja, Nigeria. Therefore, in this study, NASENI Solar Panel Plant is used as a case study. To achieve the aim of this study, the following objectives were adopted to enable determine the reduction in energy consumption per unit of product output and lower operating cost:

a. energy consumption pattern of NASENI Solar Panel Plant through electrical and heat energy.
b. diesel fuel energy consumption in the plant.
c. area where waste occur.
d. relate energy consumption to production (i.e. specific energy consumption).
e. where the most energy (significant energy) saving potential exists.
f. identify where scope for improvement exist.
g. establish practical means by which energy losses or over-consumption can be brought to minimum in the solar panel manufacturing plant.
h. create energy saving plan and policy as this project work is the first energy audit on NASENI Solar Panel Manufacturing Plant.

This study is therefore, intended to identify all energy saving units and where waste occurs; so as to improve on the performance and efficiency of the various units of the plant facility to achieve significant reduction in the cost of solar panel (Photovoltaic, PV) and as such enhance the utilisation of green and clean renewable energy resources in Nigeria and the world at large.

2. METHODOLOGY

2.1 Data Collection

Data was collected from NASENI Solar Panel Manufacturing Plant, Karshi Abuja, through the following method:

a. Interview of head and staff of various departments of company to obtain relevant information concerning their operation and facilities
b. A facility tour to obtain data of all energy systems and facilities.

c. A review of previous works along similar line
d. Searching of relevant literature in the library and internet
e. Analysis of data to determine where the most significant energy saving potential is possible.
f. Energy analysis of major energy consuming system.
g. Preparation of report summarizing audit finding.
h. Review of recommendation with facility management.

Also collected are the following data:

a. The power rating capacities of the different machines used in the solar panel manufacturing process
b. Solar panel manufacturing plants monthly diesel and electricity consumption for two audit years, 2019 and 2020
c. Monthly production output of manufactured solar panels in kg and quantity of diesel fuel consumed in litres for the audit years, 2019 and 2020.

2.2 Data Presentation

Presented in Table 1 to 9 are the data collected and used in the energy audit. These Tables contains the machine identity, power rating and hour of use per year of the process machine in 2019 and 2020.Table 1 show the energy consuming machines in the solar panel production process and their ratings.

Table 1: Energy Consuming Machines in the Solar Panel Production Process: Ratings and Capacities:

No of Machines	Machine Identity	Equipment Description	Name Plate Data	Power Rating (kW)
2	Testing & Sorting machine			1.5
1	Laser Scribing machine	Motor	220V, 3.9A, 2800rpm	0.55
23	Soldering device		220V, 50Hz, (200-400)^{0}C	0.065
1	Glass Washing machine	Blower motor	2900rpm, 2356m^3/hr	1.5
		Main motor	380V, 1.87A, 1440rpm	0.75
		Minor motor	220V,1.94A, 1400rpm	0.37
		Pump motor x2	380V, 0.68A	0.25
4	Termination machine		220V	2.52
1	EVA/TPT Cutting machine	Motor	240V,1600rpm, 60Hz	0.16
3	Laminating machine	Motor	380V, 1390rpm	0.75
4	Compressor	Motor	380V, 3.4A, 2840rpm	1.5
3	Vacuum pump	Motor	380V, 120A, 1440rpm	5.5
1	Framing machine	Main motor	380V	2.5
		Pump motor	280V, 3.7A, 1415rpm	1.5
		Compressor motor	380V, 3.4A, 2840rpm	1.5
1	Sun simulator			2.0
1	Water pump	Motor	230V	0.75

Table 2: Energy Consuming Machines in the Solar Panel Production Process in 2019:

(Monthly Operating Hours)

Month	TSM	LSM	SD	GWM	TM	EVA/TPT CM	LM	FM	SM	WP
Jan	168	80	168	126	168	126	147	105	126	42
Feb	178	85	170	131	168	126	150	105	126	42
Mar	168	90	160	129	162	122	150	100	131	40
Apr	171	100	162	135	162	126	154	110	137	48
May	170	90	164	137	163	126	152	112	135	45
Jun	167	90	164	134	160	120	149	115	130	46
Jul	170	100	175	145	172	130	164	130	145	54
Aug	166	95	169	140	169	125	160	128	140	48
Sep	160	90	162	138	165	124	154	125	136	45
Oct	158	90	160	138	165	125	155	125	136	44
Nov	158	87	157	138	166	125	155	125	134	42
Dec	143	74	145	124	150	110	140	112	120	35
Total	1,977	1,071	1,956	1,615	1,970	1,485	1,830	1,392	1,596	531

NOTE: The abbreviations below are used for Table 3 and 4

TSM – Testing and Sorting Machine
LSM- Laser Scribing Machine
SD - Soldering Device
GWM – Glass Washing Machine
TM – Termination Machine
EVA/TPT CM – EVA/TPT Cutting Machine
LM – Laminating Machine
FM – Framing Machine
SM – Sun Simulator
WP – Water Pump

Table 3: Energy Consuming Machines in the Solar Panel Production Process in 2020: (Monthly Operating Hours)

Month	TSM	LSM	SD	GWM	TM	EVA/TPT CM	LM	FM	SM	WP
Jan	168	82	168	130	168	130	150	108	130	45
Feb	164	80	168	128	165	125	146	104	128	43
Mar	168	84	168	132	168	128	149	108	126	40
Apr	165	82	164	130	165	125	144	102	123	39
May	168	80	168	130	168	126	148	107	128	40
Jun	168	80	168	131	168	126	150	107	126	40
Jul	180	95	180	145	179	136	157	112	138	45
Aug	168	80	168	130	168	126	148	105	126	42
Sep	172	83	172	135	173	130	151	110	130	43
Oct	180	94	180	145	180	136	159	112	138	45
Nov	167	82	161	130	162	125	144	105	124	40
Dec	137	68	139	117	144	106	136	107	115	34
Total	2,005	992	2,004	1,583	2,008	1,519	1,782	1,287	1,532	496

Table 4: Different Sets of Solar Panels, their Content Sizes and Masses

Packaged sets of solar panels	Content sizes (mm)	Masses (kg)
1A (200W)	1580 x 808 x 40	16

1B (175 W)	1165 x 990 x 40	10
1C (80W)	1125 x 558 x 40	8

***Source**: NASENI Solar Panel Manufacturing Plant, Karshi (2019)*

Tables 5 and 6 are data showing monthly production output of solar panels and quantity of diesel fuel used in 2019 and 2020

Table 5: Monthly Production Output and Quantity of Diesel Fuel Used in 2019

Months	Working days	Production output (kg)				Quantity of diesel fuel used (litres)
		1A	1B	1C	TOTAL	
Jan.	21	16480	9200	6480	32160	4200
Feb.	20	16320	8800	6400	31520	4000
March	20	15680	9200	6400	31280	4050
April	21	16560	8150	6480	31190	4100
May	22	17120	8300	6560	31980	4180
June	20	17600	8000	6400	32000	4170
July	23	13760	8450	14000	36210	4220
August	22	13440	8300	13600	35340	4225
Sept.	21	11440	9200	13200	33840	4160
Oct.	21	11440	8150	14880	34470	4145
Nov.	21	13120	9200	11520	33840	4225
Dec.	18	12160	10400	7680	30240	4010
Total	**250**				**394070**	**49685**

Table 6: Monthly Production Output and Quantity of Diesel Fuel Used in 2020

Months	Working days	Production output (kg)				Quantity of diesel fuel used (litres)
		1A	1B	1C	TOTAL	
Jan.	21	16816	9620	6480	32916	4150
Feb.	20	16320	9400	6720	32440	4060
March	21	13792	11720	9000	34512	4090
April	20	13440	11400	8800	33640	4105
May	21	13792	11720	8664	34176	4300
June	21	13792	11930	8160	33882	4200
July	23	17440	10060	8480	35980	4240
August	21	13120	8150	13200	34470	4230
Sept.	22	13440	7200	13600	34240	4210
Oct.	23	13760	7300	14000	35060	4270
Nov.	20	12800	7000	12800	32600	4230
Dec.	18	12160	6800	12000	30960	4000
Total	**251**				**404876**	**50,085**

Table 7 and 8 indicates monthly electricity energy consumed and cost for 2019 and 2020

Table 7: Monthly Electrical Energy Consumed and Cost for 2019

Month	Energy (kWh)	Demand (kVA)	Fixed	Energy charge (₦)	Demand charge (₦)	Fixed charge (₦)	Vat (₦)	Total cost (₦)

Jan.	1502	21,779	3910.50	1284.48	26,973.98
Feb.	1490	21,605	3910.50	1275.78	26,791.28
Mar.	1420	20,590	3910.50	1225.03	25,725.53
Apr.	1557	22,576.5	3910.50	1324.35	27,811.35
May	1630	23635	3910.50	1377.25	28,922.75
June	1376	19,952	3910.50	1193.13	25,055.63
July	1677	24,316.5	3910.50	1411.35	29,638.35
August	1532	22,214	3910.50	1306.23	27,430.73
Sept	1604	23,258	3910.50	1358.43	28,526.93
Oct	1631	23,649	3910.50	1378	28,937.5
Nov	1411	20,459.5	3910.50	1218.5	25,588.5
Dec	1390	20,155	3910.50	1203.28	25,268.78

Source: *NASENI Solar Panel Manufacturing Plant, Karshi AEDC electricity billing (2019)*

Table 8: Monthly Electrical Energy Consumed and Cost for 2020

Month	Energy (kWh)	Demand (kVA)	Fixed	Energy (₦)	Demand charge(₦)	Fixed charge	Vat(₦)	Total cost(₦)
Jan	1670			24,215		3910.50	1406.28	29,531.78
Feb	1602			23,229		3910.50	1356.98	28,496.48
March	1580			22,910		3910.50	1341.03	28,161.53
April	1618			23,461		3910.50	1368.58	28,740.08
May	1496			21,692		3910.50	1280.13	26,882.63
June	1502			21,779		3910.50	1284.48	26,973.98
July	1720			24,940		3910.50	1442.53	30,293.03
August	1598			23,171		3910.50	1354.08	28,435.58
Sept	1738			25,201		3910.50	1455.58	30,567.08
Oct	1610			23,345		3910.50	1362.78	28,618.28
Nov	1517			21,996.5		3910.50	1295.35	27,202.35
Dec	1490			21,605		3910.50	1275.78	26,791.28

Source: *NASENI Solar Panel Manufacturing Plant, Karshi, AEDC electricity billing (2020)*

Tables 9 indicates the different sets of packaged solar panels and production output for 2019 and 2020

Table 9: The Production Output of Packaged Sets of Solar Panels for 2019 and 2020

Set(packaged finish product)	Content sizes(mm)	Mass of packaged sets (kg)	(2019) Production output (kg)	(2020) Production output (kg)	(2019) Numbers of Solar Panels Produced	(2020) Numbers of Solar Panels Produced
1A	1580 x 808 x 40	16	175,120	170,672	10945	10667
1B	1165 x 990 x 40	10	105,350	112,300	10535	11230
1C	1125 x 558 x 40	8	113,600	121,904	14200	15238

2.3 Data Analysis Procedure

From the data collected, the following procedural steps were taken to get them analyzed and presented in the required forms:

a. The hours of usage of the different process machines associated with the different solar panel manufacturing processes were recorded, and these were used with other collated variables to determine the electrical energy consumption and specific energy consumption of the different process machines.

b. The total electrical energy consumption of the different solar panel manufacturing processes was determined in order to identify areas of high energy usage.

c. Energy types (electricity and fuel) were identified and collated.

d. Diesel fuel usage of the solar panel manufacturing process was identified, and from this the fuel energy consumption of the industrial process was determined.

e. Specific energy consumption of the different process machines in the different manufacturing processes was calculated.

f. Monthly production specific energy consumption for two-year energy audits, 2019 and 2020 was determined and comparison made between the values obtained for the two years

g. Annual production specific consumption for each type of energy was determined and comparisons were made of the computed data for the two years used in the audit. Production energy cost/consumption was finally evaluated.

2.4 Data Analysis Equations

The following equations in [2] were used to analyse the energy audit data collected:

2.4.1The Electrical Energy Consumption Equation of the Machines

The quantity of electricity used by the machines in the different solar panel manufacturing process is determined using equation (1):

$$E = \frac{3.6PL_f t}{\eta_m} \qquad (1)$$

E = electricalenergyconsumptionin MJ
P = powerinkW
t = timeinh
η_m = motorefficiency

Take motor efficiency as 80%
L_f = electricalloadfactor

Note,
1kWh = 1000W (3600s) = 3.6 x 10^6 J= 3.6MJ

Load factor: the ratio of the load that a piece of electrical equipment actually draws when it is in operation to the maximum load it could draw (which we call full load. The electrical load factor of a motor can be determined by:

a. opening the motor controller or switch box of the motor and connecting a clamp-on ammeter and current for reading the current entering the motor.
b. reading the full load current from the name plate of the motor,

then,

$$\text{Load factor} = \frac{\text{actual load current}}{\text{full load current on nameplate}} \qquad (2)$$

2.4.2 Diesel Fuel Consumption Equation

Energy from the diesel fuel consumed by the different solar panel manufacturing process machine is evaluated using equation (3):

$$E = m_{fu,d} \times cv_{fu,d} \quad (3)$$

where,
E = diesel fuel energyconsumption
$m_{fu,d}$ = mass of diesel fuel (kg)
$cv_{fu,d}$ = the calorific value of the diesel fuel (kJ/kg)

2.4.3 The Specific Energy Consumption Equation

The specific energy consumption of the different machines in the pot manufacturing process can be evaluated using equation (4):

$$\text{specific energy consumption} = \frac{\text{energy consumed}}{\text{production output}} \quad (4)$$

where,
specific energy consumption, SEC = MJ/kg

2.4.4 Electrical Load Equation

The electrical load of the solar panel manufacturing process is evaluated using equation (5)

$$\text{electrical load} = \frac{\text{energy input (kWh)}}{\text{period of operation (h)}} \quad (5)$$

2.4.5 Mixture Strength Equation

The mixture strength of the diesel fuel used in the solar panel manufacturing process is evaluated using equation (6).

Mixture Strength = (Stoichiometric A/F ratio) / (Actual A/F ratio) (6)

2.4.6 Mass Flow Rate of Air Equation

The mass flow rate of air is evaluated using equation (7)

$$\text{mass flow rate of air}, \dot{m}_a = m_{fuel} \times AF \quad (7)$$

2.4.7 Mass Flow Rate of Exhaust Gas Equation

The mass flow rate of exhaust gas is evaluated using equation (8)

$$\text{therefore}, \dot{m}_{g,exh} = \dot{m}_a + m_{fuel} \quad (8)$$

2.4.8 Exhaust Heat Loss Equation

The exhaust heat loss is evaluated using equation (9)

$$\text{exhaust gas heat loss}, Q_{exh} = \dot{m}_{g,exh} C_{pg} \left(T_{g,exh} - T_{amb}\right) \quad (9)$$

3. RESULTS, OBSERVATION AND DISCUSSION

3.1 Results of the Electrical Energy Consumption of the Different Process Machines for the Different Solar Panel Manufacturing Processes for 2019 and 2020

Data in Tables 1 and 2 was inputted into equation (1) to determine the energy consumption of the different process machines for the different solar panel manufacturing processes in the Karshi Plant as presented in Table 10 and 11 for the different solar panel manufacturing processes for 2019 and 2020.

Table 10: Summary of the Total Electrical Energy Consumption Requirement of the Different Process Machines for the Solar Panel Manufacturing Processes in 2019

Manufacturing processes	Electrical energy consumption (kWh/year)	Electrical energy consumption (MJ/year)	Actual (% process)
Testing and Sorting machine	4077.6	14679.36	6.49
Laser scribing machine	404.96	1457.86	0.64
Soldering device	1827.67	6579.61	2.91
Glass washing machine	3799.1	13676.76	6.05
Termination machine	13652.1	49147.56	21.70
EVA/TPT cutting machine	148.5	534.6	0.24
Laminating machine	31338.69	112819.29	49.87
Framing machine	5176.55	18635.58	8.24
Sun simulator	2158.77	7771.57	3.44
Water pump	263.55	948.78	0.42
Total	**62847.49**	**226,250.97**	**100**

Table 10 shows that the laminating machine manufacturing process has the highest electrical energy consumption for 2019. This is primarily due to the high electrical energy consumption for the heating of the laminating oil, which is the major machine using thermal energy for the lamination of the solar panels. Also, a summary of the total electrical energy consumption of the different process machines of the different solar panel manufacturing processes in year 2019 showed that the laminating machine manufacturing process account for 49.87% of the total electrical energy consumption of the solar panel manufacturing process while the EVA/TPT cutting manufacturing process account for 0.24%.

Table 11: Summary of the Total Electrical Energy Consumption Requirement of the Different Process Machines for the Solar Panel Manufacturing Processes in 2020

Manufacturing processes	Electrical energy consumption (kWh/year)	Electrical energy consumption (MJ/year)	Actual % process
Testing and Sorting machine	4135.31	14887.12	6.64
Laser scribing machine	375.1	1350.36	0.60
Soldering device	1939.8	6983.28	3.11
Glass washing machine	3647.68	13131.65	5.85
Termination machine	13802.67	49689.61	22.14
EVA/TPT cutting machine	151.9	546.84	0.24
Laminating machine	31056.2	111802.32	49.82
Framing machine	4866.47	17519.29	7.81
Sun simulator	2106.51	7583.44	3.38
Water pump	255.76	920.74	0.41
Total	**62337.4**	**224414.64**	**100**

Table 11 shows that the laminating machine manufacturing process has the highest electrical energy consumption for 2020. This is primarily due to the high electrical energy consumption for the heating of the laminating oil, which is the major machine using thermal energy for the lamination of the solar panels. Also, a summary of the total electrical energy consumption of the different process machines of the different solar panel manufacturing processes in year 2020, in Table 11 shows that the laminating machine manufacturing process account for 49.82% of the total electrical energy consumption of the solar panel manufacturing process while the EVA/TPT cutting manufacturing process account for 0.24%.

3.2 Result of Diesel Fuel Energy Consumption of the Industrial Solar Panel Manufacturing Process for 2019 and 2020

Operating Data for Diesel Generator:
Fuel Type = Diesel
Diesel Consumption Rate = 198.74 litres/day
Speed = 1500 rpm

For 2019
Fuel Consumption = 198.74 litres/day
$\text{volume of disel fuel used per year (2013)} = 198.74\ \text{litres/day} \times 250\text{day} = 49{,}685\ \text{litres/year}$
Note:
$1\text{m}^3 = 1000\text{litres}$

therefore,

$$\text{volume of diesel fuel per year } (\text{m}^3/\text{year})\ 49{,}685 \times \frac{1}{1000} = 49.685\ \text{m}^3/\text{year}$$

Calculating the density of the diesel fuel:
Relative density of diesel fuel $= 0.95$
density of water $= 1000\ \text{kg/m}^3$ density of diesel fuel
$= \text{density of water} \times \text{relative density of diesel fuel}$
$= 0.95 \times 1000\ \text{kg/m}^3 = 950\ \text{kg/m}^3$

also, calculating for the mass of diesel fuel:
mass of diesel fuel $=$ density of fuel $\times$ volume of diesel fuel
$= 950\ \text{kg/m}^3 \times 49.685\ \text{m}^3/\text{year} = 47200.75\text{kg /year}$

but, the calorific value of diesel fuel, $CV_{fu.d}$ is,
$CV_{fu.d} = 44800\ \text{kJ/kg} = 44.8\ \text{MJ/kg}$ (www.engineeringtoolbox.com, 2014)

Calculating the thermal energy consumed from the diesel fuel per year:
The thermal energy consumed from the diesel fuel is calculated using equation (1):
Therefore, energy consumed from diesel fuel per year is:

$$= 47200.75\ \text{kg/year} \times 44.8\ \text{MJ/kg} = 2{,}114{,}593.6\ \text{MJ/year}$$

but 1kWh = 3.6MJ
Therefore,

Energy consumed from diesel fuel per year is $= 587{,}387.11\ \text{kWh/year}$

3.3 Calculating for the money equivalent of the diesel fuel consumption in the industrial solar panel manufacturing process for 2020

Diesel fuel consumption in the industrial process = 198.74litres per day
diesel fuel cost = ₦150.00
cost of diesel fuel consumption per day is,
$= 198.74$ litres/day × ₦150.00/litre = ₦29,811perday

therefore,
cost of diesel fuel consumption per year (working days):
= ₦29811/day × 250days = ₦7,452,750 per year

For 2020
Fuel Consumption = 199.542 litres/day
volume of disel fuel used per year (2020) = 199.542 litres/day × 251day
= 50085.042litres per year

note:
$1m^3 = 1000$litres
then,

volume of diesel fuel per year (m^3/year) $50{,}085.042 \times \frac{1}{1000} = 50.085\ m^3$/year

calculating the density of the diesel fuel:
Relative density of diesel fuel = 0.95
density of water = 1000 kg/m^3 density of diesel fuel
= density of water × relative density of diesel fu
$= 0.95 \times 1000\ kg/m^3 = 950\ kg/m^3$

also, calculating for the mass of diesel fuel
mass of diesel fuel = density of fuel × volume of diesel fuel
$= 950\ kg/m^3 \times 50.085 = 47580.75$kg /year

but, the calorific value of diesel fuel, $CV_{fu.d}$ is,
$CV_{fu.d} = 44800\ kJ/kg$ (www. engineeringtoolbox. com, 2014) = 44.8 MJ/kg

Calculating the thermal energy consumed from the diesel fuel per year:
The thermal energy consumed from the diesel fuel is calculated using equation (1):

Therefore, energy gained/consumed from diesel fuel per year is,
$= 47580.75$ kg/year × 44.8 MJ/kg = 2,131,617.6 MJ/year

But 1kWh = 3.6MJ,
Hence,
Energy gained/consumed from diesel fuel per year = 592,116 kWh/year

3.4 Calculating for the money equivalent of the diesel fuel consumption in the industrial solar panel manufacturing process for 2020

Diesel fuel consumption in the industrial process = 199.542litres per day
Diesel fuel cost = ₦150.00
cost of diesel fuel consumption per day is,
$= 199.542$ litres/day × ₦150.00/litre
= ₦29,931.3perday
therefore, cost of diesel fuel consumption per year(workingdays) is:
= ₦29,931.3/day × 251days

then diesel fuel cost per year $= ₦7{,}512{,}756.3$ per year

3.5 Exhaust Gas Heat Loss, $Q_{net,}$ from the Heating Chamber of the Solar Module Laminating Machine

DATA:
Mass flow rate of the diesel fuel $\dot{m}_{fu,d}$: 23.75kg/hr. at 12bar = 0.0066kg/s
Ambient temperature: $36\ ^{o}C = 309$ K
Temperature of combustion products leaving heating chamber: 135^{o}C= 408K (***Source*:** NASENI Machine Manual)
Specific heat capacity of exhaust gas: 1.15kJ/kgK
Stoichiometric equation of the combustion of the diesel fuel

$$4C_{12}H_{23} + 71O_2 + \left(71\ x\frac{79}{21}\right)N_2 \rightarrow 48CO_2 + 46H_2O + \left(71\ x\frac{79}{21}\right)N_2 \qquad (10)$$

4 kmol of fuel has a mass of 4 (144 + 23) kg = 668kg;
71 kmol of oxygen have a mass of (71 x 32)kg = 2272kg
O_2 required per kg of fuel = 2272/668 = 3.401
Therefore
Stochiometric air − diesel fuel ratio $= \frac{3.401}{0.233} = 14.5974$
Considering a mixture strength of 90%, using equation (6)
Mixture Strength = (Stoichiometric A/F ratio) / (Actual A/F ratio)
0.9 = 14.595/Actual A/F ratio
Therefore,
Actual A/F ratio = 14.595/0.9 = 16.218
This means that 1/0.9 times as much air is supplied as is necessary for complete combustion. The exhaust will therefore contain (1/0.9) – 1 = 0.1/0.9 of the stoichiometric oxygen.

$$4\ C_{12}H_{23} + 1/0.9[71O_2 + (71x\ 79/21)N_2] \rightarrow$$
$$48CO_2 + 46H_2O + [(0.1/0.9)\ x\ 71]O_2 + (1/0.9)x71x\ (79/21)N_2 \qquad (11)$$

i.e. the products are:
48kmolCO_2 + 46 kmol H_2O + 7.89kmolO_2 + 296.773N_2
The total amount of substance;
= 48 + 46 + 7.89 + 296.773
= 398.7kmol
Hence wet analysis is;
(48/398.7) x 100 = 12.04% CO_2
(46/398.7) x 100 = 11.54% H_2O
(7.89/398.7) x 100 = 1.98% O_2
(296.773/398.7) x 100 = 74.44% N_2
The total dry amount of substance
= 48 + 7.89 + 296.773 = 352.663kmol
Hence the dry exhaust gas analysis is,
(48/352.663) x 100 = 13.61% CO_2
(7.89/352.663) x 100 = 2.24% O_2
(296.773/352.663) x 100 = 84.15%N_2
Obtaining the flow rate of the combustion product, $\dot{m}_{g,exh}$ using Equation 7 and 8
mass flow rate of air, $\dot{m}_a = m_{fuel} \times AF$
$= 0.0066 \times 16.218 = 0.10704$ kg/s
therefore, $\dot{m}_{g,exh} = \dot{m}_a + m_{fuel}$
$\dot{m}_{g,exh} = 0.10704 + 0.0066 = 0.114$kg/s

Exhaust gas heat loss using Equation 9, $Q_{exh} = \dot{m}_{g,exh} C_{pg} (T_{g,exh} - T_{amb})$

$Q_{exh} = 0.114 \times 1.15 \times 10^3 (408 - 309)$

$Q_{exh} = 0.114 \times 1.15 \times 10^3 (99) = 12.98kW$

Therefore, the exhaust heat loss, Q_{net}, from the heating chamber of the solar module laminating machine = 12.98kW

3.6 Result of the Specific Energy Consumption of the Different Process Machines for the Different Manufacturing Processes

To determine the specific energy consumption of the different process machines for the different solar panel manufacturing processes, Equation 4 was used. Table 12 and Table 13 show the specific energy consumption of the solar panel manufacturing process machines for 2019 and 2020 respectively.

Table 12: Solar Panel Manufacturing Process Machines Specific Energy Consumption, SEC (MJ/kg) for 2019

Manufacturing processes	Electrical energy consumption (kWh/year)	Electrical energy consumption (MJ/year)	Production output (kg/year)	Specific Energy Consumption, SEC, (MJ/kg)
Testing and Sorting machine	4077.6	14679.36	394070	0.04
Laser scribing machine	404.96	1457.86	394070	0.01
Soldering device	1827.67	6579.61	394070	0.02
Glass washing machine	3799.1	13676.76	394070	0.04
Termination machine	13652.1	49147.56	394070	0.13
EVA/TPT cutting machine	148.5	534.6	394070	0.002
Laminating machine	31338.69	112819.29	394070	0.29
Framing machine	5176.55	18635.58	394070	0.05
Sun simulator	2158.77	7771.57	394070	0.02
Water pump	263.55	948.78	394070	0.003
Total	**62847.49**	**226,250.97**		**0.605**

From Table 12, the total specific energy consumption of the laminating machine process is 0.29MJ/kg for 2019 and the EVA/TPT cutting machine is 0.002MJ/kg. When these values are compared, it can be deduced that the total specific energy consumption of the laminating machine process is the highest among the entire production process. While the EVA/TPT cutting machine specific energy consumption is the lowest.

Table 13: Solar Panel Manufacturing Process Machines Specific Energy Consumption, SEC (MJ/kg) for 2020

Manufacturing processes	Electrical energy consumption (kWh/year)	Electrical energy consumption (MJ/year)	Production output (kg/year)	Specific Energy Consumption, SEC, (MJ/kg)

Testing and Sorting machine	4135.31	14887.12	404876	0.04
Laser scribing machine	375.1	1350.36	404876	0.003
Soldering device	1939.8	6983.28	404876	0.02
Glass washing machine	3647.68	13131.65	404876	0.03
Termination machine	13802.67	49689.61	404876	0.12
EVA/TPT cutting machine	151.9	546.84	404876	0.002
Laminating machine	31056.2	111802.32	404876	0.28
Framing machine	4866.47	17519.29	404876	0.04
Sun simulator	2106.51	7583.44	404876	0.02
Water pump	255.76	920.74	404876	0.002
Total	**62337.4**	**224414.64**		**0.557**

From Table 13, the total specific energy consumption of the laminating machine process is 0.28MJ/kg for 2020 and the EVA/TPT cutting machine is 0.002MJ/kg. When these values are compared, it can be deduced that the total specific energy consumption of the laminating machine process is the highest among the entire production process. While the EVA/TPT cutting machine specific energy consumption is the lowest.

3.7 Results of the Monthly Production Specific Energy Consumption for 2019 and 2020

The data presented in Table 4, Table 5, Table 6 and Table 7 are analysed in this section using Equations 3and 4, and the results obtained are presented in tabular form.

Table 14:Monthly Production Specific Energy Consumption (SEC) for 2019

Month	No of working days	Production output (kg)	Electricity consumption		Diesel fuel consumption		SEC		Overal SEC (MJ/kg
			Energy (kWh)	**Energy (MJ)**	**Quantity (litre)**	**Fuel energy (MJ)**	**Electricity (MJ/kg)**	**Fuel MJ/kg**	
Jan.	21	32160	1502	5407.2	4200	178752	0.17	5.56	5.73
Feb.	20	31520	1490	5364	4000	170240	0.17	5.40	5.57
March	20	31280	1420	5112	4050	172368	0.16	5.51	5.67
April	21	31190	1557	5604.2	4100	174496	0.18	5.60	5.78
May	22	31980	1630	5868	4180	177900.8	0.19	5.56	5.75
June	20	32000	1376	4953.6	4170	177475.2	0.16	5.55	5.71
July	23	36210	1677	6037.2	4220	179603.2	0.17	4.96	5.13
Aug.	22	35340	1532	5515.2	4225	179816	0.16	5.09	5.25
Sept.	21	33840	1604	5774.4	4160	177049.6	0.17	5.23	5.40
Oct.	21	34470	1631	5871.6	4145	176411.2	0.17	5.12	5.29
Nov.	21	33840	1411	5079.6	4225	179816	0.15	5.32	5.47
Dec.	18	30240	1390	5004	4010	170665.6	0.17	5.65	5.82
Total	**250**	**394070**	**18220**	**65591**	**49685**	**2114593.6**	**2.02**	**64.55**	**66.57**

Table 14 shows the total production output, total electrical energy consumption and total diesel fuel energy consumption for 2019 to be 394070kg, 18220kWh (65591MJ) and 2114593.6 MJ/year. In 2019, the total specific energy consumption for diesel fuel and electricity are 64.55MJ/kg and 2.02 MJ/kg respectively. The summed total specific energy consumption for both diesel fuel and electricity energy from AEDC gives 66.57 MJ/kg for 2019. The high value of diesel fuel specific energy consumption is due to epileptic power supply (electricity) by AEDC leading to the high usage of diesel fuel. Also, from Table 14, it is shown that the month of December in 2019 has the highest value of specific energy consumption of 5.82MJ/kg. This is due to the fact that most of the machines used for the solar panel manufacturing process was due for maintenance and power supply from AEDC was poor.

Table 15: Monthly Production Specific Energy Consumption (SEC) for 2020

Month	No. of working days	Production output (kg)	Electricity consumption		Diesel fuel consumption		SEC		Overall SEC (MJ/Kg)
			Energy (kWh)	**Energy (MJ)**	**Quantity (litres)**	**Fuel energy (MJ)**	**Electricity (MJ/kg)**	**Fuel (MJ/kg)**	
Jan.	21	32916	1670	6012	4150	176624	0.18	5.37	5.55
Feb.	20	32440	1602	5767.2	4060	172793.6	0.18	5.33	5.51
March	21	34512	1580	5688	4090	174070.4	0.17	5.05	5.22
April	20	33640	1618	5824.8	4105	174708.8	0.17	5.20	5.37
May	21	34176	1496	5385.6	4300	183008	0.16	5.36	5.52
June	21	33882	1502	5407.2	4200	178752	0.16	5.28	5.44
July	23	35980	1720	6192	4240	180454.4	0.17	5.02	5.19
August	21	34470	1598	5752.8	4230	180028.8	0.17	5.22	5.39
Sept.	22	34240	1738	6256.8	4210	179177.6	0.18	5.23	5.41
Oct.	23	35060	1610	5796	4270	181731.2	0.17	5.18	5.35
Nov.	20	32600	1517	5461.2	4230	180028.8	0.17	5.52	5.69
Dec.	18	30960	1490	5364	4000	170240	0.17	5.50	5.67
Total	**251**	**404876**	**19141**	**68907.6**	**50085**	**2131617.6**	**2.05**	**63.26**	**65.31**

Table 15 shows the total production output, total electrical energy consumption and total diesel fuel energy consumption for 2020 to be 404876kg, 19141kWh (68907MJ/year) and 2131617.6MJ/year. Also in 2020, the total specific energy consumption for diesel fuel and electricity are 63.26MJ/kg and 2.05 MJ/kg respectively. The summed total specific energy consumption for both diesel fuel and electricity energy from AEDC gives 65.31 MJ/kg for 2020 respectively. The high value of diesel fuel specific energy consumption is due to epileptic power supply (electricity) by AEDC leading to the high usage of diesel fuel. Also, from Tables 15, it is shown that the month of November in 2020 has the highest value of specific energy consumption of 5.69MJ/kg respectively. This is due to the fact that most of the machines used for the solar panel manufacturing process was due for maintenance and power supply from AEDC was poor.

Table 16: Summary of Annual Production Specific Energy Consumption (SEC)

Year	Production output (kg)	Electrical energy (SEC), MJ/kg	Fuel energy (SEC), MJ/kg	Overall SEC (MJ/kg)
2019	394070	2.02	64.55	66.57

2020	404876	2.05	63.26	65.31

Table 16 shows that the total specific energy consumption for 2019 and 2020 are 66.57MJ/kg and 65.31MJ/kg respectively. From the table, it is clearly observed that there is little or no difference in the value of electrical energy Specific Energy Consumption for 2019 and 2020 of 2.02MJ/kg and 2.05MJ/kg respectively, but there is a significant difference in the diesel fuel Specific Energy Consumption for 2019 and 2020 of 64.55MJ/kg and 63.26MJ/kg. This is as a result of almost same level of fluctuation in the supply of electricity by AEDC and secondly, better maintenance practice and skilful handling of machines were done by the company in 2020 and these results in the reduction in annual total diesel specific energy consumption from 64.55 MJ/kg in 2019 to 63.26 MJ/kg. Also, when the annual production specific energy consumption for 2019 and 2020 are compared from Table 16 that of 2019 is higher. This implies that the company managed energy used in production more efficiently in 2020 than in 2019. By implication, this means that the company had more financial gain from production in 2020 than in 2019.

3.8 Result of Electrical Load Analysis

The analyses of the electrical load over the two years used for the study are determined in this section using Equation 5, by inputting energy input data obtained from electricity bill (data in Table 6 and Table 7) and diesel fuel consumption log sheet (data in Table 4 and Table 5) into the equation . Table 17 is the summary of the results of the electrical load analysis:

Table 17: Summary of Electrical Load Analysis

Year	Energy (kWh)	Period (hours)	Electrical load (kW)
2013	18220(electricity) 587387.11(diesel fuel)	2000	302.80
2014	19141(electricity) 592116(diesel fuel)	2008	304.41

3.9 Energy Cost of Manufacturing a Set of Solar Panels

For 2019:

Cost per kg = Total Annual Energy cost / Annual Production output (12)

Cost per kg=₦ 7,779,421.31 / 394070 = N19.74k per kg

Therefore energy input price per panels are,

Solar Panel (1A) = 16 x 19.74 = ₦315.84k

Solar Panel (1B) = 10 x 19.74 = ₦197.40k

Solar Panel (1C) = 8 x 19.74 = ₦157.92k

For 2020:

Cost per kg = ₦7, 853,450.4 / 404876

= ₦19.40k per kg

Therefore energy input price per panels are, Solar Panel (1A) = 16 x 19.40 = ₦310.40k

Solar Panel (1B) = 10 x 19.40 = ₦194.0k

Solar Panel (1C) = 8 x 19.40 = ₦155.20k

3.10 Energy Consumption of Manufacturing a Set of Solar Panels

For 2019:

Total energy consumption = (18220 + 587387.11)kWh = 605607.11kWh.

Annual Production = 394070kg

Hence, Energy Consumption per kg = 605607.11 / 394070= 1.5368 kWh/ kg

Therefore,

Solar Panel (1A) = 1.5368 x 16 = 24.59kWh

Solar Panel (1B) = 1.5368 x 10 = 15.37kWh

Solar Panel (1C) = 1.5368 x 8 = 12.30kWh

For 2020:

Total Energy Consumption = (19141 + 592116)kWh = 611257kWh

Annual Production = 404876kg

Energy Consumption per kg = 611257/ 404876 = 1.5097kWh/kg

Therefore,

Solar Panel (1A) = 1.5097 x 16 = 24.16kWh

Solar Panel (1B) = 1.5097 x 10 = 15.10kWh

Solar Panel (1C) = 1.5097 x 8 = 12.08kWh

3.11 Plant Efficiency

Plant Efficiency = Actual Wattage Production / Installed Wattage Production (13)

Taking data from Table 8

For 2019:

Actual Wattage Production = (10945x200) + (10535x175)+(14200x80)= 5.169MW
Plant Efficiency = 5.169 / 7.5 = 0.6892 = 68.92%

For 2020:

Actual Wattage Production = (10667x200)+(11230x175)+(15238x80)= 5.318MW
Plant Efficiency = 5.318 / 7.5 = 0.7091 = 70.91%
Plant Average Efficiency = (70.91 + 68.92) / 2 = 69.92%

3.12 Comparing Results Obtained from Similar Plants in other Locations of the World.

Table 18: Comparison of installed Wattage Production (MW) to Actual Wattage Production of Solar Panels for other Plants in the World

Company	Country	Plant Installed Annual Wattage of Solar Panels Produced				Plant Actual Annual Wattage of Solar Panels Produced				Average Plant Efficiency
		2006	2007	2008	2009	2006	2007	2008	2009	
Yingli	China		200	400	600	145	282	525.3		79.32%
Trina Solar	China	110	350	600		29	210	399		60.19%
Sun Power	Philippines	214	414	574		100	237	397		61.07%
Sharp	Japan	710	710	710		363	473	595		67.18%
Bosch	Germany	220	260	270		55	143	200		53.07%
Delsolar	Taiwan	100	120	120		54	83	88.8		66.41%
Evergreen Solar	USA	17	58.5	145		16	26.5	104		66.17%
First Solar	USA	119	147	160		119	145	145		95.54%
First Solar	Germany	158	196	214		81	192	193		81.96%
First Solar	Malaysia	392	854			167	765			74.76%
Just Solar Co. Ltd	China	120	156	205		83	156	194		90.02%
Mitsubishi Heavy	Japan	14	42	68		14	40	42		77.42%

Source: [15]

The average plant efficiency of NASENI Solar Panel Manufacturing Plant is 69.92%. This was compared to other Solar Panel Manufacturing Plant in the world as shown in Table 18. Just Solar Co Ltd, China had a production efficiency of 90.02%. So there is room for improvement of NASENI production efficiency.

3.13 Observations

From the walk-through energy audit carried out on the solar panel manufacturing process of the NASENI Solar Panel Manufacturing Plant, the following were observed:

a. Compacted Working Space and Poor Ventilation

In the course of the walk through energy audit, it was observed that the working space in the company is very compact and proper ventilation plan was not captured in the design of the production building of the company. This adversely affects production as in the case mainly at the soldering facilities where the workers experience thermal and emission discomfort.

i. removing those machines that are no longer being used in the solar panel manufacturing process.
ii. re-planning the plant layout so as to create an adequate working space and proper ventilation.

b. Electric Motors

Electric drives of one type or another use 68% of industrial electricity [16]. Examples include electric motors, compressors, fans and pumps. Improvements in these applications would have a significant effect on reducing industrial electrical energy consumption. It was observed during the walk-through energy audit that five electric motors are old and generate excessive noise because their coils have been rewound more than twice. Also, it was observed that six of the motors were dirty, dusty and poorly ventilated.

Some energy can be saved by:

i. Reconfiguring electrical motors from delta to star connection which will make it run at less than 33% of the rated output.
ii. Replacement of old electric motors with new ones
iii. Proper house-keeping and operation of electric drives. Good ventilation reduces energy loss due to heating
iv. Install variable speed drives and soft-start options on electric motors

c. Electric Generator

In the course of the walk-through energy audit, it was observed that the electric generator used at NASENI Solar Panel Manufacturing Plant, Karshi generates more electrical energy than needed in the solar panel manufacturing process. This results in energy (i.e. fuel) wastage and high cost of production.

$$kWh = kVA \times P.F \times H \times D \quad (13)$$

Equation 13 is used to calculate the actual kVA required by the process machines.

For 2019:

$kVA = 62847.49 / 0.8 \times 8 \times 250 = 39.28\ kVA$

For 2020:

$kVA = 62337.4 / 0.8 \times 8 \times 251 = 38.81 kVA$

Energy wastage can be reduced by:

i. Installing smaller generator of 100kVA capacity as this will minimize energy wastage
ii. Replacing diesel generator with gas generator. Gas is cheaper, cleaner and burns readily in air.

d. Energy Loss on Idle Running

In the course of the walk-through energy audit, it was observed that the glass washing machine runs for one- hour daily to allow sufficient absorption of water by the towelling rollers which need to be well soaked before coming in contact with the glass to avoid breakage. This results in energy wastage of 6.25% of annual energy consumption in glass washing machine i.e. 854.8MJ in 2019 and 820.73MJ in 2020. This energy wastage can be reduced by:

i. Replacing the towelling rollers in the glass washing machine with a higher absorbent material.

e. Electric Process Heat

Electricity is widely used as a source of process heat due to ease of control, cleanliness, wide range in unit capacities (watts to megawatts), safety and low initial cost. Typical heating applications include resistance heaters (metal sheath heaters, heating tubes, ovens, furnaces, boilers), electric salt bath furnaces, infrared heaters, induction and high-frequency resistance heating, dielectric heating, and direct arc electric furnaces. In this plant surveyed, heating tubes were observed to be losing much heat because they are not properly lagged. Energy can be saved in this plant by:

i. Proper lagging of heating tubes carrying hot laminating oil from the heating chamber to the laminating area of the solar cell laminating machine.

Also based on the results of data analysed in the energy audit of the solar panel manufacturing process of NASENI Solar Panel Manufacturing Plant, the followings were observed:

i. Among the machines used in the solar panel manufacturing process, the laminating machine which has energy consumption capacity of about 112,819.29MJ/year and 111,802.32 MJ/year in 2019 and 2020 respectively is the highest consumer of energy. This accounts for 49.87% and 49.82% in 2019 and 2020 respectively of the process operation consumption requirement.
ii. The EVA/TPT cutting machine is the least consumer of energy among the process machines used in the solar panel manufacturing process. It accounts for 0.24% of the process operation energy consumption requirement in 2019 and 2020
iii. Analysis of the electricity consumption data showed that heavy electricity consuming equipment like electric motors that are used to drive most of the machines in the NASENI Solar Panel Manufacturing Plant were operating below their installed capacity. This is primarily due to the fact that most of the electric motors are old and always rewound. Therefore, a significant amount of energy can be saved by overall motor inventory and replacement plan in the plant.

4. Conclusion and Recommendation

4.1 Conclusion

The energy audit of the solar panel manufacturing process of NASENI Solar Panel Manufacturing Plant, Karshi was carried out in order to examine the energy consumption pattern of the solar panel manufacturing process and identify areas of high energy usage, wastage and most significantly, energy saving potentials that are possible. From the energy audit carried out on the solar panel manufacturing process of NASENI Solar Panel Manufacturing Plant, Karshi, two sources of energy used for the process were identified, electricity from AEDC and diesel fuel. The source of electricity for the solar panel manufacturing process of the NASENI Solar Panel Manufacturing Plant, Karshi investigated was mainly from generating set; this was due to either low voltage or epileptic power supply from AEDC.

Based on the findings of the energy audit, From the calculated amount of diesel fuel energy consumption, which is about 587,387.11 kWh/yr and 592,116 kWh/yr for 2019 and 2020 respectively, when compared to the calculated energy requirement from the process machines capacities which are 62,847.49 kWh/yr and 62,337.4 kWh/yr for 2019 and 2020 respectively it can be deduced that there was over consumption of energy. Hence, excess wastage of energy in the manufacturing plant. Over the two years considered in this energy audit work, i.e. from 2019 – 2020, it was established from the analysis that the specific energy consumption for 2019 (66.57 MJ/Kg) was higher than that of 2020 (65.31MJ/kg). The implication of this is that the company gained more financially in 2020 compared to 2019, and also a higher quantity of energy was lost in 2019 compared to 2020. Also, based on results of the energy audit, it was established that in 2019, on the average, energy cost per kg is ₦19.74k and energy cost per solar panel on the three sets of solar panels are 1A (₦315.84k), 1B (₦197.40k) and 1C (₦157.92k). Also in 2020, energy cost per kg is ₦19.40k and energy cost per solar panel on the three sets of solar panels are 1A (₦310.40k), 1B (₦194.0k) and 1C (₦155.20k).Therefore, it can be concluded that in 2013, the company did not utilize energy as efficiently as it did in 2020.

In addition, it was deduced from the finding that in 2019 about 587387.11kWh and 18220kWh of diesel fuel energy and electrical energy was consumed by the solar panel manufacturing process of the NASENI Solar Panel Manufacturing Plant, Karshi. This cost about ₦7,779,421.31k, of which diesel fuel account for 95.83% and electricity 4.17%. Also in 2020, about 592116kWh and 19141kWh of diesel fuel energy and electrical energy was consumed by the solar panel manufacturing process of the NASENI Solar Panel Manufacturing Plant, Karshi, and this cost about ₦7,853,450.40k of which diesel fuel account for 95.67% and electricity 4.33%.

The Plant installed annual wattage of solar panels produced is 7.5MW/year, this means the Plant was designed to produce solar panels that could generate 7.5MW of electricity in a year. But Plant actual annual wattage of solar panels produced were 5.169MW/year for 2019 and 5.318 MW/year for 2020, this means the Plant produced solar panels that could generate 5.169MW and 5.318 MW for 2019 and 2020 respectively. The Plant average efficiency for the two years under study is 69.92%. Comparing the results of NASENI Plant to other Solar Panel Production Plants in the world, from Table 18 it could be clearly seen that there is need to improve the average efficiency of the plant to meet the standard of other Plants in the world. Conclusively, in order to curtail unnecessary wastage of energy and to reduce cost of energy consumption, the following factors must be critically looked into:

i. Procurement of test equipment for energy monitoring in the solar panel manufacturing process.
ii. Significant capital investment to improve the energy consumption.

4.2 Recommendations

Based on the results and discussion carried out on the energy audit of the solar panel manufacturing process of NASENI Solar Panel Manufacturing Plant, Karshi the following can be recommended as measures to conserve energy and save production cost:

i. Reconfiguring electrical motors from delta to star connection which will make it run at less than 33% of the rated output and replacement of old electric motors with new ones.

ii. Installing a 100kVA capacity generator set to replace the 350kVA currently providing electricity for the plant.

iii. Replacing the towelling rollers in the glass washing machine with a higher absorbent material to avoid the energy wastage of 6.25% of annual energy consumption in glass washing machine i.e. 854.8 MJ in 2019 and 820.73 MJ in 2020.

iv. Reduce heated laminating oil leakages along tubes and improve lagging of laminating oil tubes.

v. Good maintenance and control must be put in place in order to improve the energy performance of the factory.

vi. Energy reduction is another substitute for job reduction and both companies and government as well as development partners should be actively engaged in industrial energy efficiency options in developing countries like Nigeria.

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