ASSESSMENT OF ROOFTOP SOLAR PHOTOVOLTAIC POTENTIAL AND ITS CONTRIBUTION FOR GREENHOUSE GAS EMISSION REDUCTION ON MAJOR CONDOMINIUM SITES OF ADDIS ABABA, ETHIOPIA

MSc. THESIS

SAMUEL BEKELE LIBEN

HAWSSA UNIVERSITY WONDOGENET COLLEGE OF FORESTRY AND NATURAL RESOURCES

WONDOGENET, ETHIOPIA

JUNE, 2018

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SAMUEL BEKELE LIBEN

MASTERS THESIS SUBMITTED TO THE

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN RENEWABLE ENERGY UTILIZATION AND MANAGEMENT

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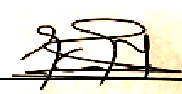
Advisors' Approval Sheet

This is to certify that the thesis entitled "Assessment of Rooftop Solar Photovoltaic Potential and Its Contribution for Greenhouse Gas Emission Reduction on Major Condominium Sites of Addis Ababa" submitted in partial fulfillment of the requirements for the degree of Master's with specialization in Renewable Energy Utilization and Management the Department of Renewable Energy Utilization and Management, and has been carried out by SAMUEL BEKELE Id. No. M.Sc./REUM/R0011/09, under my supervision.

Therefore, I recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

Kassahun Yimer (PhD)		14/06/2018 .
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______________________	______________________	______________________
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School of Graduate Study

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We, the undersigned, members of the board of examiners of the final open defense by have read and evaluated his/her thesis entitled "Assessment of Rooftop Solar Photovoltaic Potential and Its Contribution for Greenhouse Gas Emission Reduction on Major Condominium Sites of Addis Ababa" and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree Renewable Energy Utilization and Management.

______________________	______________________	______________________
Name of the Chairperson	Signature	Date
Kassahun Yimer (PhD)	______________________	14/06/2018 .
Name of Major Advisor	Signature	Date
______________________	______________________	______________________
Name of Internal Examiner	Signature	Date
Abdulkadir Aman (PhD)	______________________	14/06/18
Name of External examiner	Signature	Date
______________________.	______________________	______________________
SGS Approval	Signature	Date

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Abbreviations and Acronyms

a-Si	Amorphous Silicon
BIPV	Building Integrated Photovoltaic
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
CRGE	Climate Resilient Green Economy of Ethiopia
CSA	Central Statistics Agency
c-Si	Crystalline silicon
CSP	Concentrating Solar Power
E	East
EAC	East Africa Community
EEP	Ethiopian Electric Power
EPA	Environmental Protection Authority
ESMAP	Energy Sector Management Assistance Program
FDRE	Federal Democratic Republic of Ethiopia
GHG	Greenhouse Gas
GIS	Geographic Information System
GTP II	Second Growth and Transformation Plan of Ethiopia
IEA	International Energy Authority
IPCC	International Panel on Climate Change
kWh	Kilowatt Hour
kWh/m2/day	Kilowatt Hour per square meter per day
MW	Mega Watts

MW•h/ (m2•a)	Megawatt Hour per square meter per
N	North
NE	North-East
NW	North-West
PV	Photovoltaic
RE	Renewable Energy
S	South
SE	South-East
SW	South-West
SRREN	Special Report on Renewable Energy Sources and Climate Change Mitigation
SWERA	Solar and Wind Energy Resource Assessment
TJ	Terra-joule
TPES	Total Primary Energy Supply
TWh	Terra Watt Hour
W	West
W/m2	Watt per meter square
ºC	Degree Centigrade

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Abstract

Assessment of Rooftop Solar Photovoltaic Potential and Its Contribution for Greenhouse Gas Emission Reduction on Major Condominium Sites of Addis Ababa

Samuel Bekele (email: samuelbekele7@gmail.com)

Ethiopia has vast amount of renewable energy resources including solar energy which remains virtually undeveloped and for the projected growth of the country utilizing the available energy especially renewables is vital for its economic and environmental benefits. The aim of the study was to determine suitable rooftop area for photovoltaic installation, assesses the electricity generation potential and determining the greenhouse gas emission reduction potential of rooftop solar photovoltaic system on major condominium sites in Addis Ababa. Manual selection method using areal images, site plans, building designs and on site scrutiny were employed to assess the suitability of rooftop area of buildings blocks in the selected condominium sites, System Advisor Model was used to estimate the solar photovoltaics energy potential and Tire 1 approach of guidelines for National Greenhouse Gas Inventories was applied to estimate greenhouse emission reduction potential. The total rooftop area of all blocks in the condominium sites was 728,355-meter square, where 24 percent enables to install solar photovoltaic systems with minimum or no modification except for fitting the modules on the roof. The total estimated annual energy production of solar photovoltaic system on the determined suitable area was 65,348,081.00 Kilo Watt hours, where highest annual energy production potential of 21,968,180 Kilo Watt hours was found at Yeka-Abado followed by 13,863,342 at Tulu-Dimtu, 12,852,895 at Gelan, 8,386,071 at Jemo-1 with and 8,277,593 at Ayat-2. The cumulative estimated greenhouse emission reduction potential was 16,303.89 tons of carbon dioxide equivalent, where Ayat-2, Yeka-Abado, Jemo-1, Tulu-Dimtu and Gelan condominium sites have emission reduction potential of 2,065, 5,480.91, 2,092.27, 3,458.81 and 3,206.71 tons of carbon dioxide equivalent respectively. This indicates there is high electricity generation and notable greenhouse gas emission reduction potential from rooftop photovoltaic system even considering the suitable rooftop portions of condominiums that could strengthen the electric energy suppling capacity, increase the energy mix and contribute in reducing GHG emissions.

***Keywords**: Solar, Photovoltaics, Rooftop, Greenhouse gas, Renewable Energy*

1. Introduction

1.1. Background

Sustainable social and economic development requires assured and affordable access to the energy resources necessary to provide essential and sustainable energy services (IPCC, 2012).

Despite the growing requirement, energy consumption especially burning of fossil fuels is contributing to the climate change currently being observed (IPCC, 2011) where greenhouse-gas (GHG) emissions from the energy sector represent roughly two-thirds of all anthropogenic GHG emissions (IEA, 2015).

In order to curb the waste of fossil fuel energy, it is imperative to be aware of the dire consequences of our nation’s energy policies and make every effort to promote the use of all available renewable energy technologies (RET) so that we can reduce the demand for nonrenewable energy and safeguard the environment for future generations (Peter Gevorkian, 2008). Among the renewable energy (RE) resources solar energy resource is virtually inexhaustible, and it is available that is able to be used in all countries and regions of the world (IPCC, 2012).

Energy being a force for economic growth both in short and long run in Ethiopia and its consumption inter connected with carbon emissions it is suggested that the country should aim at increasing energy consumption with minimum pollution impacts and attain energy security (Ramakrishna, 2016) through maintaining the appropriate mix of generation from various sources of energy (MoWIE, 2012) which increasing access to electricity supply would ultimately eradicate the use of woody biomass (UN-Habitat, 2017).

Ethiopia is gifted with a vast amount of RE sources including solar energy (MoWIE, 2012) which remains virtually undeveloped and with most of electric generation capacity is from hydropower (MoWIE, 2012).

Although at present, there haven't been any large-scale solar photovoltaic (PV) projects (Hydro-China, 2012), from the development perspective of the energy sector of Ethiopia's second growth and transformation period (2016-2020) solar energy is one of the four energy resources that is given highest priority in developing 300 MW grid-connected solar energy (GTP II, 2016).

The utilization of already used spaces for solar PV like building roofs and side walls has gained high attention for it produces energy which could be used to address the energy requirement of the building itself and Developed countries are making efforts to make use of the available solar potential on building integrated PV systems (Aitken D.W., 2003).

In many of the studies to estimate solar energy potential generation from PV systems through estimating rooftop area have been developed that ranged from simple multipliers of total building space to methods that employ complex geographic information systems (GIS) or three-dimensional (3-D) models among which Constant-value, manual selection, and GIS-based methods are the three main methods that are commonly used (Meluis et al., 2013 as sited in Taha and Effat, 2015).

This research aimed to estimate the potential of solar PV electricity generation and its contribution for GHG emission reduction by determineing the rooftop area suitability of major condominium sites for Grid-connected PV installation considering a set of parameters,.

1.2. Statement of the problem

Although Ethiopia has a high potential of solar energy utility-scale solar energy is yet to be developed in the near future (MoWIE, 2012) which comes with a sizeable land requirement, depending on factors such as the technology adopted, the topography of the available site and solar intensity (World Energy Council, 2016). In prospect of this challenge, utilization of already used spaces for solar PV like building roofs and side walls has gained high attention (Aitken D.W., 2003).

Buildings or infrastructures are designed and constructed inconsideration of solar PV system design parameters such as azimuth and tilt angles and making rooftop area on already built buildings to suite the solar PV system will have an added cost. Therefore, for accurate estimation of the rooftop solar PV potential, cost-effective and socially just implementation of rooftop solar PV system, determining and utilizing, the suitable rooftop area considering all aspects (i.e. orientation, roof slope, shading, the spacing between buildings and structures on roofs) is vital.

1.3. Objective

1.3.1. General Objective

To estimate the potential of solar PV system and its contribution for GHG emission reduction on suitable rooftop area of major condominium sites in Addis Ababa by assessing the suitability of the rooftops for PV installation.

1.3.2. Specific Objectives

- To determine the total and Suitable rooftop area of major condominium sites

- ❖ To estimate the electric energy generation capacity on the determined suitable rooftop area and
- ❖ To estimate GHG reduction potential of the rooftop PV system

1.4. Research Questions

Based on the stated objectives, the following questions will be used to guide the research process and finally will be answered from the findings of the study.

1. How much is the total area and suitable rooftop of the Rooftop of major condominium sites in Addis Ababa?
2. What is the solar PV electricity generation potential of the suitable rooftop area?
3. How much GHG emission will be avoided by the rooftop solar PV system electric generation capacity?

1.5. Significance of the study

This study is presents rooftop suitability for solar PV system and energy potential on existing buildings of major condominium sites in Addis Ababa. The study sights the application of easy and accessible tools to assess the suitability of the rooftops of infrastructure for solar PV system besides indicating the solar PV electric generation potential and GHG emission reduction. The study also indicated required attention in infrustructure planning and development related to solar PV systems to address the increasing energy demand and strengthening the vision of energy self-sufficiency and green growth.

1.6. Scope of the study

The study is limited to Addis Ababa city major condominium sites; the data were collected mainly from Google Earth Pro online GIS tool, building designs, site plans, meteorological records and sight observations & measurement. The study was set to determine the suitable rooftop area of condominium buildings for solar PV installation without major modification, estimate its potential for electricity generation and GHG emission reduction potential.

1.7. Outline of the Report

A brief introduction on the contents of the thesis report is outlined as follows. Background to the study, statement of the problem, objectives, research question, significance of the study and scope of the study is covered in chapter one, Literature review of energy and climate change, solar energy, solar PV conversion system and solar energy scenarios of Ethiopia is briefed in chapter two. Chapter three focuses on the materials and methods employed in the study. Chapter four comprises the various results and their discussions. Chapter five outlines the conclusions and recommendations for future work respectively.

2. Literature Review

2.1. Energy and Climate Change

Energy is required by all societies to meet their basic needs such as lighting, cooking, space conditioning, mobility, communication and other production processes. Sustainable social and economic development requires assured and affordable access to the energy resources necessary to provide essential and sustainable energy services (IPCC, 2012).

Despite to the growing requirement of energy for socio-economic development, studies indicated that the energy consumption especially burning of fossil fuels (coal, oil, and natural gas) is contributing to the climate change currently being observed (Edenhofer O., et.al. IPCC, 2011).

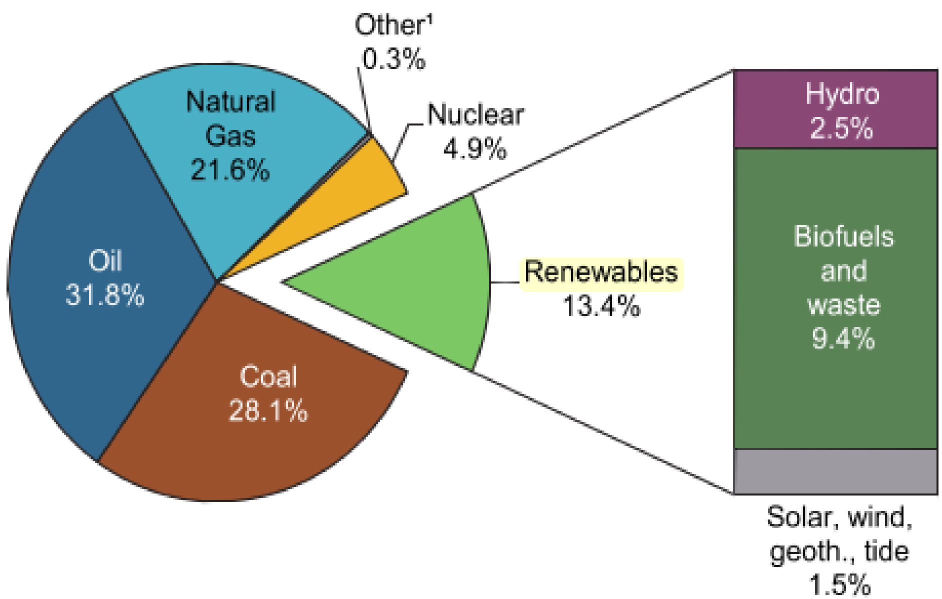

Figure 2-1: 2015 fuel shares in world total primary energy supply (source IEA, 2017)

Greenhouse gas (GHG) emissions resulting from the provision of energy services have contributed significantly to the historic increase in atmospheric GHG concentrations (Edenhofer O., et.al. IPCC, 2011).

CO_2 emissions from fossil fuel combustion and industrial processes contributed about 78% to the total GHG emission increase between 1970 and 2010, with a contribution of similar percentage over the 2000–2010 period (IPCC, 2014). Greenhouse-gas emissions from the energy sector represent roughly two-thirds of all anthropogenic GHG emissions that have risen over the past century to ever higher levels (IEA, 2015).

In order to curb the waste of fossil fuel energy, it is imperative that our nation, as a whole, from politicians and educators to the general public, be made aware of the dire consequences of our nation's energy policies and make every effort to promote the use of all available RE technologies so that we can reduce the demand for nonrenewable energy and safeguard the environment for future generations (Peter Gevorkian, 2008).

Among the identified number of ways to lower heat-trapping emissions from energy sources while still providing energy include a shift from high GHG energy carriers such as coal and oil to lower GHG energy carriers such as natural gas, nuclear fuels and RE sources (Sims et al., 2007).

RE supply sources are effective in lowering CO_2 emissions because they have low carbon intensity with emissions per unit of energy output typically 1 to 10% that of fossil fuels (IPCC, 2012). Promoting proper energy mix involving clean renewables and improving energy efficiency in a holistic framework should be attempted and also environment, trade and urbanization policies should be tailored to attain self-sufficiency in energy along with minimum CO_2 emissions (Ramakrishna, 2016).

Furthermore, the global economic and political conditions that tend to make countries more dependent on their own energy resources have caused growing interest in the development and use of RE based technologies (Jamil M. et al., 2012).

Among various RE sources based technologies, the PV technology for power generation is considered well-suited technology particularly for distributed power generation (Jamil M. et al., 2012).

Technological maturity and lower costs make wind and solar power increasingly attractive options for policymakers seeking to meet energy policy objectives because Wind and solar PV are currently the fastest-growing sources of electricity globally (IEA, 2016). For example, in 2015 their additional annual generation met almost all incremental demand for electricity and between 2008 and 2015, the average cost of land-based wind decreased by 35% and that of solar PV by almost 80% (IEA, 2016).

Declining renewable technology costs, growing power demand from urban populations and industries, expanding local technical capacity, strong foreign investment interest, the impetus for low-carbon climate change mitigation, as well as a recognition by national governments the role of non-hydro RE sources, point to continued renewables growth (REN21-EAC, 2016).

2.2. Solar Energy

The solar resource is virtually inexhaustible, and it is available and able to be used in all countries and regions of the world (IPCC, 2012). The Sun supplies the overwhelming majority of the energy resources harnessed on the Earth, including wind, wave and tidal power, hydropower, biomass, all fossil fuels (which derive from biomass laid down in the past) and direct solar energy conversion into heat, electricity or fuel (Nelson et al., 2014).

The Sun's radiation provides on average 1.73 x 10^{17}J of energy to the Earth every second that varies between 100 and 250 W/m^2 due to variations in latitude and climate (Kopp, G. and Lean, J.L, .2011). In total, the sun offers a considerable amount of power: about 885 million terawatt hours (TWh) reach the earth's surface in a year, that is 6,200 times the commercial primary energy consumed by humankind in 2008 – and 4,200 times the energy that mankind would consume in 2035 (IEA, 2011).

Solar energy is exploited in a passive sense in natural lighting, heating and cooling, and in agriculture and solar radiation reaching the earth's surface could be captured and converted into heat, fuel or electric power (Nelson et al., 2014). In recent years' energy capture and conversion from solar have improved significantly due to the advancement of solar energy resource capturing/ conversion technologies.

Solar energy can be captured and converted into heat, fuel or electric power. We may distinguish three different varieties of solar energy conversion: solar thermal (light energy is converted to heat), solar PV (light energy converted to electrical work), and solar chemical (light energy converted to stored chemical potential energy) (Nelson et al., 2014).

One of the key solar energy technologies is solar PV, where a semiconductor material is used to convert sunlight into electricity directly (Nelson et al., 2014). This PV energy conversion is the only process to convert radiant light energy directly into electricity; In PV light is absorbed in a semiconductor to liberate electrical charges which then travel through the material towards a contact with an external circuit, where they are able to do electrical work through the photovoltaic effect (Nelson et al., 2014).

Solar thermal technologies extract heat energy transferred by solar radiation. Solar thermal collectors make use of a working fluid for energy transfer, such as water, oil, salts, air, and carbon dioxide and the heat could be used for heating and cooling applications, or to drive a heat engine that in turn run a generator and produce electricity (World Energy Council, 2016). Concentrated solar power (CSP) system is used to generate electric power where sunlight is focused to heat a fluid that generates power via a heat engine (Nelson et al., 2014).

In solar photochemical energy conversion, the excited electron takes part in a chemical reaction and gives up its energy to form a new chemical bond; Solar chemical conversion is much less well developed than solar thermal or PV (Nelson et al., 2014).

2.3. Solar Photovoltaic System

A young French physicist named Edmund Bacquerel discovered the photoelectric effect in 1839 and the scientific community come to note the applicability of the photoelectric effect when Albert Einstein published a paper on the photoelectric effect in 1904 (Prasad and Bansal, 2011) which won him the Nobel Prize in physics and laid the groundwork for the theory of the photoelectric effect (Peter Gevorkian, 2008). John Twidell and Tony Weir indicated that although the photovelectric effect was discovered by Becquerel in 1839 but not developed as a power source until 1954 by Chapin, Fuller, and Pearson using doped semiconductor silicon.

Most solar cells are constructed from semiconductor material, such as silicon that has the combined properties of a conductor and an insulator and the most fascinating aspects of solar cells is their ability to convert the most abundant and free form of energy into electricity, without moving parts or components and without producing any adverse forms of pollution that affect the ecology, as is associated with most known forms of nonrenewable energy production methods, such as fossil fuel, hydroelectric, or nuclear energy plants (Peter Gevorkian, 2008)

Before 2000, most PV were in stand-alone systems, progressing from space satellites to lighting, water pumping, refrigeration, telecommunications, solar homes, proprietary goods and mobile or remotely isolated equipment (e.g. small boats, warning lights, parking meters) and Grid-connected PV power, e.g. incorporated with buildings, has become a major activity for the 21st century (Twidell J. and Weir T., 2006).

The solar PV market is currently dominated by crystalline silicon (c-Si) technology, of which two types are used; The first is mono-crystalline, produced by slicing wafers (up to 150 mm diameter and 200 microns thick) from a high-purity single crystal boule and the second is polycrystalline, made by sawing a cast block of silicon first into bars, and then into wafers. Aside from crystalline silicon cells, other PV cell technologies including amorphous silicon (a-Si), thin-film and organic cells are commercially available (World Energy Council, 2016).

Figure 2-2. Different Types of Solar Cell (source: World Energy Council, 2016)

PV technology offers some unique benefits that are not realized by other RE technologies which is a silent energy source requiring no moving parts, it has a long system lifetime with low maintenance costs and has experienced substantial reduction in upfront cost over the past two decades and can also increase the resilience of the energy infrastructure (Bhandari et al., 2015). Solar PV is becoming increasingly cost-competitive with traditional power sources, with large-scale solar PV outcompeting even new fossil fuel projects in some markets, especially in regions with low-cost financing (REN21, 2017).

2.4. Rooftop Solar Photovoltaic Systems and Potential Estimation

Rooftop solar PV systems can be permitted and installed faster than most ground-mounted systems as interconnection and site eligibility norms for rooftop systems are easier to execute and not only do these systems provide a clean, quiet, and visually unobtrusive source of power, they also improve the reliability of power supply without the need to establish long-distance transmission lines associated with large-scale solar generation plants (International Finance Corporation, 2014).

The utilization of already used spaces for solar PV like building roofs and side walls has gained high attention for it produces energy which could be used to address the energy requirement of the building itself and Developed countries are making efforts to make use of the available solar potential on building integrated PV systems (Aitken D.W., 2003).

Building-integrated PV systems (BIPV) with modest amounts of storage can provide for continuity of essential governmental and emergency operations, and help to maintain the safety and integrity of the urban infrastructure: streetlights and communication links will continue to operate, and essential city and safety services will continue to be available from civic and administration buildings with their own energy systems; This should be a basic element of security planning for all cities and urban centers in the world (Aitken D.W., 2003).

In many of the studies to estimate solar energy potential generation from PV systems through estimating rooftop area have been developed that ranged from simple multipliers of total building space to methods that employ complex geographic information systems (GIS) or three-dimensional (3-D) models. Constant-value, manual selection, and GIS-based methods are the three main methods that are commonly used (Meluis et al., 2013 as sited in Taha and Effat, 2015).

In GIS-based methods, the majority of rooftop analyses use GIS-based methods for estimating the suitable space for rooftop PV (Taha and Effat, 2015). With regards to the state of GIS based potential estimation for solar conversion technologies the methodologies vary widely based on data availability, data quality, size and context of the study area, and practical limitations such as: time, storage capacity and hardware (Wolfs, 2017).

Manually selecting methods derive rooftops from sources such as aerial photography (Taha and Effat, 2015). Zhang et al. (2009) use Google Earth to identify suitable rooftops by considering only roofs with south-, southeast-, and southwest-facing planes to select suitable rooftops. In solar energy potential estimation process, information on relevant variables such roof area, slope, orientation, height and neighboring objects are crucial to provide a proper estimation of the solar energy potential of rooftops and if such variables can be considered in a sampling approach it will improve both the representativeness of sampled areas and the accuracy of the potential (Wolfs, 2017).

2.5. Solar Energy and Rooftop Photovoltaic system in Ethiopia

Ethiopia is gifted with a vast amount of RE sources that includes hydropower solar wind, geothermal and biomass energy sources. The vast potential of other forms of RE (solar, wind, geothermal, hydropower, etc.) remains virtually undeveloped and with most of electric generation capacity being in hydropower, Ethiopia may face challenging times during droughts due to majority of power plants in Ethiopia depend on water from different rivers and tributaries (MoWIE, 2012).

The energy sector is sharply split between the traditional and the modem where the electricity coverage has reached 60% as of 2014/2015 and it is planned to expand it to 90% by 2020/2019 (FDRE National Planning Commission, 2016). The study by CSA at the country level, suggests that about 81.4 % of the households use firewood, around 11.5 % cook with leaves and dung cakes and only 2.4 % use kerosene for cooking (as cited in MoWIE, 2012). In Addis Ababa traditional stoves and woody biomass represent the major source of energy for cooking, heating and lighting among low income households that is associated with multiple negative implications for the environment including deforestation, CO_2 emissions and indoor pollution (UN-Habitat, 2017).

The prevailing pattern of energy supply and consumption shows many elements of unsustainability that arises not from excessive reliance on non-renewable energy sources, but rather the main source of energy being fuel wood for the population is being consumed at an unsustainable rate (MoWIE, 2012).

Energy being a force for economic growth both in short and long run in Ethiopia and its consumption inter connected with carbon emissions it is suggested that the country should aim at increasing energy consumption with minimum pollution impacts and attain energy security (Ramakrishna, 2016) through maintaining the appropriate mix of generation from various sources of energy (MoWIE, 2012) which increasing access to electricity supply would ultimately eradicate the use of woody biomass (UN-Habitat, 2017).

Major policies and strategies in Ethiopia related to energy such as the energy policy and CRGE strategy emphasize on environmental sound development, generation and utilization of energy resources of the country. The energy policy emphasizes on the need for equitable development of the energy sector in parallel with other social and economic developments and highlights attainment of self-sufficiency through the development of indigenous resources with minimum environmental impact and equitable distribution of electricity. The policy envisages the development of hydro, geothermal, natural gas, coal, wind and solar energy resources based on their techno-economic viability, social and environmental acceptability.

The climate resilient strategy of Ethiopia initiated to protect the country from the adverse effects of climate change and to build a green economy that will help realize its ambition of reaching middle- income status before 2025 while limiting 2030 GHG emissions to around today's 150 Mt CO_2e – around 250 Mt CO_2e less than estimated under a conventional development path. Under current practices, GHG emissions would be more than double from 150 Mt CO_2e in 2010 to 400 Mt CO_2e in 2030. Expanding electricity generation from renewable sources of energy for domestic and regional markets is one of the main pillar among the four pillars of the strategy.

According to the GTP II plan in 2014/2015, the total electricity generating capacity reached 4,180MW where hydropower takes the larger share and from the future development perspective of the energy sector of Ethiopia's second growth and transformation period (2016-2020) solar energy is one of the four energy resource that is given priority to develop 300 MW grid-connected solar energy.

Wind and solar resource assessment of Ethiopia in 2012 by Hydro-china Corporation indicated average annual solar radiation energy density of the unit area and annual total solar energy reserve are 1.992 $MW \cdot h/(m^2 \cdot a)$ and 2,199 $PW \cdot h$ in the whole country, respectively. These indicate Ethiopia owns very rich solar energy resources. Figure 1.3. shows distribution of average annual total Solar Radiation in Ethiopia.

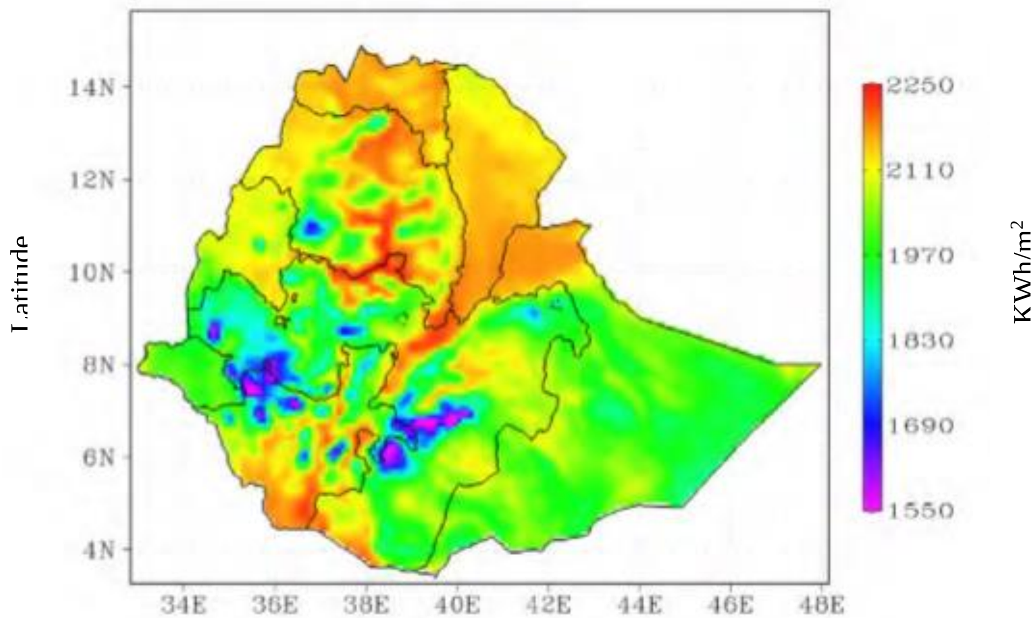

Figure 2-3 Distribution of Average Annual Total Solar Radiation KWh/m^2 (2000 - 2009) (source: Ethiopian Solar & wind MP report; Hydrochina, 2012)

According to the SWERA solar resource data, the annual average daily radiation on a horizontal surface in Ethiopia is 3.74 kWh/m^2 and according to CESEN, the annual average daily radiation in Ethiopia reaching the ground is 5.2 kWh/m^2/day (Ethiopian Rural Energy Development and Promotion Center, 2007). The minimum annual average radiation for the country as a whole is estimated to be 4.5kWh/m^2/day in July to a maximum of 5.55kWh/m^2/day in February and March. Based on the data gathered from the National Meteorological agency, the last 10 years average daily sunshine hours in Addis Ababa is estimated at about 6.6 h (Kebede, 2015).

Based on the SWERA data the estimated potential of the solar resource for power generation and thermal applications is also analyzed for various end users and found that for grid-based systems, the technical potential for Building Integrated Solar PV (BIPV) from the connected residential buildings in the country is estimated to be 1.1TWh/year (Ethiopian Rural Energy Development and Promotion Center, 2007).

From Identified 195 sites with an estimated area of 6000 Km^2 as ideal locations for large scale solar PV farms in Ethiopia more than 500 TWh electricity could be generate per annum (Tekle, 2014) and Kebede (2015) also indicatied grid connected 5 MW solar system in the northern part of Addis Ababa could generate 7658 MWh of electricity annually and the investment is economically viable as long as there is incentives and conducive environment.

Ethiopian Rural Energy Development and Promotion Center, 2007 considering only 50% of total built-up area in Addis Ababa and SWERA annual average daily radiation of 3.0 $kWh/m^2/day$, the BIPV solar energy technical potential of different types of buildings is about 2.8 TWh per year. The details are shown in Table 2-1. Higher technical potential of about 5 TWh per year was obtained with CESEN resource estimation of annual average daily radiation of $5.2kWh/m^2/day$ (Ethiopian Rural Energy Development and Promotion Center, 2007).

Table 2-1. Built up area per land service and potential for yearly power(source: Report by Ethiopian Rural energy center and Ethio Resource Group with Partners in 2007)

Land Service/Purpose of Building	Total No. of houses	Total Built up Area (m^2)	Technical Potential (GWh/yr)
Residence	321114	35843701.96	2390
Government Offices	395	516458.45	34
Institutions	30815	4206850.21	281
Diplomat & Int. Organizations	89	37747.08	3
Defense	39	568549.87	38
Others	8299	1393481.08	93
Total	360751	42566788.65	2839

a - includes facilities used for residential purpose and commercial activities together b b - includes businesses and industries

c - includes facilities used for purposes of recreation, religious activities, sport, etc

The Integrated Housing Development Program (IHDP) launched in Addis Ababa with the aim alleviating the problem of housing, to clear all slums and contribute to job creation (UN-Habitat, 2017), in the first GTP period over 174,190 housing units were constructed under different housing programs and different sites (FDRE National Planning Commission, 2016).

The huge scale of the condominium housing project is an opportunity for environmental sustainability to be introduced such as utilizing solar energy on roofs of the condominium projects to its significance in cost reduction and also for its environmental contribution through reduction of GHG emissions from nonrenewable energy (Netsanet, 2014).

3. Materials and Methods

3.1. Description of the Study Area

3.1.1. Location

Addis Ababa is the capital city of Federal Democratic Republic of Ethiopia located at the very center of the country between 8º56’ and 9 º 05’ North latitude and between 38º43’ and 38º50’ East Longitude.

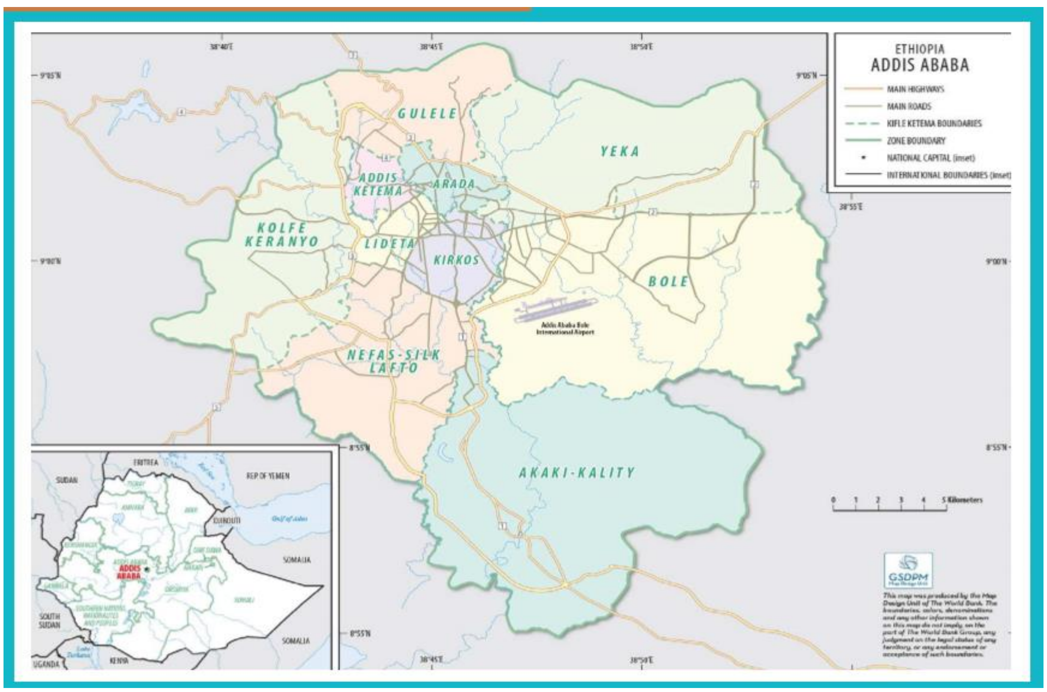

Figure 3-1 Map of Addis Ababa (Source: World Bank, 2015)

3.1.2. Topography and landscape

The altitude of Addis Ababa city ranges from 2,200 and 2,500 meters above sea level in the south up to 3000 m above sea level in the north around Entoto mountain ranges. The landscape in the north has a steep slope with rugged terrain, followed by rolling and flat topographic characteristics as one descends towards central and southern part of the city respectively.

3.1.3. Climate

Addis Ababa falls in the weina-Dega ecological zone with moderate climatic conditions. It has bi-modal rains; The mean annual rainfall varies between 1067 mm and 1257 mm within the administrative areas.

Addis Ababa average maximum temperature varies between 20 ºC and 25 ºC, while the minimum average temperature is between 7 ºC and 12 ºC.

The wind wind blows at an average speed of 5.658 m/s and Annual average daily solar radiation in Addis Ababa on inclined surface at the latitude angle is 5.07 kWh/m^2/d (Kebede, 2015) .

3.1.4. Demography

The 2012 Central Statistics Agency (CSA) census shows that the total population of Addis Ababa is 3.061,404 million with the average household size 4.1 and sex ratio 45.58 % male and 54.42 % female.

3.2. Methods

3.2.1. Sampling Method

For this study Complete census method was employeed, where all sites in this study where assessed to determine the number and type of buildings alon with rooftop area of the identified building blocks. This was performed using data sets that contain building-based information such as site plans, building typology designs, number of buildings and information from Google Earth Pro.

3.2.2. Data Source and Method of Collection

The source of data for the research is both from primary and secondary data sources. Primary data sources are generated from site plans, building designs, site visit and measurement condominium sites and data was collected from Housing Development Office that include sight plans, roof designs, building height and other relevant data.

Google earth pro online GIS tool was also used to generate the data about the number and typologies of buildings, building and roof orientation, the rooftop area, and roof structures to evaluate suitability of rooftop. The solar radiation data used in this study is taken from the System Advisor Model database and the recent Solar and Wind Resource Assessment reports.

3.2.3. Analysis Methods

Descriptive analysis was applied for the assessment of the suitability of the rooftop area on major condominium sites with respect to the building orientation, roof design and the requirement for solar PV system design parameters of the study area.

Quantitative analysis was employed for analysis of the data's regarding total rooftop area, the rooftop area under each category based on the suitability analysis, the potential of the solar PV system under categories and GHG reduction potential based on the solar PV potential. The results of the descriptive and quantitative analysis are discussed and presented using tables, graphs, diagrams and charts where appropriate.

3.2.4. Methodology

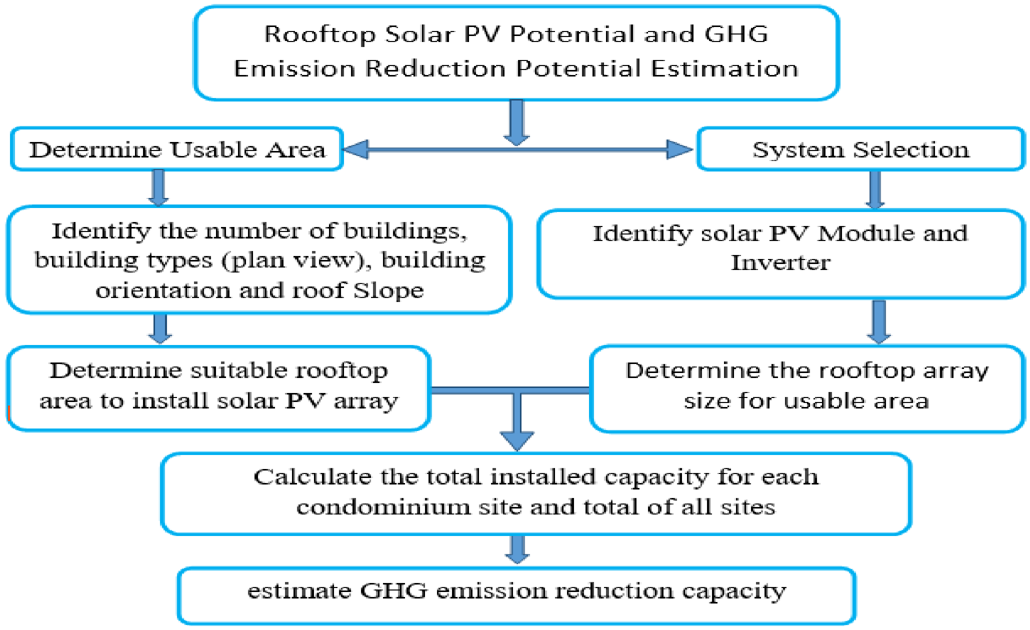

Figure 3-2: Methodological Framework

3.2.4.1. Assessment of Rooftop Area suitability for Solar PV installation

Based on the data from Addis Ababa Housing Development Agency complete online census of the condominium sites was performed to determine total number of blocks and manual selecting methods (Taha and Effat, 2015) using sources such as aerial photograph from Google earth pro online GIS tool (Zhang et al., 2009) is employed to assess suitability of rooftop area by considering orientation of the building and the roof and typology of the building. The tool is available in the professional version of Google Earth (https://www.google.com/earth/).

Data from site plan of the condominium sites along measurement from Google Earth with the polygon tool on the rooftop area based on their orientation and roof characteristics was measured and recorded. The record was categorized based on the orientation (North-South, East-West, South-East/ North-West, South-West/ North-East), roof design and building typology type.

Figure 3-3 : Building and Roof orientation assessment using Google Earth areal image

3.2.4.2. Rooftop Solar PV Potential Estimation

For the Solar PV potential estimation System Advisor Model (SAM) is used. SAM is a performance and financial model provided by the National Renewable Energy Laboratory ("NREL") designed to facilitate decision making for people involved in the RE industry such as project managers, engineers, policy analysts, technology developers and researchers. (http://pvwatts.nrel.gov/SAM.php).

SAM makes performance predictions and cost of energy estimates for grid-connected power projects based on system design parameters and installation and operating costs that users specify as inputs to the model. SAM includes several databases of performance data and coefficients for system components such as PV modules and inverters, parabolic trough receivers and collectors, wind turbines, or bio-power combustion systems. The Following parameters are considered when running the model to eastimate rooftop solar PV potentials.

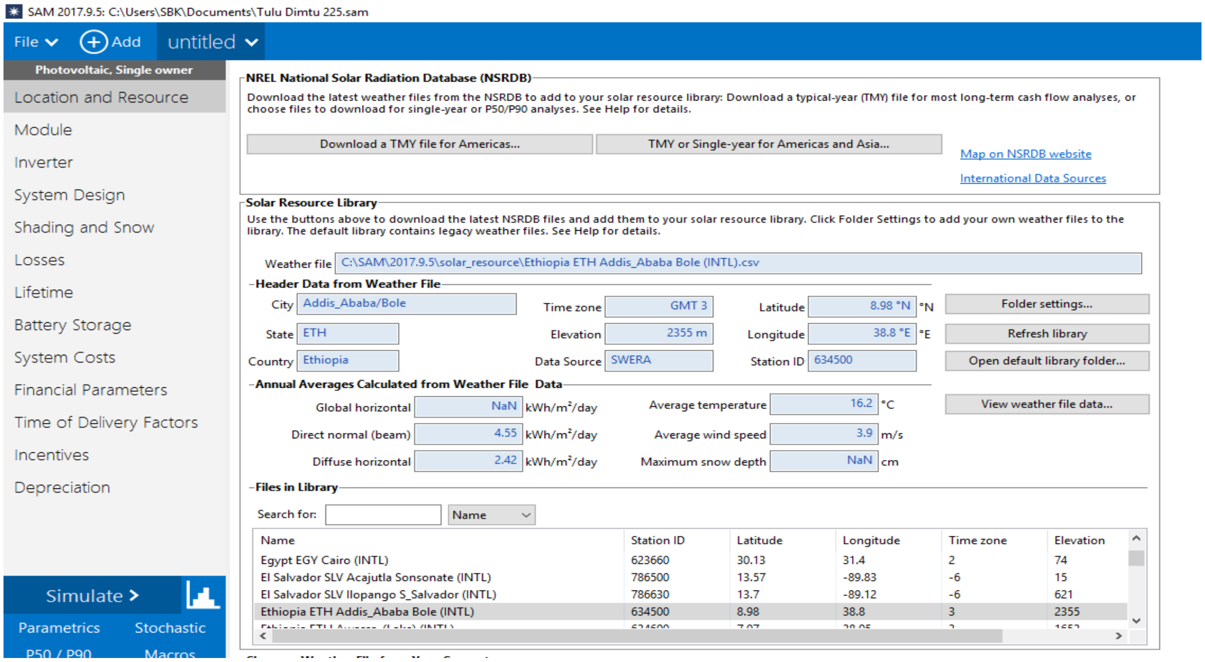

Figure 3-4: System Advisor Model

Solar PV System Design

Azimuth Angle

The azimuth angles of the south facing (suitable) rooftop area vary with the orientation of buildings as 0˚for south, 315˚for South-East and 45˚for South-West facing roof portion of the buildings (SAM takes azimuth angel 0˚for North and 180˚for south, 90˚East and 270˚West).

Shading

Shading was not considered because the modules are to be placed along the roof surface there is no self-shading and the building are in similar height categories in one location which eliminates inter buildings shading.

Project Life time

Project life time considered was 25 years with 0.5% system degradation rate.

Tilt Angle of the PV Modules

The tilt angle of PV system was taken same as 14˚, the average slope angle of the roof of the different building types in the study sites.

Solar Radiation Data

The SWERA solar radiation data was used in this study from the National Solar Radiation Database (NSRDB) of System Advisor Model (www.nrel.com).

System Losses

In the estimation of rooftop PV potential of condominium sites in this study the 10.% losses are taken in to account from the following parameters.

- 5% loss due to Soiling
- 2% loss due to Module mismatch
- 0.5% for loss from Diodes and Connection
- 2% loss from DC wiring
- 1% loss from AC wiring

Solar PV Modules and Invereter

Sunpower-SPR-X22-360-COM solar PV module manufactured by Sun-Power (www.sunpower.com) is selected for its high efficiency and maximum rated power in a relatively smaller module area compared to others in the SAM database. The module specifications are listed in table 3.2.

SMA America SC800CP-US 360V inverter manufactured by SUNNY (www.sma-america.com) is also selected for its high efficiency, wide range of input voltage and output frequency which is in line with the grid frequency of Ethiopia. The Inverter specifications are listed in table 3.3.

Table 3-1: Specification of Solar PV module

Specification of PV module	
Manufacturer	Sun-Power
PV Model	SPR-X22-360-COM
Module Efficiency	22%
Maximum Power (Pmp)	360 Wdc
Maximum Power Voltage (Vpm)	60.6 Vdc
Maximum Power Current (Ipm)	5.9 Adc
Open Circuit Voltage (Voc)	69.5 Vdc
Short Circuit Current (Isc)	6.5 Adc
Temperature Coefficient (Pmax)	-0.351 %/C˚
Temperature Coefficient (Voc)	-0.285 %/C˚
Temperature Coefficient (Isc)	0.035 %/C˚
Maximum System Voltage	1000V UL & 1000V IEC
Module Area	1.631 m^2
Dimensions L *W* H (mm)	1559 *46*1046
Weight	18.6 Kg
Ambient Operating Temperature	-40 to +85˚ C

Table 3-2: Inverter Specification

Inverter Specification	
Manufacturer	SUNNY
Model	SMA America SC800CP-US 360V
Efficiency- %	98.2
Max AC power – Wac	823,000.00
Max DC Power – Wdc	838,567
Power consumption during operation Wdc	2247.8
Power consumption at night Wac	360
Nominal AC voltage – Vac	342
Maximum DC voltage – Vdc	1000
Maximum DC current – Adc	1600
Minimum MPPT DC voltage – Vdc	570
Nominal DC voltage – Vdc	663.758
Maximum MPPT DC voltage – Vdc	820
Output frequency – HZ	50/60

Number of modules

Total Modules = Modules per String × Strings in Parallel, or

Number of Modules = Available Rooftop Area (m^2)/ Module Area (m^2) (www.nrel.com).

Nameplate capacity, kWdc

The maximum DC power output of the array at the reference conditions:

Nameplate Capacity (kWdc) = Module Maximum Power (Wdc) × 0.001 (kW/W) × Total Modules

(www.nrel.com).

Inverters Total capacity, kWac

Inverter Total Capacity (kWac) = Inverter Maximum AC Power (Wac) × 0.001 (kW/W) × Number of Inverters

(www.nrel.com).

Total capacity, kWdc

Inverter Total Capacity (kWdc) = Inverter Maximum DC Input Power (Wdc) × 0.001 (kW/W) × Number of Inverters (www.nrel.com).

Capacity Factor

The capacity factor is the ratio of the system's predicted electrical output in the first year of operation to the nameplate output, which is equivalent to the quantity of energy the system would generate if it operated at its nameplate capacity for every hour of the year (www.nrel.com).

Capacity Factor (%) = Net Annual Energy (kWhac/yr) / System Capacity (kWdc or kWac) / 8760 (h/yr) (www.nrel.com).

3.2.4.3. Green House Gas reduction potential estimation

The GHG emission reduction potential was estimated considering the avoided emission from the introduction of RE into the energy supply. For estimation of the GHG emission reduction potential of the solar PV system the IPCC`s Guidelines for National Greenhouse Gas Inventories 2006 (Eggleston, H.S. et.al. 2006), TIER 1 APPROACH for stationary combustion is used. Tier 1 emission estimate requires the following for each source category and fuel:

- Data on the amount of fuel combusted in the source category and or energy generated in TJ
- A default emission factor

GHG Emissions from Stationary Combustion

Emissions GHG fuel = Fuel Consumption fuel • Emission Factor GHG, fuel

Where:

Emissions GHG fuel = emissions of a given GHG by type of fuel (kg GHG)

Fuel Consumption fuel = amount of fuel combusted (TJ)

Emission Factor GHG fuel = default emission factor of a given GHG by type of fuel (kg gas/TJ). For CO2, it includes the carbon oxidation factor, assumed to be 1.

4. Result and Discussion

4.1. Assessment of Rooftop Area suitability for Solar PV installation

4.1.1. Slope of the Rooftop area system

The average slope of roof of the buildings is found to be 14˚. The average slope of roofs on the condominium sites is high compared with the rule of thumb tilt angle of solar PV system for Addis Ababa. Since the focus of this study is to estimate the solar PV potential of the suitable roof portion that does not require significant modification except for mounting the modules on the selected roof surface the average slope of the roofs is taken as the tilt angel for potential estimation of the solar system. The slope of roofs on the identified building types varies as shown in table 4.

Table 4-1: Slope of the different building types in the selected condominium sites.

Building Type	Roof Slope (˚)
type 1 (L1)	7.97
type 2 (A1)	14.90
type 3 (E2)	20.21
type 4 (A2)	14.90
type 5 (L2)	14.77
type 6	16.37
type 7 (L3)	10.18
Type 8 (S7)	10.18
Type 9 (T16)	17.42
Type 10 (M2)	10.7665
type 11 (com)	14.90
Average	14

4.1.2. Number of Blocks and Orientation

The total number of blocks in the selected condominium sites is 2359 and the buildings are of 11 typologies. The number and type of blocks at each site is shown in table 4-1.

Table 4-2: Number of buildings and building type in the selected condominium sites

Building Type	Condominium Site					Building Type Total
	Ayat-2	Tulu-Dimtu	Gelan	Jemo-1	Yeka-Abado	
Type 1	24	58	31	0	41	**154**
Type 2	163	135	82	0	170	**550**
Type 3	143	62	108	0	202	**515**
Type 4	27	89	81	114	82	**393**
Type 5		72	0	0	48	**120**
Type 6		4	0	0	0	**4**
Type 7		0	0	0	16	**16**
Type8		0	0	0	14	**14**
Type9		0	64	125	0	**189**
Type10		0	15	64	0	**79**
Type 11(com)	46	69	59	53	98	**325**
Site Total	**403**	**489**	**440**	**356**	**671**	**2359**

The orientation of the buildings is found to be 15% (355) east-west, 26% (611) south-east, 36% (850) south-west and 23% (543) north-south. Out of the total blocks 77% (1816) are in the preferred orientation that have roof portion that enables to directly install PV modules with no or minimum adjustment and 23% (543) are not in preferred orientation. The orientation of building blocks in their respective type is shown in table 4-4.

Table 4-3: Building orientation at selected condominium site

No.	Condominium site	Orientation				Total
		East-West	South-West	South-East	North-South	
1.	Ayat-2	112	53	69	169	**403**
2.	Tulu – Dimtu	5	288	43	153	**489**
3.	Gelan	71	132	186	51	**440**
4.	Jemo-1	59	119	125	53	**356**
5.	Yeka-Abado	108	258	188	117	**671**
	All sites	**355**	**850**	**611**	**543**	**2359**

As shown in table 4-3, at Ayat-2 58 % buildings are oriented in preferred orientation. At Tulu-Dimtu 69% of the buildings are orientation in the preferred orientation, 88 %. of the buildings at Gelan site are in the preferred orienteation, the orientation of the buildings at Jemo-1 was 85% in the preferred orientation and at Yeka-Abado 82% of the buildings are in the prefered orientation.

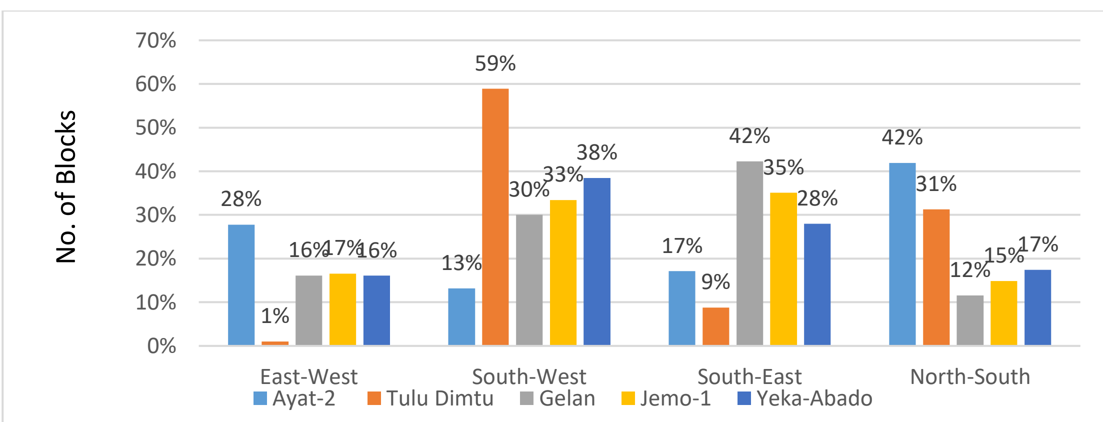

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Figure 4-1: Building Orientation at selected condominium site

Table 4-4 Buildings types, Number of Buildings and Building orientation

Building Design	Orientation				Total
	EW	SW	SE	NS	
Type 1	30	56	31	37	**154**
Type 2	88	226	110	126	**550**
Type 3	115	170	110	120	**515**
Type 4	65	146	97	85	**393**
Type 5	9	29	33	49	**120**
Type 6	0	4	0	0	**4**
Type 7	0	8	8	0	**16**
Type8	0	2	12	0	**14**
Type9	23	81	61	24	**189**
Type10	1	18	49	11	**79**
Type 11(com)	24	110	100	91	**325**
Total	**355**	**850**	**611**	**543**	**2359**

With respect to number of buildings Yeka-Abado condominium site has more buildings than the others sites in this study and with respect to the building orientation Gelan (85%), Jemo-1 (83%) and Yeka-Abado (83%) has more buildings in the preferred orientation compared to Ayat-2 (58%) and Tulu-Dimtu (69%). For this study south facing roof portion of the buildings oriented east-west, south-east and south-west are considered 77% (1816 blocks).

4.1.3. Roof top area Estimations

The roof area on all condominium sites and building type can be used to install solar PV system and generate energy but for gaining the maximum energy output and economical implementation, modifying or adjusting it to meet the requirement of the PV system (i.e. south facing for locations in the northern hemisphere and optimum tilt angle most commonly similar with latitude of the location) is imperative. Suitable roof area is to indicate the roof portion that enables to install or mount the PV modules on the roof surface with minimum modification required.

On this study the identified building types have roof designs generally that incline in two directions halfway and if the one side is facing south the other faces north. Therefore, to make use of the north facing roof portion the PV module has to be raised almost double of the roof inclination angle.

Based on the identified building types, the total and the suitable roof portion were identified using the Google Earth Pro GIS tool considering the orientation of the building and the roof design. Table 8: shows the result of total and suitable rooftop area of determined on unit building of each building type.

Table 4-5: Rooftop area on unit block of the identified building Types

Building Type	Total Area (m^2)	Usable roof area on EW, SE & SW oriented buildings (m^2)	Usable area (%)	Remarks
Type 1	350	210	60%	
Type 2	376	101	27%	
Type 3	260	87	33%	
Type 4	340	66	19%	
Type 5	310	119	38%	
Type 6	850	340	40%	
Type 7	513	240	47%	
Type8	513	s450	88%	
Type9	285	94	33%	
Type10	320	70	22%	
Type 11(com)	200	65	33%	
Total	4317	1842	43%	

As shown on table Table 4-5 From the determined total rooftop area on the 11 buildings types 43% was determined as suitable for rooftop PV system and building type 8 and 1 has the highest percent of usable area as compared to the others.

Building Design	Suitable Area (m^2)			NS	Unsuitable (North facing) Rooftop area on EW,SE &SW	**Total**
	EW	SW	SE			
Type 1	6300	11760	6510	12950	16380	**53900**
Type 2	8888	22826	11110	47376	116600	**206800**
Type 3	10005	14790	9570	31200	68335	**133900**
Type 4	4290	9636	6402	28900	84392	**133620**
Type 5	1071	3451	3927	15190	13561	**37200**
Type 6	0	1360	0	0	2040	**3400**
Type 7	0	1920	1920	0	4368	**8208**
Type 8	0	900	5400	0	882	**7182**
Type 9	2162	7614	5734	6840	31515	**53865**
Type 10	70	1260	3430	3520	17000	**25280**
Type 11 (com)	1560	7150	6500	18200	31590	**65000**
Total	**34346**	**82667**	**60503**	**164176**	**386663**	**728355**

Table 4-6: Roof Area with respect to building orientation and building Type

The suitable area considering the south facing roof portion of east-west, south-east and south-west oriented buildings and the roof characteristics is 24 % (177,516 m^2). North-south oriented building's roof area is 23 % (164,176 m^2) and unsuitable (North facing) roof area on east-west, south-east and south-west oriented buildings is 53% (386,663 m^2) from the total roof area 728,355 m^2. Yeka-Abado, Gelan, Tulu-Dimtu, Jemo-1, and Ayat-2 have 29%, 26%, 24%, 22% and 18% respectively suitable roof area portion to install solar PV modules directly on the roof surface.

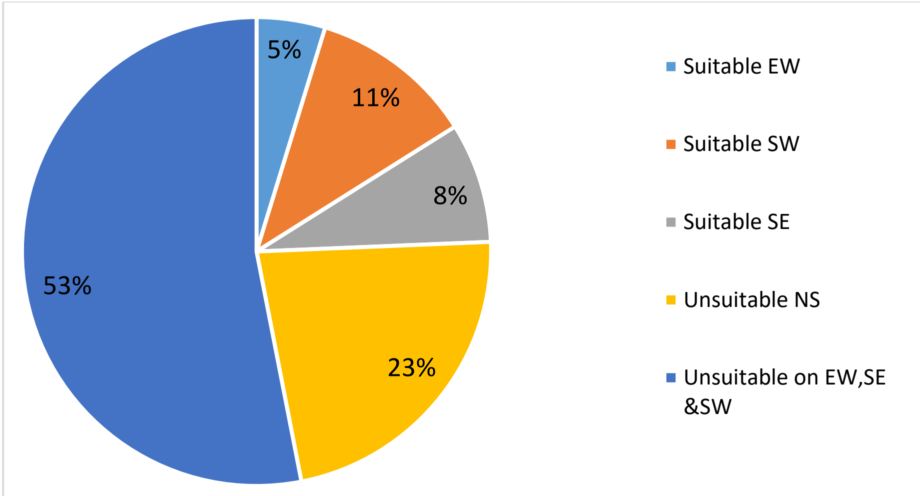


Figure 4-2: Rooftop Area of buildings with respect to their roof orientation

- **Rooftop Area at each condominium**

As figure 4-3. shows Yeka-Abado has the highest roof area compared to the other sits in this study. And the common buildings types in the selected sites are type 2, type 4 and type 11 as shown in figure 4-4.

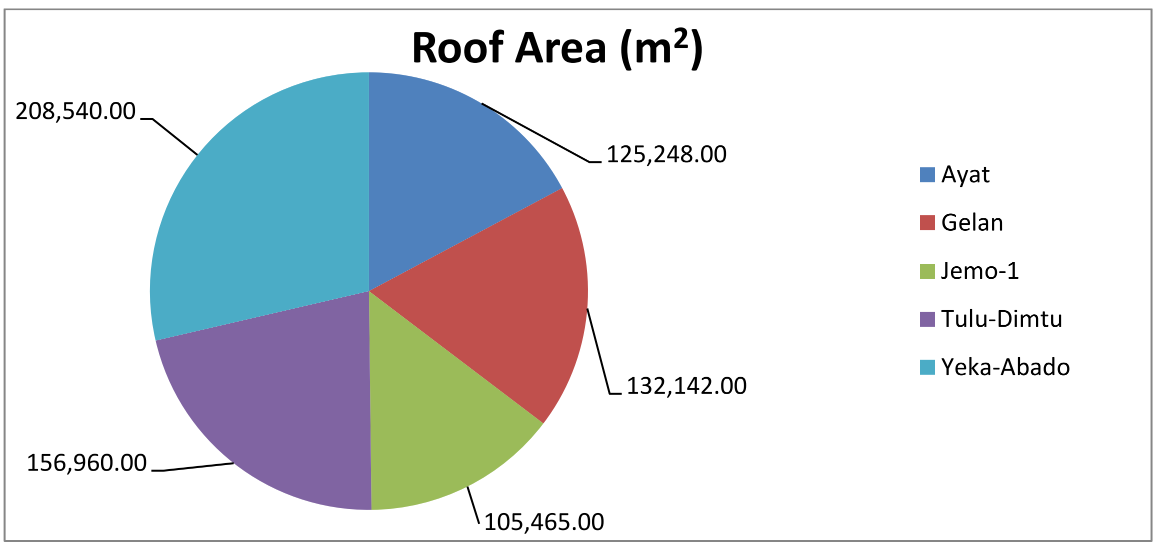


Figure 4-3: Total rooftop area at each condominium sites

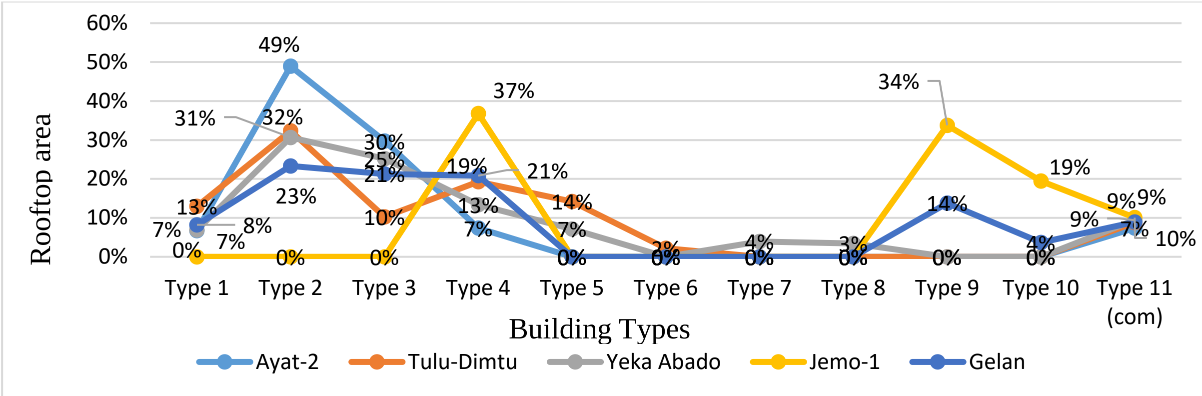


Figure 4-4: Rooftop area at each condominium sites by building type

The Suitable area considering the south facing roof portion of east-west, south-east and south-west oriented buildings and the roof characteristics at Yeka-Abado 29 % (59,540 m^2), Gelan 26 % (34,806 m^2), Tulu-Dimtu 24 % (37,554 m^2), Jemo-1 22 % (23,052 m^2) and Ayat-2 has 18 % (22,564 m^2). The unsuitable (north facing) roof area on east-west, south-east and south-west oriented buildings was found to be 53% (50,218 m^2) at Ayat-2, 48% (75,850 m^2) at Tulu-Dimtu, 24 % (37,554 m^2) at Gelan, 64% (67,363 m^2) at Jemo-1 and 54% (111,888 m^2) at Yeka-Abado. Comulatively the condominium sites have 24% sutable rooftop area out of the total.

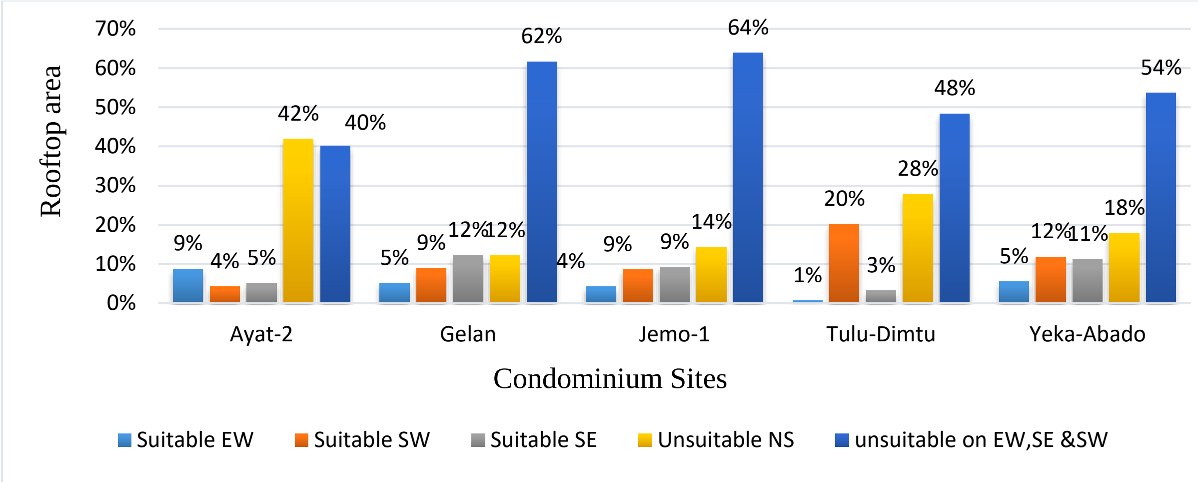


Figure 4-5: Rooftop area at each condominium site based on building Orientation and suitability

4.2. Rooftop Solar PV Potential Estimates

The suitable roof area on the blocks of the considered condominium sites are in three categories with respect to their orientation such as east-west, south-east and south-west. Therefore, the analysis could not be performed on total suitable roof area per condominium site but separately for each building orientation category i.e. the model is run for specific azimuth angle of the building orientation category per condominium site which is summed up to give the site total potential.

4.2.1. Rooftop PV Potential Estimates in the Condominium sites

4.2.1.1. Rooftop Solar PV Potential of Ayat-2 condominium Site

The suitable Roof area to install solar module directly on the roof of buildings oriented East-West with azimuth angle of 0° is 10,968 m^2, south-West with azimuth angle of 45° is 5,249 m^2 and south-East with azimuth angle of 315° degrees is 6,347 m^2. By using 10,962.3 m^2, 5220.8 m^2 and 6,333.2 m^2 area an array of 2420 KWdc, 1155 KWdc and 113.97.74 KWdc nameplate capacity can be installed respectively. The annual energy production potential on East-West, south-West and south-East oriented buildings are 4,091,972 kWh, 1,836,224 kWh and 2,349,397 kWh with Capacity factor with Capacity factor 19.3%, 18.2% and 19.2% respectively.

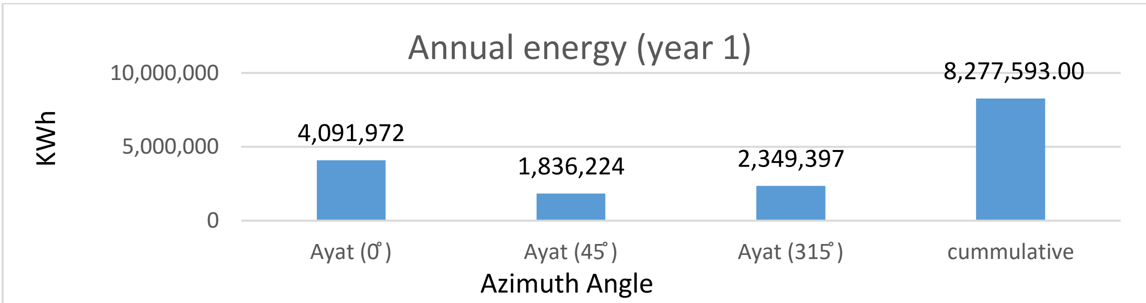


Figure 4-6: Annual Energy potential of suitable rooftop area at Ayat-2 Condominium site

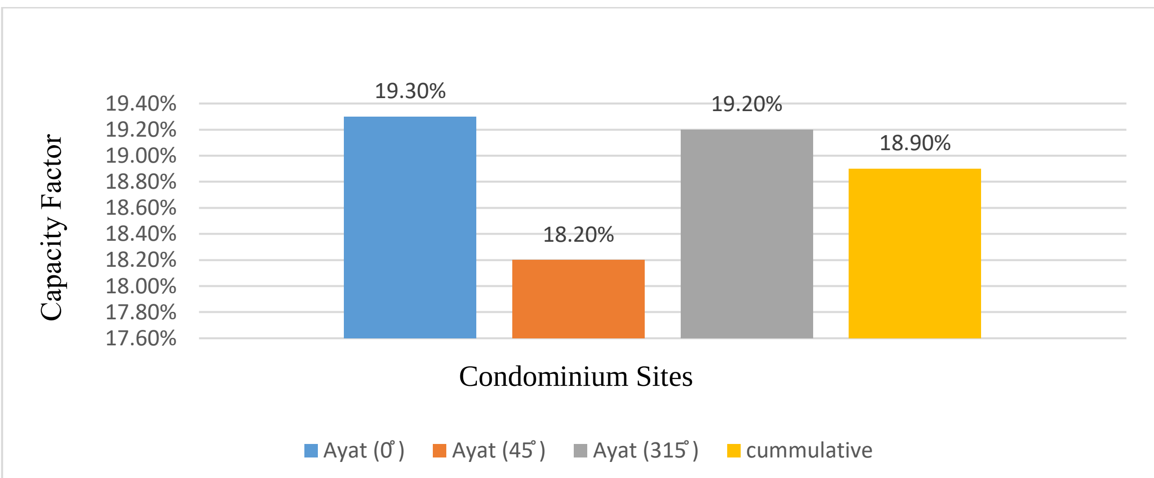


Figure 4-7: Capacity factor of rooftop PV system at Ayat-2 Condominium site

The cumulative energy produced from the suitable roof area of 22,516 m^2 oriented in three azimuth angles at the condominium site is 8,277,593.00 KWh. The system totally requires 13805 PV modules arranged in 1255 Parallel strings with 11 modules per string and 6 inverters. The capacity factor is 18.90%.

Table 4-7: Solar PV Potential of Ayat-2 Condominium site

No.	Metric	Azimuth angle 315˚	Azimuth angle 0˚	Azimuth angle 45˚	Cumulative
1	Annual energy (year 1) KWh	2,349,397	4,091,972	1,836,224	8,277,593
2	Capacity factor (year 1)	19.20%	19.30%	18.20%	18.90%
3	Energy yield (year 1) KWh/KW	1,681	1,691	1,594	1,655
4	Performance ratio (year 1)	0.81	0.81	0.78	0.80
5	Nameplate capacity	1397.74	2419.318	1,152	4969.303
6	Number of Modules	3883	6721	3201	13805
7	Modules per string	11	11	11	11
8	string in Parallel	353	611	291	1255
9	Total Module area M^2	6333.2	10962	5220.8	22516
10	Number of Inverters	2	3	1	6

4.2.1.2. **Rooftop Solar PV Potential of Yeka-Abado condominium Site**

The suitable Roof area to install solar module directly on the roof of buildings oriented East-West with azimuth angle of 0˚ is 11,439 m^2, south-West with azimuth angle of 45˚ is 24,667 m^2 and south-East with azimuth angle of 315˚ degrees is 23,434 m^2. By using 11,428.4 m^2, 24,650.9 m^2 and 23,430 m^2 area an array of 2525 KWdc, 5443 KWdc and 5172 KWdc size can be installed respectively. The annual energy production potential on East-West, south-West and south-East oriented buildings is 4,265,596 kWh, 9,011,088 kWh and 8,691,496 kWh with Capacity factor with Capacity factor 19.3%, 18.9% and 19.2% respectively.

The cumulative energy produced from the suitable roof area of 59500.2 m^2 oriented in three azimuth angles at the condominium site is 21,968,180 KWh. The system totally requires 36,487 PV modules arranged in 3290 Parallel strings with 11 modules per string and 15 inverters. The capacity factor is 19.13%.

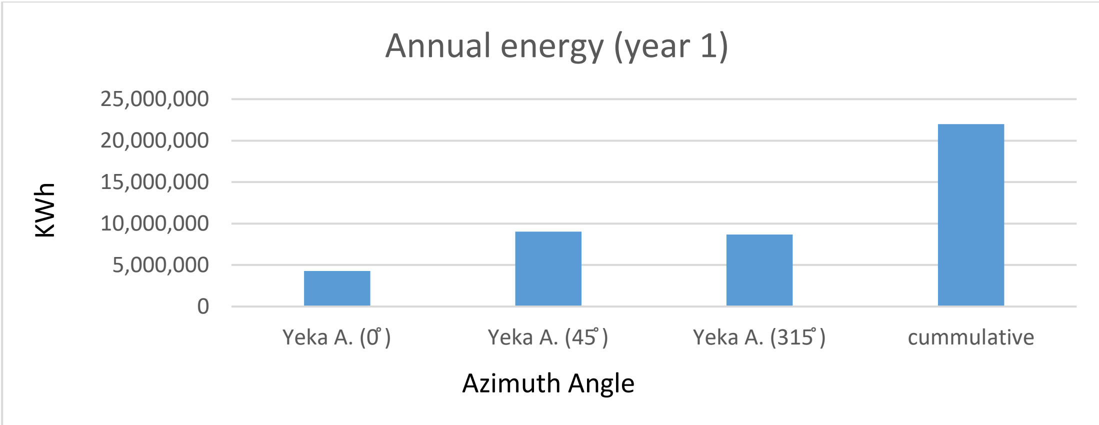


Figure 4-8: Annual Energy potential of suitable rooftop area at Yeka-Abado site

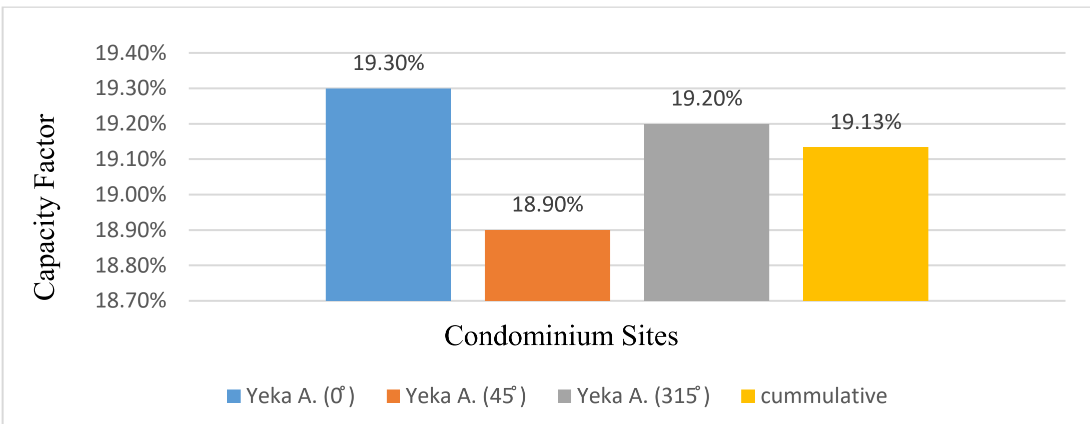


Figure 4-9: Capacity factor of rooftop PV system at Yeka-Abado site

Table 4-8: Solar PV potential on suitable Roof area of Yeka-Abado Condominium site

No.	Metric	Azimuth angle 315˚	Azimuth angle 0˚	Azimuth angle 45˚	Cumulative
1	Annual energy (year 1) KWh	8,691,496	4,265,596	9,011,088	21,968,180
2	Capacity factor (year 1)	19.20%	19.30%	18.90%	19.13%
3	Energy yield (year 1) KWh/KW	1,681	1,691	1,656	1,676
4	Performance ratio (year 1)	0.81	0.81	0.81	0.81
5	Nameplate capacity	5171.243	2522.268	5440.496	13134.007
6	Number of Modules	14366	7007	15114	36487
7	Modules per string	11	11	11	11
8	string in Parallel	1306	637	1347	3290
9	Total Module area m^2	23420.9	11428.4	24650.9	59500.2

10	Number of Inverters	6	3	6	15

4.2.1.3. Rooftop Solar PV Potential of Tulu-Dimtu condominium Site

The suitable Roof area to install solar module directly on the roof of buildings oriented East-West with azimuth angle of 0° is 941 m^2, south-West with azimuth angle of 45° is 31,636 m^2 and south-East with azimuth angle of 315° degrees is 4,977 m^2. By using 932.9 m^2, 31,630 m^2 and 4,969.7 m^2 area an array of 206 KWdc, 6981 KWdc and 1096.81 KWdc size can be installed respectively. The annual energy production potential on East-West, south-West and south-East oriented buildings is 342,093 kWh 11,730,390 kWh and 1,790,859 kWh with Capacity factor with Capacity factor 19.0%, 19.2% and 18.6% respectively.

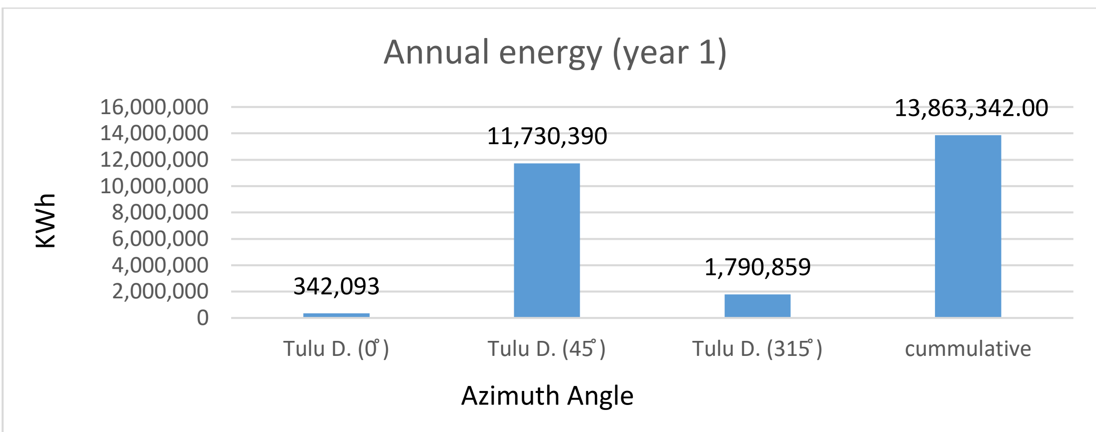


Figure 4-10: Annual Energy potential of solar PV system on suitable rooftop area at Tulu-Dimtu site

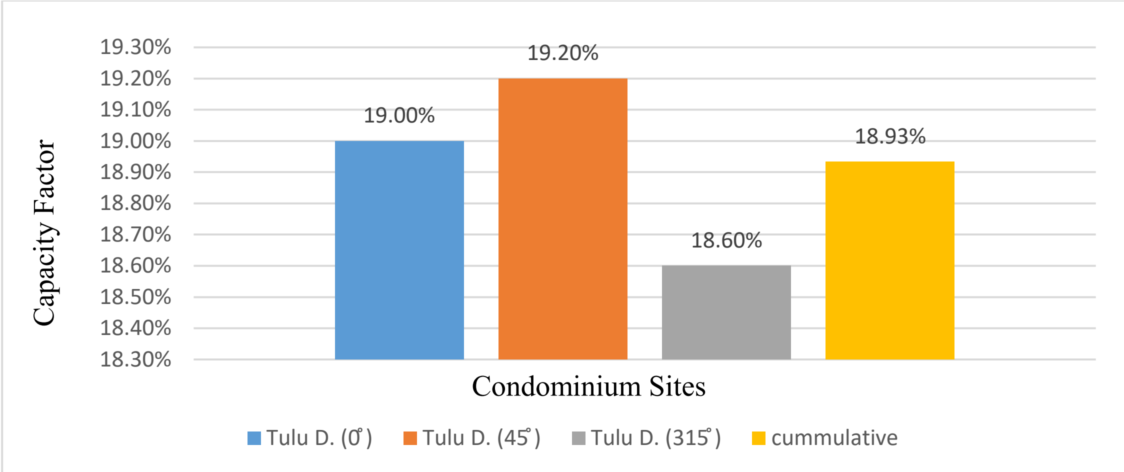


Figure 4-11: Capacity factor of solar PV system at Tulu-Dimtu site

The cumulative energy produced from the suitable roof area of 37,532.6 m^2 oriented in three azimuth angles at the condominium site is 13,863,342 KWh. The system totally requires 23,012 PV modules arranged in 2092 Parallel strings with 11 modules per string and 6 inverters. The capacity factor is 18.93%.

Table 4-9: Solar energy Potential of Suitable roof area of Tulu-Dimtu condominium site

No.	Metric	Azimuth angle 315˚	Azimuth angle 0˚	Azimuth angle 45˚	Cumulative
1	Annual energy (year 1) KWh	1,790,859	342,093	11,730,390	13,863,342
2	Capacity factor (year 1)	18.60%	19.00%	19.20%	18.93%
3	Energy yield (year 1) KWh/KW	1,633	1,661	1,680	1,658
4	Performance ratio (year 1)	0.79	0.79	0.81	0.80
5	Nameplate capacity	1096.81	205.899	6,981	8283.491
6	Number of Modules	3047	572	19393	23012
7	Modules per string	11	11	11	11
8	string in Parallel	277	52	1763	2092
9	Total Module area M^2	4969.7	932.9	31630	37532.6
10	Number of Inverters	1	1	8	10

4.2.1.4. Rooftop Solar PV Potential of Jemo-1 condominium Site

The suitable Roof area to install solar module directly on the roof of buildings oriented East-West with azimuth angle of 0˚ is 4,429 m^2, south-West with azimuth angle of 45˚ is 9,029 m^2

and south-East with azimuth angle of 315̊ degrees is 9,594 m^2. By using 4,413.5 m^2, 9,024 m^2 and 9,580.5 m^2 area an array of 974 KWdc, 1992 KWdc and 2114.43 KWdc size can be installed respectively. The annual energy production potential on East-West, south-West and south-East oriented buildings is 1,632,808 kWh, 3,272,436 kWh and 3,480,827 kWh with Capacity factor with Capacity factor 19.1%, 18.8%.and 19% respectively.

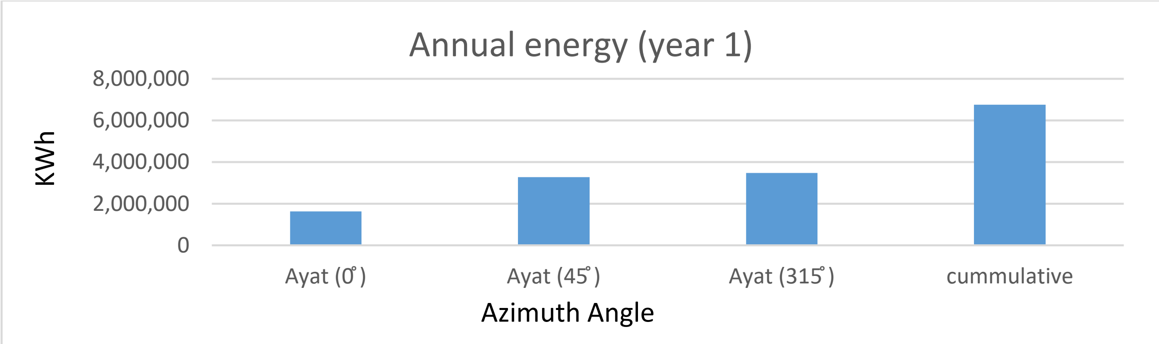


Figure 4-12: Annual Energy potential of solar PV system on suitable rooftop area at Jemo-1 site

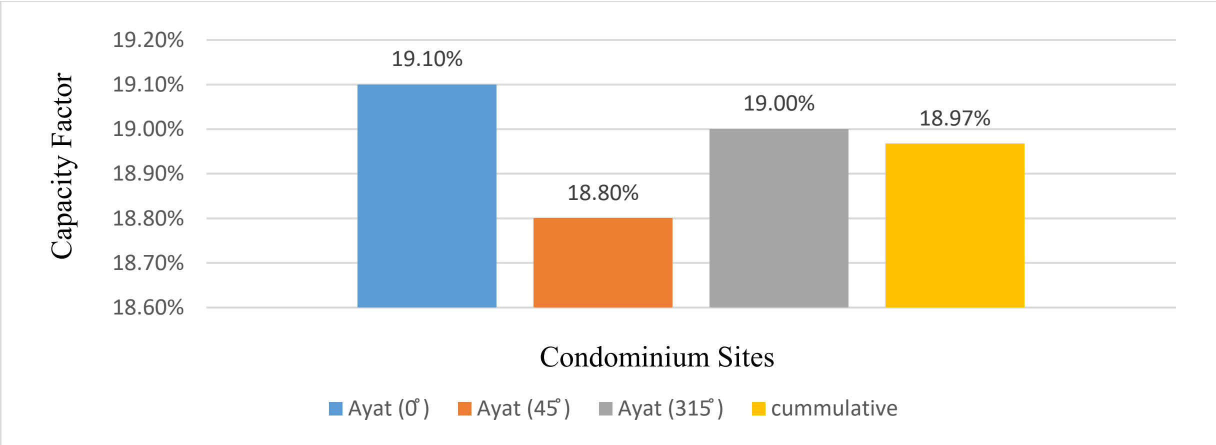


Figure 4-13: Capacity factor of rooftop PV system at Jemo-1 site

The cumulative energy produced from the suitable roof area of 23018.3 m^2 oriented in three azimuth angles at the condominium site is 8,386,071 KWh. The system totally requires 14,113 PV modules arranged in 1,283 Parallel strings with 11 modules per string and 5 inverters. The capacity factor is 18.90%.

Table 4-10: The solar PV potential on suitable roof area of Jemo-1 condominium site

No.	Metric	Azimuth angle 315˚	Azimuth angle 0˚	Azimuth angle 45˚	Cumulative
1	Annual energy (year 1) KWh	3480827.00	1,632,808	3,272,436	8,386,071
2	Capacity factor (year 1)	19%	19.10%	18.80%	18.90%
3	Energy yield (year 1) KWh/KW	1,646	1,676	1,643	1,655
4	Performance ratio (year 1)	0.79	0.8	0.8	0.80
5	Nameplate capacity	2114.428	974.063	1,992	5080.172
6	Number of Modules	5874	2706	5533	14113
7	Modules per string	11	11	11	11
8	string in Parallel	534	246	503	1283
9	Total Module area M^2	9580.5	4413.5	9024.3	23018.3
10	Number of Inverters	2	1	2	5

4.2.1.5. **Rooftop Solar PV Potential of Gelan condominium Site**

The suitable Roof area to install solar module directly on the roof of buildings oriented East-West with azimuth angle of 0˚is 6,569 m^2, south-West with azimuth angle of 45̊ is 12,086 m^2 and south-East with azimuth angle of 315̊ degrees is 16,151 m^2. By using 6,566.4 m^2, 12,074.3 m^2 and 16,146.9 m^2 area an array of 1449.22 KWdc, 2665 KWdc and 3563.64 KWdc size can be installed respectively. The annual energy production potential on East-West, south-West and south-East oriented buildings is 2,450,870 kWh, 4,416,637 kWh and 5,985,388 kWh with Capacity factor with Capacity factor 19.3%, 18.9% and 19.2% respectively.

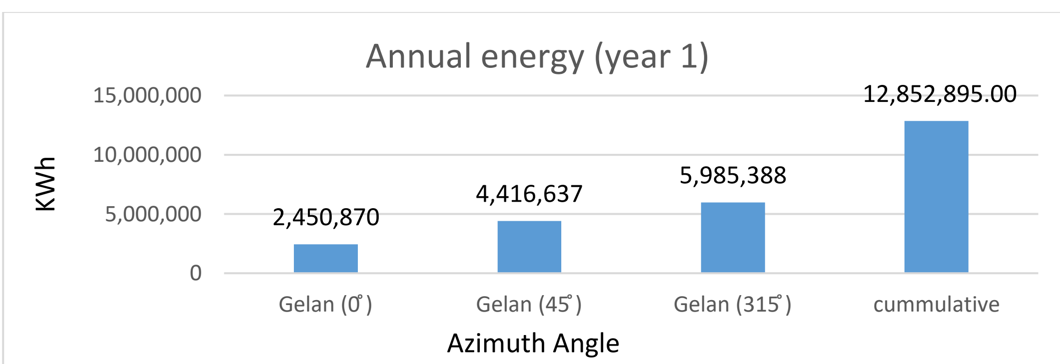


Figure 4-14: Annual energy potential of solar PV system on suitable rooftop area at Gelan site

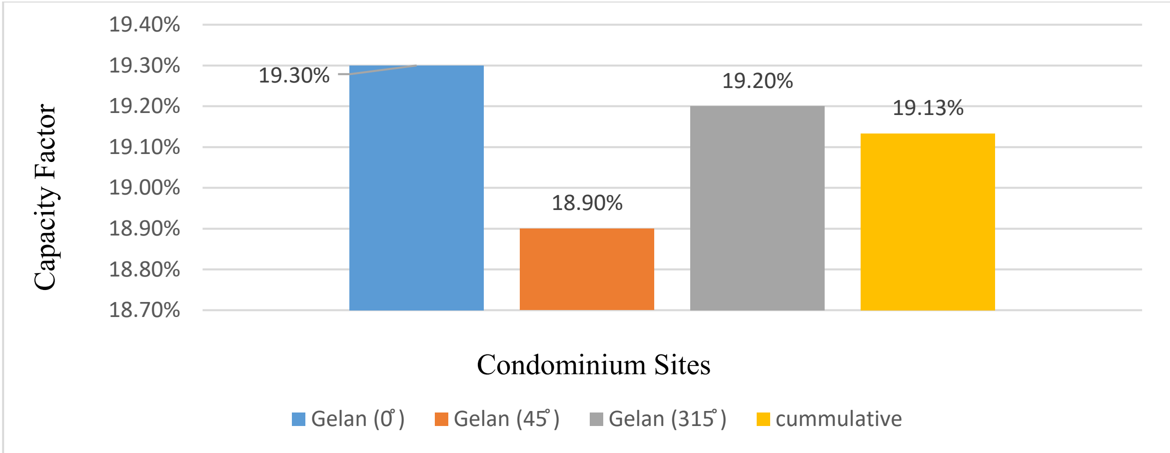


Figure 4-15: Capacity factor of rooftop PV system at Gelan site

The cumulative energy produced from the suitable roof area of 34787.6 m^2 oriented in three azimuth angles at the condominium site is 12,852,895 KWh. The system totally requires 21329 PV modules arranged in 1,939 Parallel strings with 11 modules per string and 9 inverters. The capacity factor is 19.13%.

Table 4-11: The solar PV potential of suitable roof area of Gelan condominium site

No.	Metric	Azimuth angle 315˚	Azimuth angle 0˚	Azimuth angle 45˚	Cumulative
1	Annual energy (year 1) KWh	5,985,388	2,450,870	4,416,637	12,852,895
2	Capacity factor (year 1)	19.20%	19.30%	18.90%	19.13%
3	Energy yield (year 1) KWh/KW	1,680	1,691	1,657	1,676
4	Performance ratio (year 1)	0.81	0.81	0.81	0.81
5	Nameplate capacity	3563.644	1449.215	2,665	7677.672
6	Number of Modules	9900	4026	7403	21329
7	Modules per string	11	11	11	11
8	string in Parallel	900	366	673	1939
9	Total Module area M^2	16146.9	6566.4	12074.3	34787.6
10	Number of Inverters	4	2	3	9

4.2.1.6. Comulative Rooftop Solar PV Potential of all sites

The cumulative annual energy potential of the condominium sites included in this study from the suitable roof area of 177,516 m^2 is estimated to be 65,348,081.00 KWh with capacity factor of 19% and 80% performance ratio at first year.

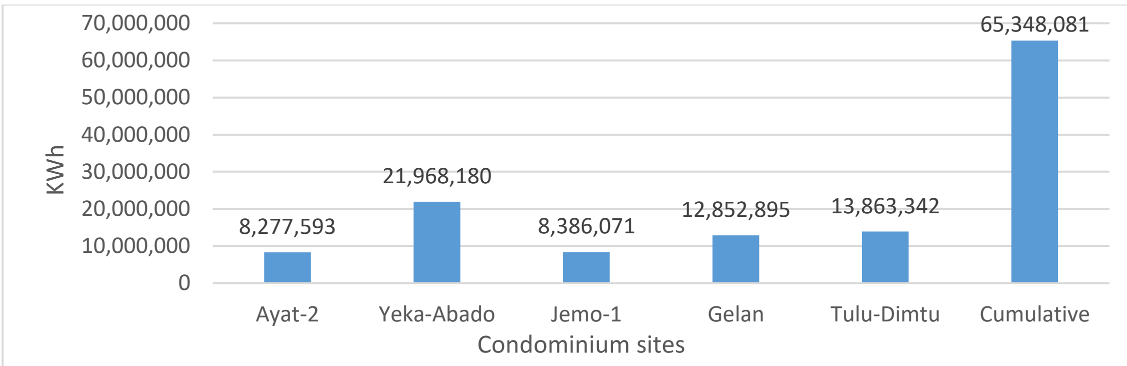


Figure 4-16: Annual Energy Potential of suitable rooftop area by condominium site

Yeka-Abado has the highest annual energy production potential with 21,968,180 KWh followed by Tulu-Dimtu with 13,863,342 KWh, Gelan with 12,852,895 KWh, Jemo-1 with 8,386,071 KWh and Ayat-2 8,277,593.0 KWh.

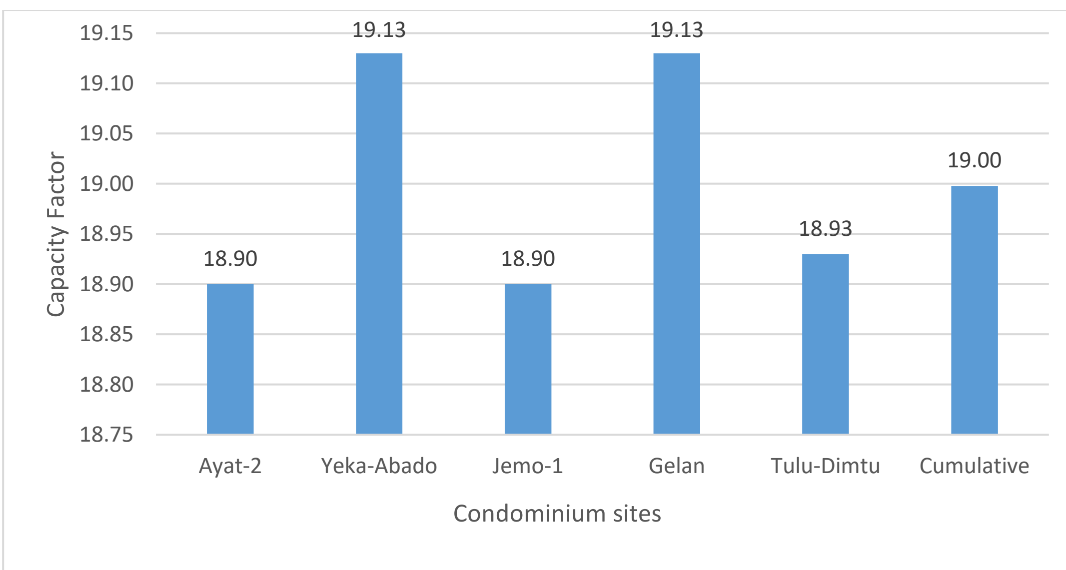


Figure 4-17: Capacity factor of rooftop Solar PV system in selected condominium site

Similarly, Kebede (2015) in his study found that from the selected 35 locations in Ethiopia the mean generation potential of a 5MW PV plant is 8674 MWh/yr. Using GIS models to find out solar energy potential Luqman et al. (2015) found an estimated 39,613,072 kWh/year from 27,376 m^2 Rooftop area of Punjab Government Servants Cooperative Housing Society and study by Mcintyre (2012) also indicated that coverage of all roofs in Guelph with Sun-Power E20/327 PV panels could provide the city with up to 2,950 GWh of electricity.

4.3. Green House Gas reduction potential

The common fossil fuel used in electric generator especially large scale is motor gasoline. Therefore, the fuel type considered for the emission estimation is based on the motor gasoline and the default emission factors for the fuel. According to the IPCC (2006) GHG emission inventory guidelines the default emission factors of motor gasoline are 69.30 t CO_2/TJ for carbon dioxide, 3 Kg CH_4 /TJ for Methane and 0.6 Kg N_2O/TJ for Nitrogen dioxide.

Table 4-12: GHG emission Reduction from Rooftop Solar PV system

GHG emission Reduction Potential								
			Emission Factor of Gasoline)			GHG Emissions		
Site	Energy Generation Potential (KWh)	Energy Generation Potential (TJ)	CO_2 Emission Factor (t CO_2/TJ)	CH_4 Emission Factor (kg CH_4/TJ)	N_2O Emission Factor (kg N_2O/TJ)	Actual CO_2 Emissions (t CO_2)	Actual CH_4 Emissions (t CH_4)	Actual N_2O Emissions (t N_2O)
AYAT- 2	8,277,593	29.80	69.30	3	0.6	2,065.09	0.0894	0.0179
Yeka-Abado	21,968,180	79.09	69.30	3	0.6	5,480.62	0.2373	0.0475
Jemo-1	8,386,071	30.19	69.30	3	0.6	2,092.16	0.0906	0.0181
Tulu-Dimtu	13,863,342	49.91	69.30	3	0.6	3,458.63	0.1497	0.0299

Gelan	12,852,895	46.27	69.30	3	0.6	3,206.54	0.1388	0.0278

The result as shown on table 20 indicates the GHG emission reduction from 3.5 MW solar PV system at Ayat-2 condominium site with annual energy production capacity of 8,277,593.00 KWh (29.80 TJ) is estimated to be 2,065.09 t CO_2, 0.0894 CH_4 and 0.0179 N_2O; A 9.3 MW solar PV system at Yeka-Abado condominium site with annual energy production capacity of 21,968,180.00 KWh (79.09 TJ) is estimated to be 5,480.62 t CO_2, 0.2373 t CH_4 and 0.0475 t N_2O; A 3.54 MW solar PV system at Jemo-1 condominium site with annual energy production capacity of 8,386,071.00 KWh (30.19 TJ) is estimated to be 2,092.16 t CO_2, 0.0906 t CH_4 and 0.0181 t N_2O; A 5.843 MW solar PV system at Tulu-Dimtu condominium site using suitable roof areas with annual energy production capacity of 13,863,342.00 KWh (49.91 TJ) is estimated to be 3,458.63 t CO_2, 0.1497 t CH_4 and 0.0299 t N_2O and A 5.42 MW solar PV system at Gelan condominium site with annual energy production capacity of 12,852,895.00 KWh (46.27 TJ) is estimated to be 3,206.54 t CO_2, 0.1388 t CH_4 and 0.0278 t N_2O.

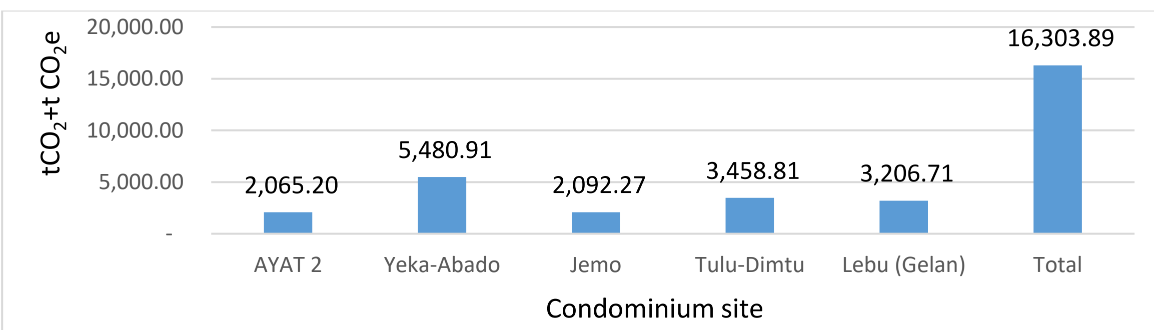


Figure 4-18: Greenhouse gas emission reduction potential of roof top PV system in selected condominium sites

Cumulatively the GHG emission reduction potential from the rooftop solar PV system only considering the suitable roof portion of the selected condominium sites with estimated 27.544 MW power and annual energy production capacity of 65,348,081.00 KWh is 16,303.04 tCO_2, 0.70576 t CH_4 and 0.14115 t N_2O. Viability study of 5 MW solar power plant by Kebede (2015) in norther part of Addis Ababa also shows GHG emission reduction of 1089 tCO_2. Luqman et al. (2015) also found from estimated 39,613,072 kWh/year to have 27,333 Metric tons of CO_2 reduction potential.

5. Conclusion and Recommendations

5.1. Conclusion

Total number of blocks in the selected condominium sites were 2359 where 77% (1816) were oriented in the preferred orientation to install PV system and 23% (543) are not.

The total roof area of the condominium sites in this study is estimated to be 728,355 m^2 where 24% (177,516 m^2) enables to install solar PV systems with minimum or no modification of the roof except for mounting module on the roof surface.

The rooftop solar PV system annual energy potential of the suitable roof area was estimated to be 65,348,081.00 KWh. Highest annual energy production potential were found at Yeka-Abado with 21,968,180 KWh, Tulu-Dimtu with 13,863,342 KWh and Gelan with 12,852,895 KWh. This indicates rooftop areas in condominium sites posses have high energy potential that could strengthen the electric energy suppling capacity by the additional energy and increase the energy mix of the national grid.

GHG emission reduction potential of 16,303.04 tCO_2, 0.70576 t CH_4 and 0.14115 t N_2O was found from the estimated annual solar PV potential that indicates the rooftop PV system has notable GHG emission reduction potential which could contribute for the clean and green development goals of our country.

Based on the result it can be concluded that out of the total roof area on condominium sites in

5.2. Recommendations

- Future detailed feasibility and socio-economic study on selected condominium site especially on the sites with high potential estimate such as Yeka-Abado, Tulu-Dimtu and Gelan;

- Similar Rooftop solar PV potential assessment on large scale infrastructures like industry parks and real states areas is recommended.
- future housing developments to make majority of the infrastructures to be oriented in the preferable orientation (East-West) and use typologies that have higher suitable rooftop area like type 8 (S7), type 1(L1), type 7 (L3), and Type 6 to install solar energy capturing technologies and use of the huge solar potential in Ethiopia.

6. References

Central Statistical Agency, 2012. The 2012 Urban Employment Unemployment Survey. Addis Ababa, Ethiopia.

Cesen-Ansaldo, 1986. Wind Energy Resources, Technical Report 4, Ethiopian Nation Energy Committee.

Donald W. Aitken, 2003. Transitioning to a renewable energy future. ISES White Paper. Wiesentalstr. 50-79115 Freiburg, Germany.

Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Seyboth, K., Kadner, S., Zwickel, T., Eickemeier, P., Hansen, G., Schlömer, S., von Stechow, C. and Matschoss, P. eds., 2011. Renewable energy sources and climate change mitigation: Special report of the intergovernmental panel on climate change. Cambridge University Press.

Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T. and Tanabe, K., 2006. IPCC guidelines for national greenhouse gas inventories. Institute for Global Environmental Strategies, Hayama, Japan, 2, pp.48-56.

Ethiopian Rural Energy Development and Promotion Center, 2007. Solar and Wind Energy Utilization and Project Development Scenarios Country background information.

FDRE National Planning Commission, 2016. ‘Ethiopian Growth and Transformation Plan II’, I (GTP II).

IEA, (2011) Renewable Energy Technology Solar Energy Perspectives. Paris. International Energy Agency 9 rue de la Fédération 75739 Paris Cedex 15, France.

IEA, 2015. Energy and climate change, world energy outlook special report. International Energy Agency 9 rue de la Fédération 75739 Paris Cedex 15, France.

IEA, 2016., Next Generation Wind and Solar Power. International Energy Agency 9 rue de la Fédération 75739 Paris Cedex 15, France.

IEA, 2017. Renewables information: Overview. International Energy Agency 9 rue de la Fédération 75739 Paris Cedex 15, France.

International Finance Corporation. 2014. Harnessing Energy From The Sun : Empowering Rooftop Owners White Paper on Grid-Connected Rooftop. IFC. Vasant Kunj, New Delhi-110070, India.

IPCC, 2012. Renewable Energy Sources and Climate Change Mitigation. Special Report of the Intergovernmental Panel on Climate Change. Cambridge University Press 32 Avenue of the Americas, New York, NY 10013-2473, USA.

IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland.

Johnson George, 2009. Plugging Into the Sun. National Geographic.

Kebede, Kassahun Yimer, 2015. 'Viability study of grid-connected solar PV system in Ethiopia', SUSTAINABLE ENERGY TECHNOLOGIES AND ASSESSMENTS. Elsevier Ltd, 10, pp. 63–70. doi: 10.1016/j.seta.2015.02.003.

Khagendra P. Bhandari, Jennifer M. Collier, Randy J. Ellingson and Defne S. Apul, 2015. 'Energy payback time (EPBT) and energy return on energy invested (EROI) of solar photovoltaic systems: A systematic review and meta-analysis', Renewable and Sustainable Energy Reviews. Elsevier, 47, pp. 133–141. doi: 10.1016/j.rser.2015.02.057.

Kopp Greg and Lean Judith L., 2011. A new, lower value of total solar irradiance: Evidence and climate significance. Geophysical Research Letters, 38. L01706, doi: 10.1029/2010GL045777, 2011.

Luqman Muhammad, Ahmad Sajid Rashid, Khan Samiullah, Ahmad Usman and Raza, Ahmad, 2015. 'Estimation of Solar Energy Potential from Rooftop of Punjab Government Servants Cooperative Housing Society Lahore Using GIS', Smart Grid and Renewable Energy, 6, pp. 128–139.

Minstrry of Water Irrigation and Energy, 2012. 'Scaling - Up Renewable Energy Program Ethiopia Investment Plan'.

Masters Gilbert M., 2013. Renewable and efficient electric power systems. John Wiley & Sons, Inc., Hoboken, New Jersey.

Nelson, J., Gambhir, A., and Ekins-Daukes, N., 2014. Solar power for CO2 mitigation. Grantham Institute for Climate Change, Imperial College London, Briefing paper, (11).

Netsanet Seife, 2014. 'Condominium Buildings Versus Environmental Sustainability', MSc. Thesis. Ethiopian Institute of Architecture, Building construction and City Development (EiABC)

Prasad, R. D. and Bansal, R. C., 2011. 'Photovoltaic Systems', in Ahmed, F. Z. and Ramesh, C. B. (eds) HANDBOOK OF RENEWABLE ENERGY TECHNOLOGY. World Scientific Publishing Co. Pte. Ltd., pp. 205–223.

Peter Gevorkian, P., 2008. Solar Power in Building. The engineer's complete design resource. No. Sirsi i9780071485630. 2008. New York: McGraw-Hill.

Ramakrishna, G., 2016. ‘Energy Consumption and Economic Growth: The Ethiopian Experience’, Journal of Economic and Financial Modelling, 2(April), p. pp35-47. Available at: www.ecofinmodelling.com.

REN21, 2017. Renewables 2017 global status report. Paris: REN21 Secretariat.

Ryan, L. and Campbell, N., 2012. Spreading the net: the multiple benefits of energy efficiency improvements.

Sims, R.E.H., R.N. Schock, A. Adegbululgbe, J. Fenhann, I. Konstantinaviciute, W. Moomaw, H.B. Nimir, B. Schlamadinger, J. Torres-Martínez, C. Turner, Y. Uchiyama, S.J.V. Vuori, N. Wamukonya, and X. Zhang, 2007. Energy supply. In: Climate Change 2007: Mitigation of Climate Change. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. B. Metz, O.R. Davidson, P.R. Bosch, R. Dave and L.A. Meyer (eds.), Cambridge University Press, pp. 251-322.

Tekle, F. T., 2014. ‘Assessment of Solar Energy Resources in Ethiopia’, (May). MSc. Thesis. Norwegian University of Science and Technology.

Twidell, J., and Weir, T., 2015. Renewable energy resources. Routledge. 2nd Ed. Taylor & Francis 2 Park Square, Milton Park, Abingdon, Oxon OX14 4RN

UN-Habitat., 2017. THE STATE OF ADDIS ABABA 2017 THE ADDIS ABABA WE WANT. United Nations Human Settlements Programme (UN- Habitat). Available at: www.unhabitat.org%0AHS.

Shalini P. Vajjhala, 2006. Siting renewable energy facilities: A spatial analysis of promises and pitfalls. Resources for Future. Washington, DC 20036. (No. dp-06-34)

Wolfs, T., 2017. ‘A GIS-based approach to estimate the geographic potential for rooftop solar PV: Developing a database at building-level for Denmark’ MSc. Thesis. Aalborg University, Copenhagen.

World Energy Council., 2016. World Energy Resources Solar. World Energy Council.

www.nrel.gov (accessed on 10th February, 2018

www.sma-america.com (accessed on 14th March, 2018)

www.sunpower.com (accessed on 14th March, 2018)

Zhang, X., Walker, R., Salisbury, M., Hromiko, R. and Schreiber, J. Creating a Solar City: 2009. Determining the Potential of Solar Rooftop Systems in the City of Newark. University of Delaware, Center for Energy and Environmental Policy.

Zobaa, A.F., and Bansal, R.C., 2011. Handbook of renewable energy technology. World Scientific Publishing Co.Pte. Ltd. 5 Toh Tuck Link, Singapore 596224

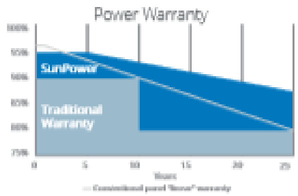
7. Annex

Annex 1: Inverter Data Sheet

MV Power Station 800SC	MV Power Station 900SC	MV Power Station 1000SC	
898 kW	1,010 kW	1,122 kW	
1,000 V	1,000 V	1,000 V	
641 V to 850 V / 583 V to 850 V	722 V to 850 V / 656 V to 850 V	688 V to 850 V / 596 V to 850 V	
641 V	722 V	688 V	
1,400 A	1,400 A	1,635 A	
1	1	1	
9	9	8	
880 kVA / 832 kVA / 800 kVA	990 kVA / 936 kVA / 900 kVA	1,100 kVA / 1,000 kVA / 900 kVA	
20 kV	20 kV	20 kV	
6.6 to 35 kV	6.6 to 35 kV	6.6 to 35 kV	
50 Hz / 60 Hz	50 Hz / 60 Hz	50 Hz / 60 Hz	
● / ○	● / ○	● / ○	
26 A	29 A	32 A	
< 3%	< 3%	< 3%	
1 / 0.9 overexcited to 0.9 underexcited			
3 / 3	3 / 3	3 / 3	
97.4%	97.4%	97.5%	
97.2%	97.2%	97.2%	
Motor-driven DC load-break switch			
○ (Load-break switch with HV/HVR fuses or circuit breaker)			
Surge arrester type I			
● / ○ (via Sunny Portal)			
○ / ○	○ / ○	○ / ○	
○	○	○	
●	●	●	
I	I	I	
IAC A 20 kA 1 s	IAC A 20 kA 1 s	IAC A 20 kA 1 s	
6.058 m / 2.591 m / 2.438 m	6.058 m / 2.591 m / 2.438 m	6.058 m / 2.591 m / 2.438 m	
< 10 t	< 10 t	< 10 t	
● / ○	● / ○	● / ○	
< 1,900 W[3] / < 100 W + 630 W	< 1,900 W[3] / < 100 W + 710 W	< 3,800 W[3] / < 200 W + 770 W	
230 / 400 V (3 / N / PE), 50/60 Hz	230 / 400 V (3 / N / PE), 50/60 Hz	230 / 400 V (3 / N / PE), 50/60 Hz	
IP23D, IP00	IP23D, IP00	IP23D, IP00	
● / ○	● / ○	● / ○	
In unprotected outdoor environments / ○	In unprotected outdoor environments / ○	In unprotected outdoor environments / ○	
15% to 95%	15% to 95%	15% to 95%	
● / ○	● / ○	● / ○	
3,000 m^3/h	3,000 m^3/h	3,000 m^3/h	
Ring terminal lug	Ring terminal lug	Ring terminal lug	
Outer-cone angle plug	Outer-cone angle plug	Outer-cone angle plug	
LC graphic display			
Ethernet (optical fiber optional) / Modbus			
● / ○			
RAL 7004			
○			
○			
IEC 62271-202, IEC 62271-200, IEC 60076, IEC 61439-1			
1 x SC 720 / 760 / 800CP-XT	1 x SC 850 / 900CP-XT	1 x SC 1000CP-XT	
1 x SCS 720 / 760 / 800	1 x SCS 850 / 900	1 x SCS 1000	
MVPS 800SC 21	MVPS 900SC 21	MVPS 1000SC 21	

Annex 2: Solar PV Module Data Sheet

SunPower Offers The Best Combined Power And Product Warranty



More guaranteed power: 95% for first 5 years, −0.4%/yr. to year 25 [7]

Combined Power and Product defect 25-year coverage [8]

Electrical Data	
	SPR-X22-360-COM
Nominal Power (Pnom)[11]	360 W
Power Tolerance	+5/-3%
Avg. Panel Efficiency[12]	22.2%
Rated Voltage (Vmpp)	59.1 V
Rated Current (Impp)	6.09 A
Open-Circuit Voltage (Voc)	69.5 V
Short-Circuit Current (Isc)	6.48 A
Max. System Voltage	1000 V UL & 1000 V IEC
Maximum Series Fuse	15 A
Power Temp Coef.	−0.29% / ° C
Voltage Temp Coef.	-167.4 mV / ° C
Current Temp Coef.	2.9 mA / ° C

REFERENCES:

1 All comparisons are SPR-X21-345 vs. a representative conventional panel: 250 W, approx. 1.6 m², 15.3% efficiency.

2 Typically 8–10% more energy per watt, BEW/DNV Engineering "SunPower Yield Report," Jan 2013.

3 SunPower 0.25%/yr degradation vs. 1.0%/yr conv. panel. Campeau, Z. et al. "SunPower Module Degradation Rate," SunPower white paper, Feb 2013; Jordan, Dirk "SunPower Test Report," NREL, Q1-2015.

4 "SunPower Module 40-Year Useful Life" SunPower white paper, May 2015. Useful life is 99 out of 100 panels operating at more than 70% of rated power.

5 Highest of over 3,200 silicon solar panels, Photon Module Survey, Feb 2014.

6 1% more energy than E-Series panels, 8% more energy than the average of the top 10 panel companies tested in 2012 (151 panels, 102 companies), Photon International, Feb 2013.

7 Compared with the top 15 manufacturers. SunPower Warranty Review, May 2015.

8 Some restrictions and exclusions may apply. See warranty for details.

9 X-Series same as E-Series, 5 of top 8 panel manufacturers tested in 2013 report, 3 additional panels in 2014. Ferrara, C., et al. "Fraunhofer PV Durability Initiative for Solar Modules: Part 2". Photovoltaics International, 2014.

10 Compared with the non-stress-tested control panel. X-Series same as E-Series, tested in Atlas 25+ Durability test report, Feb 2013.

11 Standard Test Conditions (1000 W/m² irradiance, AM 1.5, 25° C). NREL calibration Standard: SOMS current, LACCS FF and Voltage.

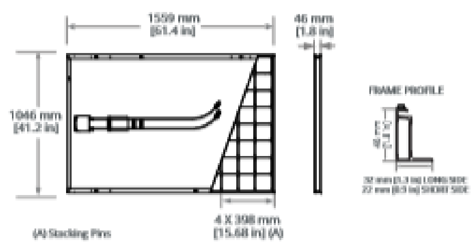
12 Based on average of measured power values during production.

13 Type 2 fire rating per UL1703:2013, Class C fire rating per UL1703:2002.

14 See salesperson for details.

Tests And Certifications	
Standard Tests[13]	UL1703 (Type 2 Fire Rating), IEC 61215, IEC 61730
Quality Certs	ISO 9001:2008, ISO 14001:2004
EHS Compliance	RoHS, OHSAS 18001:2007, lead free, REACH SVHC-163, PV Cycle
Sustainability	Cradle to Cradle Certified™ Silver (eligible for LEED points)[14]
Ammonia Test	IEC 62716
Desert Test	10.1109/PVSC.2013.6744437
Salt Spray Test	IEC 61701 (maximum severity)
PID Test	Potential-Induced Degradation free: 1000 V[9]
Available Listings	UL, TUV, JET, CEC

Operating Condition And Mechanical Data	
Temperature	−40° F to +185° F (−40° C to +85° C)
Impact Resistance	1 inch (25 mm) diameter hail at 52 mph (23 m/s)
Appearance	Class B
Solar Cells	96 Monocrystalline Maxeon Gen III
Tempered Glass	High-transmission tempered anti-reflective
Junction Box	IP-65, MC4 compatible
Weight	41 lbs (18.6 kg)
Max. Load	Wind: 50 psf, 2400 Pa, 244 kg/m² front & back Snow: 112 psf, 5400 Pa, 550 kg/m² front
Frame	Class 2 silver anodized; stacking pins



Please read the safety and installation guide.

See www.sunpower.com/facts for more reference information.
For more details, see extended datasheet: www.sunpower.com/datasheets.

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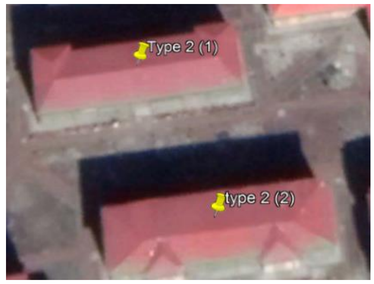
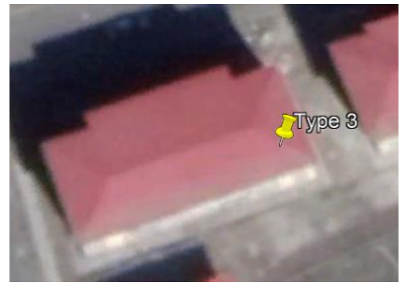
Annex 3: Building typologies in the condominium Sites

Type 1 (L1)



TYPE 2 (A1)



Type 3 (B2)

Type 4 (A2)

Type 5 (L2)

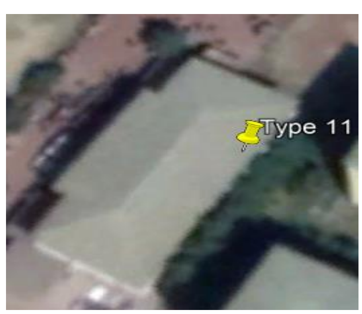
Type 6

Type 7 (L3)

Type 8

Type 9 (T16)

Type 10 (M2)



Type 11 (communal)

Annex 4: Default Emission Factors For Stationary Combustion In The Energy Industries (Kg Of Greenhouse Gas Per Tj On A Net Calorific Basis)

Table 2.2
Default emission factors for stationary combustion in the energy industries
(kg of greenhouse gas per TJ on a Net Calorific Basis)

Fuel		CO_2			CH_4			N_2O		
		Default Emission Factor	Lower	Upper	Default Emission Factor	Lower	Upper	Default Emission Factor	Lower	Upper
Crude Oil		73 300	71 100	75 500	r 3	1	10	0.6	0.2	2
Orimulsion		r 77 000	69 300	85 400	r 3	1	10	0.6	0.2	2
Natural Gas Liquids		r 64 200	58 300	70 400	r 3	1	10	0.6	0.2	2
Gasoline	Motor Gasoline	r 69 300	67 500	73 000	r 3	1	10	0.6	0.2	2
	Aviation Gasoline	r 70 000	67 500	73 000	r 3	1	10	0.6	0.2	2
	Jet Gasoline	r 70 000	67 500	73 000	r 3	1	10	0.6	0.2	2
Jet Kerosene		r 71 500	69 700	74 400	r 3	1	10	0.6	0.2	2
Other Kerosene		71 900	70 800	73 700	r 3	1	10	0.6	0.2	2
Shale Oil		73 300	67 800	79 200	r 3	1	10	0.6	0.2	2
Gas/Diesel Oil		74 100	72 600	74 800	r 3	1	10	0.6	0.2	2
Residual Fuel Oil		77 400	75 500	78 800	r 3	1	10	0.6	0.2	2
Liquefied Petroleum Gases		63 100	61 600	65 600	r 1	0.3	3	0.1	0.03	0.3
Ethane		61 600	56 500	68 600	r 1	0.3	3	0.1	0.03	0.3
Naphtha		73 300	69 300	76 300	r 3	1	10	0.6	0.2	2
Bitumen		80 700	73 000	89 900	r 3	1	10	0.6	0.2	2
Lubricants		73 300	71 900	75 200	r 3	1	10	0.6	0.2	2
Petroleum Coke		r 97 500	82 900	115 000	r 3	1	10	0.6	0.2	2
Refinery Feedstocks		73 300	68 900	76 600	r 3	1	10	0.6	0.2	2
Other Oil	Refinery Gas	n 57 600	48 200	69 000	r 1	0.3	3	0.1	0.03	0.3
	Paraffin Waxes	73 300	72 200	74 400	r 3	1	10	0.6	0.2	2
	White Spirit and SBP	73 300	72 200	74 400	r 3	1	10	0.6	0.2	2
	Other Petroleum Products	73 300	72 200	74 400	r 3	1	10	0.6	0.2	2
Anthracite		98 300	94 600	101 000	1	0.3	3	r 1.5	0.5	5
Coking Coal		94 600	87 300	101 000	1	0.3	3	r 1.5	0.5	5
Other Bituminous Coal		94 600	89 500	99 700	1	0.3	3	r 1.5	0.5	5
Sub-Bituminous Coal		96 100	92 800	100 000	1	0.3	3	r 1.5	0.5	5
Lignite		101 000	90 900	115 000	1	0.3	3	r 1.5	0.5	5
Oil Shale and Tar Sands		107 000	90 200	125 000	1	0.3	3	r 1.5	0.5	5
Brown Coal Briquettes		97 500	87 300	109 000	n 1	0.3	3	r 1.5	0.5	5
Patent Fuel		97 500	87 300	109 000	1	0.3	3	n 1.5	0.5	5
Coke	Coke Oven Coke and Lignite Coke	r 107 000	95 700	119 000	1	0.3	3	r 1.5	0.5	5
	Gas Coke	r 107 000	95 700	119 000	r 1	0.3	3	0.1	0.03	0.3
Coal Tar		n 80 700	68 200	95 300	n 1	0.3	3	r 1.5	0.5	5

	Fuel	CO2 Default Emission Factor	CO2 Lower	CO2 Upper	CH4 Default Emission Factor	CH4 Lower	CH4 Upper	N2O Default Emission Factor	N2O Lower	N2O Upper
Derived Gases	Gas Works Gas	n 44 400	37 300	54 100	n 1	0.3	3	0.1	0.03	0.3
	Coke Oven Gas	n 44 400	37 300	54 100	r 1	0.3	3	0.1	0.03	0.3
	Blast Furnace Gas	n 260 000	219 000	308 000	r 1	0.3	3	0.1	0.03	0.3
	Oxygen Steel Furnace Gas	n 182 000	145 000	202 000	r 1	0.3	3	0.1	0.03	0.3
Natural Gas		56 100	54 300	58 300	1	0.3	3	0.1	0.03	0.3

TABLE 2.2 (CONTINUED)
DEFAULT EMISSION FACTORS FOR STATIONARY COMBUSTION IN THE ENERGY INDUSTRIES
(kg of greenhouse gas per TJ on a Net Calorific Basis)

Fuel		CO_2			CH_4			N_2O		
		Default Emission Factor	Lower	Upper	Default Emission Factor	Lower	Upper	Default Emission Factor	Lower	Upper
Municipal Wastes (non-biomass fraction)		n 91 700	73 300	121 000	30	10	100	4	1.5	15
Industrial Wastes		n 143 000	110 000	183 000	30	10	100	4	1.5	15
Waste Oils		n 73 300	72 200	74 400	30	10	100	4	1.5	15
Peat		106 000	100 000	108 000	n 1	0.3	3	n 1.5	0.5	5
Solid Biofuels	Wood / Wood Waste	n 112 000	95 000	132 000	30	10	100	4	1.5	15
	Sulphite lyes (Black Liquor)[a]	n 95 300	80 700	110 000	n 3	1	18	n 2	1	21
	Other Primary Solid Biomass	n 100 000	84 700	117 000	30	10	100	4	1.5	15
	Charcoal	n 112 000	95 000	132 000	200	70	600	4	1.5	15
Liquid Biofuels	Biogasoline	n 70 800	59 800	84 300	r 3	1	10	0.6	0.2	2
	Biodiesels	n 70 800	59 800	84 300	r 3	1	10	0.6	0.2	2
	Other Liquid Biofuels	n 79 600	67 100	95 300	r 3	1	10	0.6	0.2	2
Gas Biomass	Landfill Gas	n 54 600	46 200	66 000	r 1	0.3	3	0.1	0.03	0.3
	Sludge Gas	n 54 600	46 200	66 000	r 1	0.3	3	0.1	0.03	0.3
	Other Biogas	n 54 600	46 200	66 000	r 1	0.3	3	0.1	0.03	0.3
Other non-fossil fuels	Municipal Wastes (biomass fraction)	n 100 000	84 700	117 000	30	10	100	4	1.5	15

(a) Includes the biomass-derived CO_2 emitted from the black liquor combustion unit and the biomass-derived CO_2 emitted from the kraft mill lime kiln.
n indicates a new emission factor which was not present in the 1996 Guidelines
r indicates an emission factor that has been revised since the 1996 Guidelines