International Journal of Engineering and Technical Research (IJETR)
ISSN: 2321-0869 (O) 2454-4698 (P), Volume-3, Issue-7, July 2015

The Potentials of Solar Thermal Technology for Sustainable Development in Nigeria

Olabomi Rasaq Adekunle, A. Bakar Jaafar, Md Nor Musa

***Abstract*— Energy crisis and climate change are serious global issues, whereas energy demand keeps increasing as a result of population increase and the need for more comfort. Meanwhile the current major source of energy (fossil fuel) is being threatened with imminent depletion despite its global warming potentials. Alternative (renewable) energy is being sourced by all countries of the world to ensure safety of environment and to have dependable and sustainable energy supply as energy is rightly seen as pivot to technology and modern day development. Solar energy is free, clean, renewable, sustainable, and abundantly available in Nigeria with the potentials of daily 3.5 kWhm^2 in the South and 7.0 kWh/m^2 in the North. Solar energy is tapped by different methods and can be applied in industrial, domestic, agricultural, as well as public and commercial sectors. Meanwhile, the current solar energy utilization in Nigeria is relatively insignificant. This paper takes a look at application potentials of solar energy in Nigeria towards solving the current energy crisis as well as other environmental problems resulting from current energy usage. It covers different ways of tapping of solar energy for different applications and their associated challenges while suggestions are made to encourage the utilization of solar energy in Nigeria**

***Index Terms*— Coefficient of Performance, Environment, Global Warming, Renewable Energy, Solar collector**

I. INTRODUCTION

In recent years, research interest has been focused on utilization of alternative and renewable energy (solar, wing, biomass, ocean thermal, tidal, geothermal, etc) due to overwhelming awareness on issues surrounding the current energy supply; anticipated extinction and environmental issues resulting from their production and/or application. Alternative energy is seen as green, sustainable, abundantly free, and with very little or no harmful effect on environment either from the usage or process of production. Nigerian is endowed with both renewable and non-renewable energy potentials (Petroleum, Natural gas, Coal, Hydro, Solar, Wind, Geothermal, Tidal, Ocean thermal, Biomass etc) [1, 2], but only non-renewable sources are being explored (Fig 1.1) with little consideration for the finite nature of these energy sources and their likely environmental effects.

Olabomi Rasaq Adekunle, Razak School of Engineering and Advanced Technology, Universiti Teknologi Malaysia

A.Bakar Jaafar, Ocean Thermal Energy Conversion Center, Universiti Teknologi Malaysia

Md Nor Musa, Mechanical Engineering Department, Universiti Teknologi Malaysia

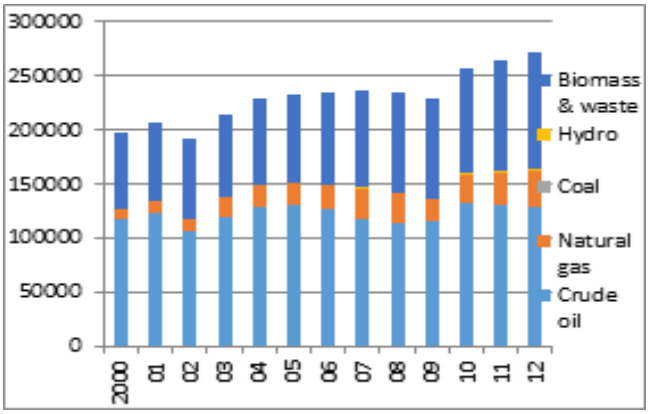

Figure 1.1: Nigeria Primary Energy Production (IEA)

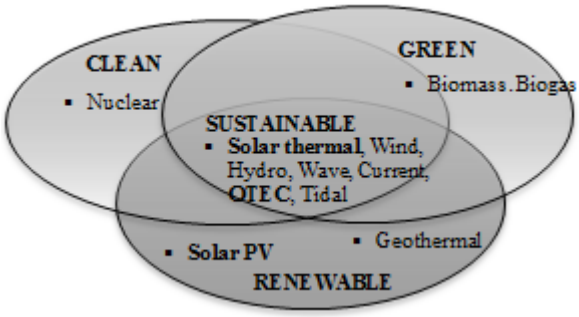

Figure 1.2: Forms of Energy and Classification [6]

Solar energy appears to be very promising among the renewable energy sources (Fig 1.2). It is in-exhaustive and under no monopoly but with more potentials in the tropical climate [4, 5] like Nigeria. Solar energy is applied in a number of ways (agricultural, commercial, domestic and industrial sectors) and it is tapped using either solar photovoltaic, solar thermal collector or solar PV/T [7-9]. It is estimated that about 1.8 x 10^{11}MW of solar energy falls on the earth surface daily which if properly utilized is more than the world energy consumption [10]. Meanwhile, Nigeria as a tropical country enjoys substantial amount of daily sunlight with an average of 4.851 x 10^{12}kWh of incident solar energy per day [1]. Utilizing this (virtually) free energy will help in the promotion of energy security with resultant effects on socio-economic development of the country. With a population of 170 million, only 30 – 40 % have access to electricity [11] and the demand for this electricity keeps increasing as a result of increase in population [12] and urban development. As a decentralized source, solar energy will solve many of the energy problems if the technology embraced and appropriate government legislation is made to create enabling environment for its utilization especially in the areas with no access to the national grid.

II. QUESTS FOR ALTERNATIVE ENERGY

Global awareness on the need for alternative (renewable) energy started in the year 1973 as a result of crisis between the Arab Nations and the Western Countries. Although the crisis was brought to an end in the early 1980s but the demand for energy continued on the increase[13]. The crisis triggered researchers' interests towards finding new solution that would both solve energy supply and environmental problems, thereby reducing (or eliminating) heavy dependence on fossil fuels and ensuring safe environment.

In response to this, the federal government of Nigeria established the Energy Commission of Nigeria (ECN) in 1979 with mandate to "*conduct research and development on renewable energy technologies and to popularize its applications all over the country*" [2]. Meanwhile more work still needs to be done on renewable energy in Nigeria. Globally, non-renewable source (coal, natural gas and oil) carry the larger percentage (80%) of energy consumption (Fig 2.1), while in Nigeria, the share of domestic energy carrier, according to [1] are Kerosene (13%), LPG (1%) and fuel-wood & others (82%), out of the total energy consumption (shown in Fig 2.2). It is estimated that consumption of fuel-wood in Nigeria is about 27.5 million Kg/day which is a major cause of deforestation and indoor pollution. While some countries already have percentage renewable energy in their power generation mix; Brazil (5% from all sources), china (1% from solar & 3% from others), and Egypt (10%), Nigeria's current renewable energy share in power generation is 0% but 7% is targeted by the year 2025.

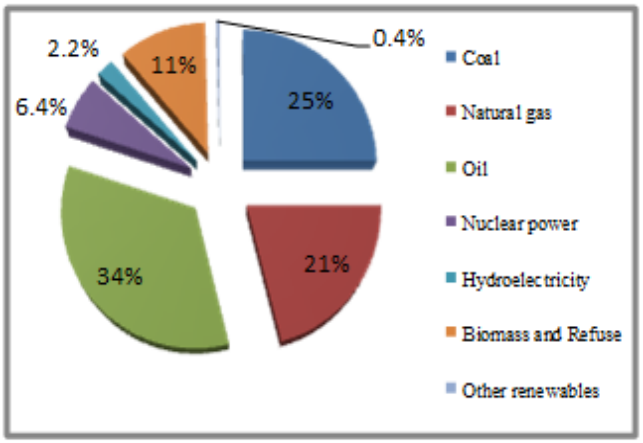

Fig 2.1: Global energy consumption (Energy Security)

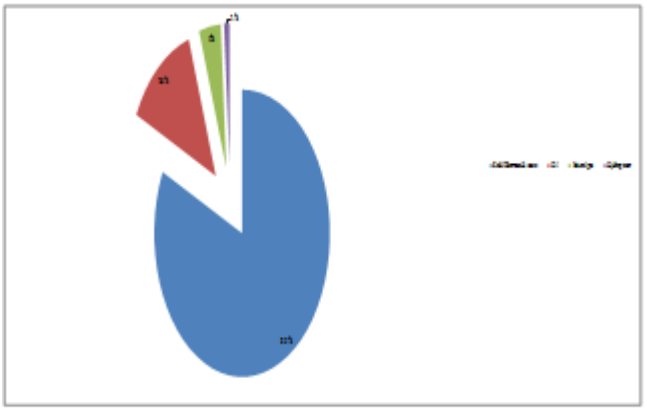

Figure 2.2: Nigeria Energy consumption (EIA)

III. SOLAR ENERGY AS AN ALTERNATIVE

About 1.8×10^{11}MW of daily solar radiation is released by the sun to the earth surface [10], Nigeria receives solar radiation of 3.5kW/m^2/day in the South and 7.0kWm^2/day in the North which shows her high potential for solar energy utilization. However the current usage of solar energy is insignificant, many communities do not have access to National grid; therefore a decentralized energy supply is most appropriate to cater for their energy needs. Solar energy offers this advantage as decentralized source which is tapped and used at the point of need. Available technologies include:

A. Solar Photovoltaic: This involves the conversion of the solar energy into electrical energy which can be utilized for various applications (Fig 4.1). A substantial amount of work has been done on solar photovoltaic. These include, solar perimeter light, solar street lighting, solar water pumping, solar rural electrification, solar cooker and variety of other solar energy projects in Nigeria majorly by the Energy Commission of Nigeria. The National Agency for Science and Engineering Infrastructure (NASENI) had recently established a fully operational solar PV manufacturing plant in Karishi, Abuja, with a current capacity of 7.5 Megawatt of power generation per year with plan to upgrade the plant capacity. Meanwhile the impact is still low considering the available potentials. The major challenge with the solar photovoltaic is the low efficiency in the range of 0.124 and 0.15 [8, 14]

B. Solar Thermal Collector: The solar thermal collector does not directly convert the heat energy to electrical energy but majorly supplies the heat which can be used for space heating, for sorption cooling systems or for combined heat, power and cooling system using Rankine cycle and sorption cooling cycle [15-19] in which electrical energy is generated along with cooling and heating. The efficiency of solar collector is higher than that of PV (between 0.58 and 1.4) depending on the type of the collector. Meanwhile this application is not very common in Nigeria

C. Solar Photovoltaic-Thermal (PV/T) Collector: This is the hybrid of the two systems where both the thermal and electrical gains can be used for different purposes. With this arrangement, the system can be operated on a stand-alone basis where the thermal (working) fluid from the collector side is used to power the sorption cooling system and the electricity needed to run the pumps and other ancillary loads is supplied by the PV part. The thermal fluid can also supply the hot water needs. This usually results in improved efficient of performance [20].

IV. SOLAR THERMAL APPLICATION POTENTIALS

Table and figure 4.1 show some of the potential areas of solar thermal technology

Table 4.1 Solar energy applications and potentials

System	Application	Collector type
Solar water heating	1. Thermo-syphon system	FPC
	2. Integrated collector system	CPC
	3. Direct circulation	FPC, CPC, ETC, PV/T
	4. Indirect water heating system	FPC, CPC, ETC, PV/T
	5. Air system	FPC, PV/T
Space heating and cooling	1. Space heating service and hot water	FPC, CPC, ETC, PV/T
	2. Air systems	FPC, PV/T
	3. Water systems	FPC, CPC, ETC, PV/T
	4. Heat pump systems	FPC, CPC, ETC, PV/T
	5. Absorption systems	FPC, CPC, ETC
	6. Adsorption (desiccant) cooling	FPC, CPC, ETC
	7. Mechanical systems	PDR
Solar refrigeration	1. Absorption units	FPC, CPC, ETC
	2. Adsorption units	FPC, CPC, ETC
Industrial process heat	1. Industrial air and water systems	FPC, CPC, ETC
	2. Steam generation systems	PTC, LFR
Solar desalination	1. Solar stills	FPC, CPC, ETC, PV/T
	2. Multistage flash (MSF)	FPC, CPC, ETC, PV/T
	3. Multi-effect boiling (MEB)	FPC, CPC, ETC, PV/T
	4. Vapour compression (VC)	FPC, CPC, ETC, PV, PV/T
Solar thermal power systems	1. Parabolic trough collector systems	PTC
	2. Parabolic tower systems	HFC
	3. Parabolic dish systems	PDR
	4. Solar furnaces	HFC, PDR
Combined power, heating, and cooling systems	1. Organic Rankine and absorption refrigeration cycle	FPC, CPC, ETC
	2. Solar assisted Ocean thermal energy conversion (SOTEC)	FPC, CPC, ETC
Solar lighting systems	1. Fence perimeter lighting	PV
	2. Street lighting	PV

A. Solar Water Heating: Partly as a result of high cost of electricity, solar water heaters takes major share (90%) of solar energy use in Botswana, mostly by residents [21]. Combined photovoltaic thermal (PV/T) solar water heater was presented by [20] to be installed in rural areas in India to meet their hot water and electrical needs. Hot water production actually consumes large amount of energy, thus it becomes a major problem when the energy is insufficient (as the case in Nigeria). With substantial solar energy availability in Nigeria, most of the hot water needs (especially for domestic and agriculture) can be supplied via solar heating thereby reducing heavy reliance on the national grid which may not be readily available. Solar water heating is achieved through solar collector or its combination with PV (PV/T) and the technology is readily available, only to be adapted to the local environment

B. Solar Space Heating / Drying and Cooling / Refrigeration: In addition to domestic power problems, agriculture is another energy-effected sector in Nigeria. More than 30% of fresh produce are lost to post harvest wastage due to lack of cold storage facilities and power supply, resulting to wide seasonal variation in the prices of farm produce and substantial loss of financial resources by the farmers. With solar dryers, fruits and vegetables can be preserved in dried form with better quality [22]. Cooling and refrigeration help to prolong the freshness of fruits and vegetables and this will help to possibly eliminate farm produce wastes. It should be noted that the conventional cooling system requires substantial amount of electricity (which may not be available) and uses environmental unfriendly working fluids. With solar sorption cooling systems, the fresh farm produces are securely preserved and the environmental safety is also ensured.

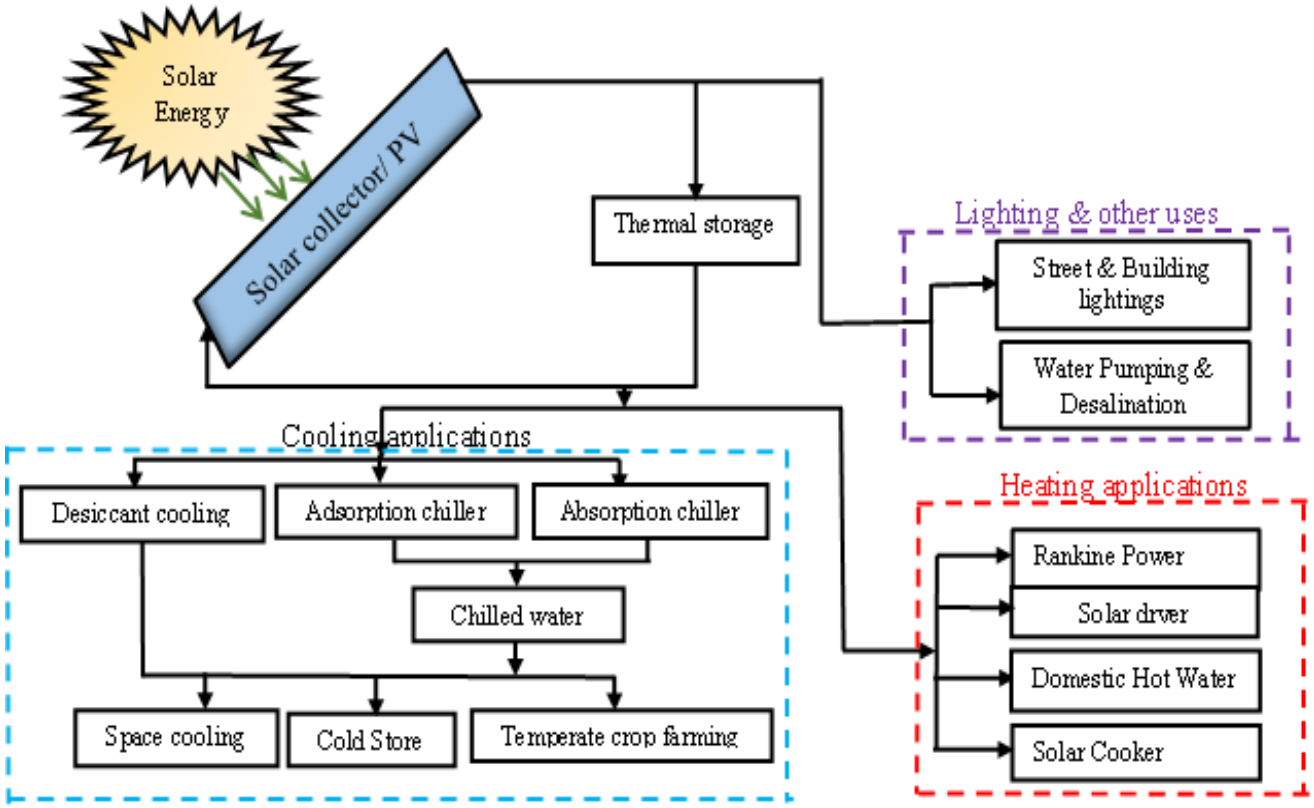

Figure 4.1: Schematic Representation of solar Energy Applications

C. Solar Desalination: The importance of water to life can never be overemphasized, interestingly water is one of the most abundant resources on earth but how portable is it for human consumption? It is estimated that about 97% of the earth water (sea) is salty [8], the remaining 3% (ground water, lakes, and river) are fresh. Meanwhile continuous increase in population has put pressure on the little available fresh water [23] making the desalination of salty water necessary to secure fresh water for consumption. Water desalination consumes huge amount of energy; about 25 million m^3/day requires 230 million of tons of oil per year [8]. While many areas are lacking portable water to sustain their daily activities, Nigeria is blessed with large volume of sea and fresh water which though may need to be desalinated (purified) for consumption. With solar desalination (direct or indirect), portable water can be produced independent of power from the grid, thereby improving the life of the populace especially the rural communities

D. Solar Thermal Power System: Traditional thermal power generation involves burning of oil, gas or coal, all of which are neither renewable nor sustainable [6]. Meanwhile the present power generation in Nigeria is about 80% natural gas fired supply [3] with no significance contribution from Solar thermal energy (Fig. 4.2). Solar thermal power generation has been extensively researched [8, 24-26] using either of the concentrating or non-concentrating solar collector. Solar (low-grade) thermal power generation is suitably achieved with organic Rankine cycle [27, 28]. The organic Rankine cycle can also be integrated with absorption refrigeration cycle [29, 30] in which cooling is achieved alongside with power generation. With relatively high solar energy availability, Nigeria can possibly replace gas-fired power generation with (virtually free operating cost) solar thermal-fired power generation, more so it is a decentralized energy source and more suitable for the rural communities.

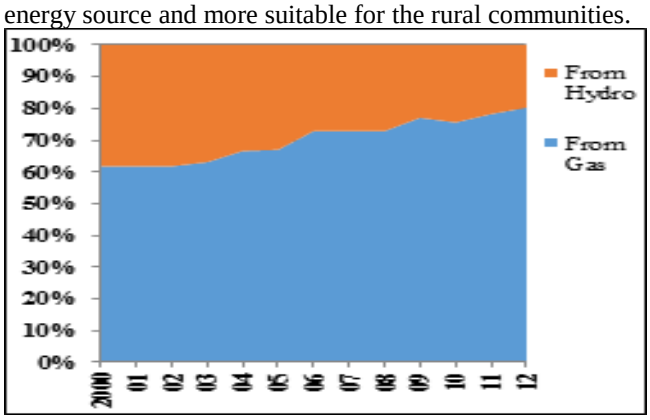

Fig 4.2: Electricity Production summary [IEA]

E. Solar lighting systems: Lighting is one of the most critical energy needs of the population (Fig. 4.3). Presently, there are a number of solar PV applications (fence perimeter lighting, street lighting, etc) in Nigerian mostly by ECN and NASENI. But there are more potentials than these limited uses considering the enormous solar energy availability in the country. Going by the projection of the Nigeria Federal Ministry of Science and Technology cited by [11], "*the total annual energy consumption of about 21 x 10^9 kWh could be made by converting only 0.1% of the total solar radiation incident on the country at a (solar PV) conversion efficiency of 1%*". With this decentralized energy generations, lighting can be secured for office and domestic uses as well as the rural schools, clinics, etc. It is also observed that one of the factors responsible for electricity crisis in Nigeria is **losses** (Fig. 4.4) which can be eliminated through decentralized energy supply offered by solar technologies.

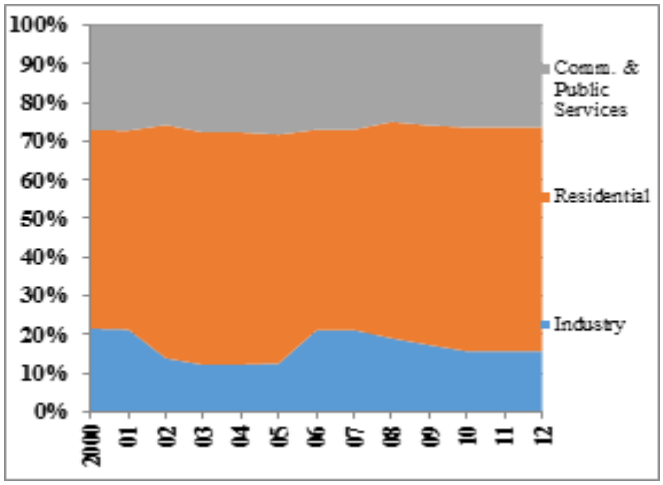

Figure 4.3: Electricity Consumption summary

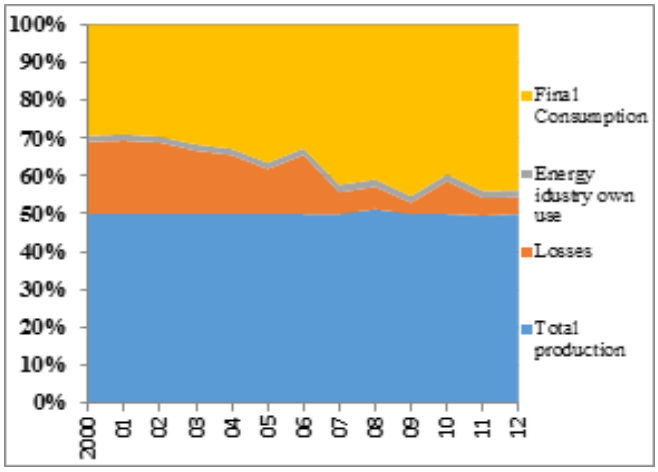

Figure 4.4: Electricity Production, consumption and losses

Some of the challenges and probable solutions of the solar energy utilization are itemized below.

Challenges	Possible solution
Variation in availability due to day and night and change in season	This is compensated for by the introduction of thermal storage in form of the hot and cold storage tanks and the battery-bank to take care of night and overcast periods
High initial cost of the solar energy equipment	i. This is usually offset with relatively free operating and maintenance costs. ii. Introduction of incentives such as Feed-In-Tariff etc. iii. Grid-tied arrangement can be employed in the case of solar PV to encourage individual participation in decentralized power generation and supply iv. Creation of enabling environment for **public-private-partnership** to promote small and medium scale solar (and other renewable energy) plants initiatives. v. Implementation of stable and affordable energy pricing policy systems
Technical knowhow on the technology of the solar energy application	i. This can be addressed through government programs such as technology incubation to import and adapt the technology to Nigeria local environment and continuous research activities ii. Encouragement of more renewable energy focused research as well as promotion of strong link between the research institutions and industries iii. Introduction of renewable energy in the early school curriculum; young minds are always effective **tools of change**. This will instill the renewable energy culture in the children at early age.

V. Conclusion

Energy is pivot to development, and sustainable energy supply is a key to sustainable development. Considering the geographical location of Nigeria, solar energy utilization potential is very high and this can improve access to energy at the point of need for either domestic use, industrial use or for agricultural purposes. The application will have direct impacts on the masses especially in the rural areas for the basic human needs. Huge loss presently being incurred in agricultural sector resulting from lack of storage facility and power can be reduced. Solar fired power generation is "operating and maintenance" costs free, and will help in reducing the losses incurred in the current energy distribution process. However, the basic impedance to solar energy utilization can be addressed through continuous research, appropriate government legislations and creation of awareness on the importance of its applications

References

[1] Akintola., T. and O. Alamu, *Application Potentials and Sustainability of Solar Energy in Nigeria.* The Pacific Journal of Science and Technology, 2010. **11**(2): p. 132-138.

[2] Ilenikhena, P.A. and L.I.N. Ezemonye, *Solar Energy Application in Nigeria*, in *WEC Montreal 2010*. 2010. p. 1-13.

[3] IEA. *International Energy Agency statistics report*. Available from: http://www.iea.org/statistics/statisticssearch/report/?&country=MYANMAR&year=2000&product=ElectricityandHeat.

[4] Chua, S.C. and T.H. Oh, *Solar energy outlook in Malaysia.* Renewable and Sustainable Energy Reviews, 2012. **16**(1): p. 564-574.

[5] Lychnos, G. and P.A. Davies, *Modelling and experimental verification of a solar-powered liquid desiccant cooling system for greenhouse food production in hot climates.* Energy, 2012. **40**(1): p. 116-130.

[6] Jaafar, A.B., *Ocean Thermal ENergy-driven Development in Malaysia*. 2014, Ocean Thermal Energy Conversion Center, Universiti Teknologi Malaysia. p. 1-114.

[7] Tian, Y. and C.Y. Zhao, *A review of solar collectors and thermal energy storage in solar thermal applications.* Applied Energy, 2013. **104**: p. 538-553.

[8] Kalogirou, S.A., *Solar thermal collectors and applications.* Progress in Energy and Combustion Science, 2004. **30**(3): p. 231-295.

[9] Fong, K.F., et al., *Comparative study of different solar cooling systems for buildings in subtropical city.* Solar Energy, 2010. **84**(2): p. 227-244.

[10] Bajpai, V.K., *Design of Solar Powered Vapour Absorption System*, in *Proceedings of the World Congress on Engineering*. 2012: London, U.K. p. 1-5.

[11] Muhammad, U., *Rural Solar Electrification in Nigeria: Renewable Energy Potentials and Distribution for Rural Development*, in *Energy and Environment*. 2012: Gusau, Nigeria. p. 1-8.

[12] Sodeik, M., *Solar Energy and its Role in the Third World.* Renewable Energy, 1993. **3**(4/5): p. 545-548.

[13] Parameshwaran, R., et al., *Sustainable thermal energy storage technologies for buildings: A review.* Renewable and Sustainable Energy Reviews, 2012. **16**(5): p. 2394-2433.

[14] Daghigh, R., M.H. Ruslan, and K. Sopian, *Advances in liquid based photovoltaic/thermal (PV/T) collectors.* Renewable and Sustainable Energy Reviews, 2011. **15**(8): p. 4156-4170.

[15] Smith, A.D., P.J. Mago, and N. Fumo, *Benefits of thermal energy storage option combined with CHP system for different commercial building types.* Sustainable Energy Technologies and Assessments, 2013. **1**: p. 3-12.

[16] Mago, P.J., A. Hueffed, and L.M. Chamra, *Analysis and optimization of the use of CHP–ORC systems for small commercial buildings.* Energy and Buildings, 2010. **42**(9): p. 1491-1498.

[17] Saitoh, T., N. Yamada, and S.-i. Wakashima, *Solar Rankine Cycle System Using Scroll Expander.* Journal of Environment and Engineering, 2007. **2**(4): p. 708-719.

[18] Datla., B.V. and J. Brasz, *Organic Rankine Cycle System Analysis for Low GWP Working Fluids*, in *International Refrigeration and Air Conditioning Conference*. 2012: Purdue University Purdue e-Pubs. p. 1-8.

[19] Ziviani, D., A. Beyene, and M. Venturini, *Design, Analysis and Optimization of a Micro-CHP System Based on Organic Rankine Cycle for Ultralow Grade Thermal Energy Recovery.* Journal of Energy Resources Technology (ASME), 2013. **136**(1): p. 011602.

[20] Dubey, S. and G.N. Tiwari, *Thermal modeling of a combined system of photovoltaic thermal (PV/T) solar water heater.* Solar Energy, 2008. **82**(7): p. 602-612.

[21] Jain., P.K., N. Nijegorodov., and K.C. G, *Role of solar energy in development of Botswana.* Renewable Energy, 1994. **4**(2): p. 174-184.

[22] Belessiotis, V. and E. Delyannis, *Solar drying.* Solar Energy, 2011. **85**(8): p. 1665-1691.

[23] Orhan, M.F., et al., *Coupling of copper – chloride hybrid thermochemical water splitting cycle with a desalination plant for hydrogen production from nuclear energy.* International Journal Hydrogen Energy, 2010. **35**(4): p. 1560-1574.

[24] Feng, X., D.Y. Goswami, and S.B. Sunil, *A combined power/cooling cycle.* Energy, 2000. **25**: p. 233-246.

[25] Flueckiger, S.M., Z. Yang, and S.V. Garimella, *Review of Molten-Salt Thermocline Tank Modeling for Solar Thermal Energy Storage.* Heat Transfer Engineering, 2013. **34**(10): p. 787-800.

[26] Schröder, E., et al., *Study on Heat Transfer in Heat Exchangers for a New Supercritical Organic Rankine Cycle.* Heat Transfer Engineering, 2014. **35**(18): p. 1505-1519.

[27] Quoilin, S., et al., *Techno-economic survey of Organic Rankine Cycle (ORC) systems.* Renewable and Sustainable Energy Reviews, 2013. **22**: p. 168-186.

[28] Canada, S., et al. *Parabolic Trough Organic Rankine Cycle Solar Power Plant*. in *National Renewable Energy (NREL/CP-550-37077)*. 2005. DOE Solar Energy Technologies Denver, Colorado.

[29] Sotomonte, C.A.R., et al., *Organic Rankine Cycle Associated with an Absorption Chiller for Biomass Applications.* Thermal Engineering, 2011. **10**(01): p. 15-22.

[30] Sanjay, V., *Thermodynamic Studies on Alternative Binary Working Fluid Combinations and Configurations for a Combined Power and Cooling Cycle*, in *Graduate School*. 2003, UNiversity of Florida: ProQuest Information and Learning Company. p. 1-226.