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Quantifying The Greenhouse Gas Emissions and Carbon footprint of Activated Sludge Wastewater Treatment Plants

Case: The 13 UCBP-WWTPs of Ethiopia

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ABSTRACT

As many countries are increasing commitments to address climate change, national governments are exploring how they could best reduce the impact of their greenhouse gas (GHG) emissions. All sectors have contribution to the GHG problem. Neglecting the old thinking, providing end-of –pipe solution- that is WWTP for the protection of the environment is holistic; nowadays, new challenges are under consideration (GHG), oriented to ensure the sustainability of WWTPs in terms of their economic feasibility and environmental impact. The operation of wastewater treatment plants results in direct emissions, from the biological processes, of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), as well as indirect emissions resulting from fossil fuel consumption for energy generation. A carbon footprint is provided as a tool to quantify the life cycle GHG emissions and identify opportunities to reduce climate change impacts.

Basing their design future, process design data and current working conditions of the working -13-TPs; in this paper it is tried to investigate the GHGs generation potential of 15-UCBP-WWTPs, Following the life cycle approach; emission factors were used to calculate the carbon footprint. Then the possible solutions for the reduction of GHGs generation are tried to be provided.

The released GHGS in the TPs with Focal drawbacks:- indirectly from power consumption (67 - 170 t CO_2-e/year) to cover the energy demand of the plant , directly in Sewer network (13.69-2.62 t CH_4/year) due to improper ventilation system and poor operation practices, direct methane venting to the atmosphere in the Imhoof tank (46-12.88 t CH_4/year), Aeration tank (3.0-0.88t N_20/year), solid waste and sludge handling (119-35 t CO_2e/year) and fuel consumption (120.9-63t CO_2e/year) to substitute grid power supply.

Since the treatment plants are stand-in, considered and treated as the first demonstrating plants for providing training and showing the technology in the country; making the TP more environmentally friendly and sustainable though possible and mandatory modification works will give dual benefit to the country, the impact generated from the centers will reduce and better, improved, and up-to-date technical knowledge will be transferred.

Keywords: GHG, CO_2, CH_4, N_2O, Activated sludge WWTP

Table of content

List of Figure

LIST OF TABLES

LIST OF ABBREVIATIONS

AFU AGRICULTURE, FORESTRY AND LAND USE

ASTU ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

BAU BUSINESS AS USUAL EMISSION

BNR BIOLOGICAL NUTRIENT REMOVAL

BOD BIOCHEMICAL OXYGEN DEMAND

BOD_5 FIVE-DAY BIOCHEMICAL OXYGEN DEMAND

CFCs CHLORO FLORO CARBON

CO_2 CARBON DIOXIDE

COD CHEMICAL OXYGEN DEMAND

DS DRY SOLID

DO DISSOLVED OXYGEN

GIZ-IS GESELLSCHAFT FÜR INTERNATIONALE ZUSAMMENARBEIT INTERNATIONAL SERVICES

GHG GEREANHOUSE GASE

GWP GLOBAL WARMING POTENTIAL

INCFCCC INTERGOVERNMENTAL NEGOTIATING COMMITTEE FOR A FRAMEWORK CONVENTION ON CLIMATE CHANGE

LCA LIFE CYCLE ASSESSMENT

LULUF LAND USE, LAND USE CHANGE, AND FORESTRY

NMVOCs NON-METHANE VOLATILE ORGANIC COMPOUNDS

P.E. **POPULATION EQUIVALENT**

SNC SECOND NATIONAL COMMUNICATION

TPs TREATMENT PLANT

UCBP UNIVERSITY CAPACITY BUILDING PROGRAM

UN UNITED NATION

UNFCCC United Nations Framework Convention on Climate Change

UV ULTRAVIOLET RADIATION

WWTW WASTEWATER TREATMENT WORK

WWTP WASTEWATER TREATMENT PLANT

1. INTRODUCTION

It is marked that the increase in concentrations of greenhouse gases in the atmosphere continues to cause global warming, leading to adverse climatic changes. The propagation of these gases is mainly due to increased anthropogenic activities [8-10], including use of fossil fuels in transport and energy generation, land use changes and deforestation due to expansion of agriculture and settlements. The impacts of anthropogenic greenhouse gas emissions on the earth's climate system has been the subject of considerable study, legislation, debate, and international treaties over the past two decades; and anthropogenic releases of greenhouse gases (GHGs) into the atmosphere are now accepted as the cause of global changes in climate [5]. GHG emissions alter the climate system energy balance by absorbing infrared radiation that results in heat trapping within the surface troposphere [3-6]. The resulted Climate change has widespread negative implications for the economy, people, and the natural and built environment. The increased on global warming result more awareness about emissions of greenhouse gases (GHGs) worldwide.

As of any others human activities, the treatment of wastewater also has a significant environmental impact on global environment and the economy in terms of its contribution to greenhouse gases. Seeing the energy demand of wastewater treatment works (WWTW), only; it consumes a significant amount of energy derived from fossil fuels. With the recent climate change and concern, the increasing cost of electricity and the need to minimize the carbon footprint of an organization or an activity, the wastewater treatment works is considered dualistically as a challenge and an opportunity. In addition to CO_2 resulted from fuel consumption, the other main GHG generated by the treatment plant are N_2O and CH_4.

To search solution and resolve the problem GHGs worldwide, the UN General Assembly the Intergovernmental Negotiating Committee for a Framework Convention on Climate Change (INCFCCC) is established in 1990. The above efforts do well, and the United Nations Framework Convention on Climate Change (UNFCCC) came into power on 21 March 1994. The Kyoto Protocol passed in into force in February, 2005. The UNFCCC sets an overall framework for intergovernmental efforts to handle the challenge posed by global climate change [5].

The global community adopted the historic Paris Agreement in December 2015, which includes GHG mitigation actions covering the time period from 2020 onward [2]. It is the first international climate agreement to spread mitigation responsibilities to all countries, both developed and developing. The long-term goals of the Paris Agreement are ambitious: to limit temperature rise to "well below 2°C above pre-industrial levels" and pursue efforts to limit the rise to 1.5°C [2].

Ethiopia approved the UNFCCC on 31 May1994 and the Kyoto Protocol on 21^{t}February 2005 as a Non- Annex l party, thereby signifying its commitment to join the international community in combating the problem of climate change [26]. The final goal of this agreement and any related legal instruments that the Conference of Parties need to accept its' accomplishment, in harmony with the relevant provisions of the convention, stabilization of greenhouse gas concentrations globally. Today; Ethiopia is implementing the Climate Resilient Green Economy (CRGE) Strategy to achieve the vision of becoming a low carbon; middle income economy by 2030 [24].

Due to major agricultural activity in Ethiopia GHG emissions trend rose by 86% between 1993 and 2013, and contribute 0.3% of world total figure - 46,906 $MtCO_2e$). The solid by large and the wastewater treatment contribute around 31% of CH_4 emission in country. The data registered for the Emission of N_2O shows that around 85% of N_2O generated come from manure management (44%), agricultural soil management, energy generation and waste management.wastewater treatment and discharge contributed around 5% [23-25].

Forecasts designate that with population and economic growth, Ethiopia's level of emissions will grow significantly, from 150 million tonnes in 2010 to 450 million by 2030 [22-26]. Henceforward Ethiopia should focus both on mitigation and adaptation measures in order to reduce emission as well as build resilience and reduce susceptibility to the impacts of climate change [25, 26].

2. OBJECTIVES OF THE WORK

The Major objectives are:-

1. The main objective of the work is to identifying the greenhouse gas emission points in activated sludge wastewater treatment plants of 15 UCBP-WWTPs and quantified the amount of the emitted greenhouse gases and the carbon footprint of each of the treatment plants.
2. Providing operational solution for the reduction of the GHG generation in the treatment plants with in the defined boundary.
3. Indicating technological modification for minimization of the GHGs generation if possible.

3. LITERATURE REVIEW

3.1 Greenhouse Gases

Greenhouse gas (GHG) is a gases that are found in earth atmosphere, and absorbs and emits radiant energy within the thermal infrared range. These gases are mainly water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3). Greenhouse gases cause the greenhouse effect on planets [1, 2]. The greenhouse gases keep the average temperature of Earth's surface around 15 °C (59 °F) , in the absence of them; the temperature would be about −18 °C (0 °F), rather than the present value [9].

One thing about the global warming debate that well knows is that concentrations of several greenhouse gases in the atmosphere are increasing due to the activities of man and anthropogenic releases of greenhouse gases (GHGs) into the atmosphere are now accepted as the cause of global changes in climate [4]. The table shows Greenhouse gases, past and present concentrations and sources as well as the percentage increases since 1750 due to human activity.

Greenhouse gases have far-ranging environmental and health effects. They cause climate change by trapping heat, and they contribute to respiratory disease from smog and air pollution [1-4]. Dangerous weather conditions, problem in food supply, and increased wildfires are other effects of climate change caused by greenhouse gases. Scientist forecasted that; due to the effect of GHGs; the typical weather patterns we've known expected to be changed in the future; some species will disappear; others will migrate or populated and dominate [9].

The last column indicated the major natural and anthropogenic sources for each of the gases. Some of these greenhouse gases produced by humans have no natural sources. The production, the use and realize of ozone-depleting CFCs has been greatly reduced in recent years, and the concentrations of these chemicals in the atmosphere have happening to decline [6]. However, the ozone-friendly chemical substitutes that are now used for air conditioning, HFCs are also greenhouse gases [3, 7]; they do contribute to global warming, with 1000 to 3000 times that of CO2 [7]. In addition to the mentioned once; human activities discharge other greenhouse gases to the atmosphere, such as PFCs, and SF_6, that have an atmospheric lifetime of more than 1000 years. The amounts in escalation of these gases are entirely humans' fault. They are powerful greenhouse gases and today's emissions of these gases will still be affecting earth's climate in the next millennium [8]. The only discovered sinks for these greenhouse gases are light destruction (photolysis) or ion reactions in our mesosphere. The hybrid greenhouse gas of PFCs and SF6, which is SF5CF3 is a new worry. Development and discovery indicated it is the most powerful greenhouse gas discovered until now and whose concentration is rising rapidly [10].

The over increasing concentrations of ozone in the troposphere related to photochemical smog is also a concern. *Figure-1* shows the percentage of GHG emitted in 2019 and the *Table-1* indicated the global warming potential of the GHG and *Table-2* illustrates the concentrations of GHGs that are given in either ppm (parts per million) or ppb (parts per billion), or ppt (parts per trillion). From the figure-1 carbon dioxide makes up 76% of all human emissions of greenhouse gases, with methane and nitrous oxide making up another 22%. The F-gases, which include the other gases in the table, except ozone, only make up about 2% of the total greenhouse gas emissions. The top figure in *Figure-1* shows the percentage of greenhouse gas emissions that are associated with different economic sectors

Table: 1. 100-Year Global Warming Potentials (GWP) For Selected Greenhouse Gases [4].

Gas	GWP
Carbon dioxide (CO_2)	1
Methane (CH_4)	28
Nitrous oxide (N_2O)	310
Hydrofluorocarbons (HFCs)	560-12,100
Perfluorocarbons (PFCs)	6,000-9,200
Sulfur hexafluoride (SF_6)	23,900

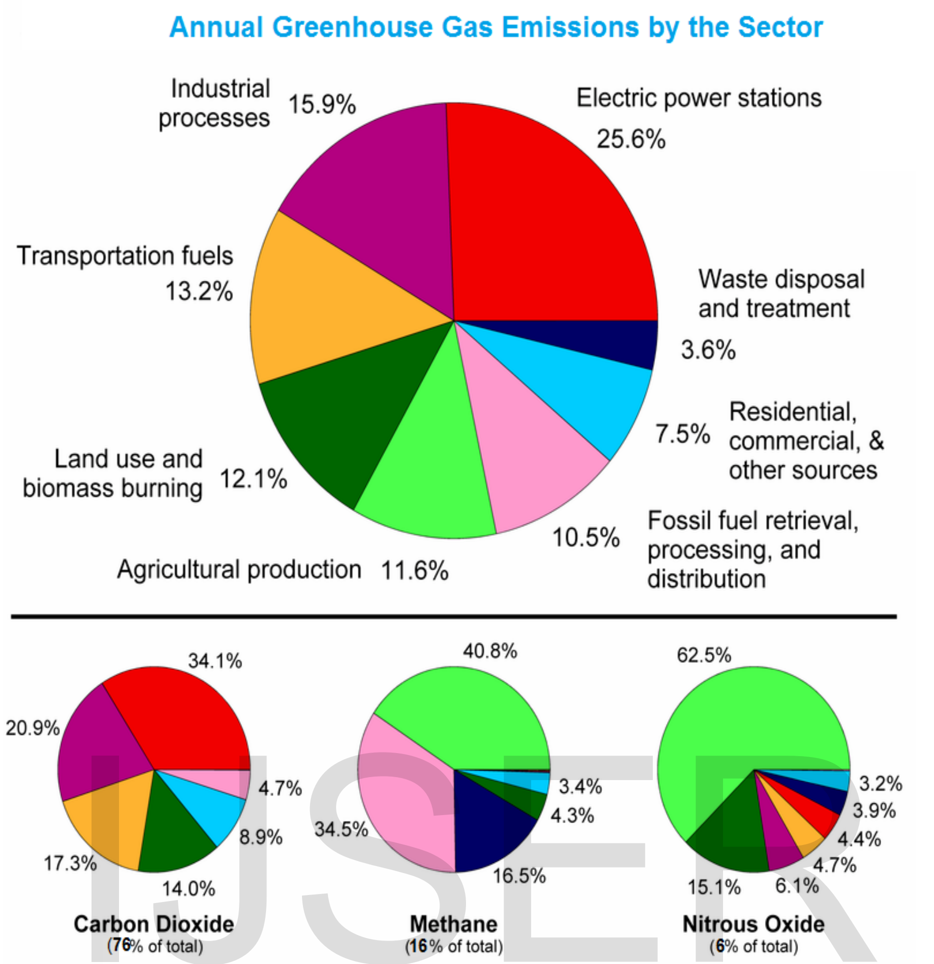

Figure: 1- World Annual GHG Emission by sectors

This figure illustrates the comparative portion of anthropogenic greenhouse gases coming from each of eight categories of sources [6]. These values are intended to provide a snapshot of global annual greenhouse gas emissions in the year 2019 (43 billion tons CO_2). The top panel shows the sum over all anthropogenic greenhouse gases, weighted by their global warming potential over the next 100 years. This contains of 76% carbon dioxide, 16% methane, 6% nitrous oxide and 3% other gases. Lower part demonstrates the comparable information for each of these three primary greenhouse gases; Segments with less than 1% fraction are not labeled.

Table: 2- Greenhouse Gases, Past and Present Concentrations and Sources.

Greenhouse gas	Concentration 1750	Present concentration	Percent change	Natural and anthropogenic sources (in bold)
Carbon Dioxide (CO_2)	280 ppm	415 ppm [2]	46 %	The vast majority of anthropogenic carbon dioxide emissions come from combustion of fossil fuels, principally coal, oil, and natural gas, with additional contributions coming from deforestation, changes in land use, soil erosion and agriculture (including livestock). Other source Organic decay; Ocean outgassing; Forest fires; Volcanoes [2, 4].
Methane (CH_4)	0.722 ppm [4,6]	1.858ppm [4,6]	157 %	Termites; The leading source of anthropogenic methane emissions is animal agriculture, followed by fugitive emissions from gas, oil, coal and other industry, solid waste, organic decay, wastewater and rice production [3,4].
Nitrous Oxide (N_2O)	270 ppb	328 ppb	21.5 %	Forests; Grasslands; Oceans; Soils; Soil cultivation; Artificial Fertilizers; Biomass burning; Burning of fossil fuels
Chlorofluorocarbons (CFCs) and Hydrochlorofluorcarbons (HCFCs)	0	1106 ppt	Not Applicable	Refrigerators; Aerosol spray propellants; Cleaning solvents; Banned to protect Ozone layer
Hydrofluorocarbons (HFCs)	0	84 ppt	Not Applicable	Ozone-friendly CFC substitute used mostly for refrigeration and air conditioning
Perfluorocarbons (PFCs)	34 ppt	82 ppt	141%	Minute quantities exist naturally; Aluminum smelting; semiconductor industry [3].
Sulfur hexafluoride (SF_6)	0	8.6 ppt	Not Applicable	Used in equipment for transmission of electricity, and various industrial applications
Tropospheric Ozone (O_3)	237 ppb	337 ppb	42 %	Created artificially through photochemical smog production

3.2 Greenhouse Gases Emission in Ethiopia

The environmental impact of GHG is global and so the activity and the emission related to these gases by one country on one part of the world has direct effect on the other countries on the other party of the world. Due to this fact; all over the world the topic is treated almost equally. Climate change resulted from environmental degradation –GHGs emission is already taking place in Ethiopia, over the last decades, the temperature in the country increased at about 0.2° C per decade. The increment in minimum temperatures is more pronounced with roughly 0.4° C per decade [21].

According to European Commission, [22] in 2011 the emission by the eight countries in East Africa indicated that East Africa is responsible for only 1.43% of global emissions of GHG. Except CAR, where per capita emissions are more than twice the world average, on a per capita basis, the region's emissions are 2.5 times below the world average. But the GHG emissions with respect to GDP are very high, ranging from 1.5 times the world average in Djibouti and Rwanda to 37.5 times in the CAR. These results put the east Africa the high regional GDP carbon intensity, the value is eight times the world average. Within the region since 1990; most rapidly, total GHG emissions is registered by Ethiopia, where emissions have grown 86%, resulted by the increase in agriculture sector emissions basically due to livestock-related activities [22-24].

Based on the Second National Communication (SNC) summited in 2015 to UNFCCC; the total national emissions and removals of Ethiopia was estimated to be 146 $MtCO_2e$ for 2013. This includes about 1 $MtCO_2e$ from international bunkers. In Ethiopia the primary gases, Methane and carbon dioxide, are main gases generated by human activities. In 2013, methane and carbon dioxide covered about 52 and 26 per cent of all greenhouse gas emissions from human activities in the country respectively. Figure 2 and 3 indicates agriculture, forestry and other land use (AFOLU) have been responsible for about 115 $MtCO_2e$, nearly 80% of Ethiopia's total greenhouse gas (GHG) emissions. With 22 $MtCO_2e$, the energy sector contributed a share of about 15%, 7 $MtCO_2e$ -5% is registered by the waste sector, Industrial processes and product use only have a portion of about 1% of Ethiopia's total emissions (nearly 2 $MtCO_2e$) [26].

CO_2 emitted largely by cropland and grassland at 59 per cent and 33 per cent while the transport sector generated only 3 per cent. Mostly; CH4 emissions were from fermentation associated with domestic livestock, at 26 per cent, other energy sector which is primarily from the use of fuel wood and wood waste in the residential and commercial institutions at 26 per cent, and solid waste disposal and decomposition at 25 per cent. The other sources of methane included wastewater treatment and discharge responsible for (6 per cent), manure management and biomass burning (5 per cent) each, rice cultivation (3 per cent), transport (2 per cent), solid fuels (coal) and energy industries (1 per cent) each [24-26].

Nitrous oxide was major contributed of from manure management at 44 per cent with direct emission account about 38 % while the indirect emission is registered 6%. This was followed by direct and indirect N_2O emissions from managed soils, at 24 per cent and 16 per cent respectively.

The fuel burning activities, energy consumption at residential and commercial sectors, and wastewater treatment and discharge contributed around 15 percent with almost equal figure for each. This shows that manure management, agricultural soil management, energy generation and waste management were the major sources of N_2O emissions in the investigated year.

Despite the population and expected economic growth to overcome Poverty rate of ~22% [25]; Ethiopia is expected to limit 2030 greenhouse gas emissions at 145 MtCO2e, a 64 percent reduction from projected business as usual emission (BAU) levels in 2030. The pledge includes greenhouse gas reductions from agriculture, forestry, industry, transport and buildings sectors [22, 23].

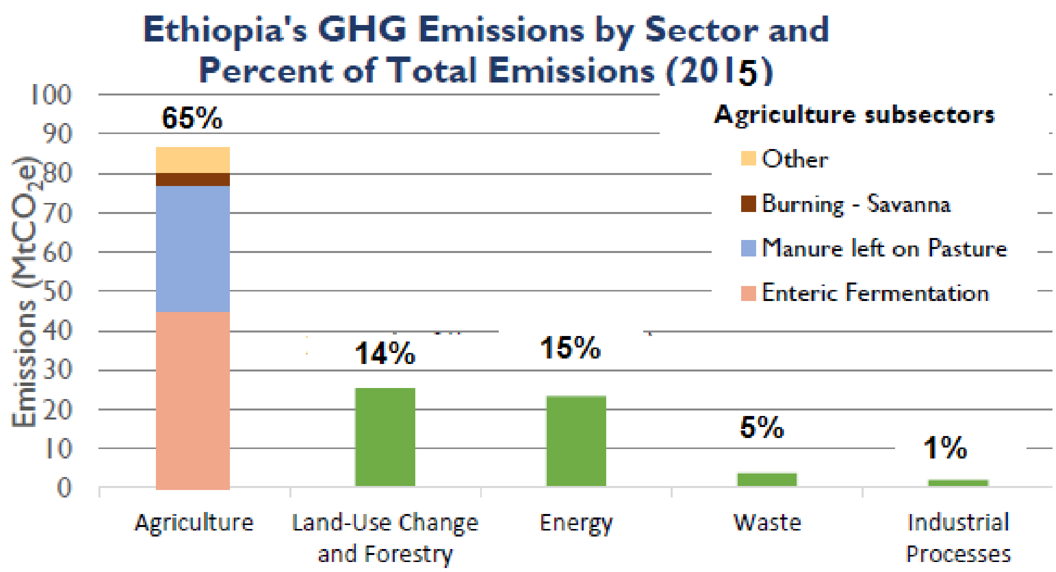

Figure 2: Ethiopian GHG Emissions by Sector for 2015[Draw form 23 data].

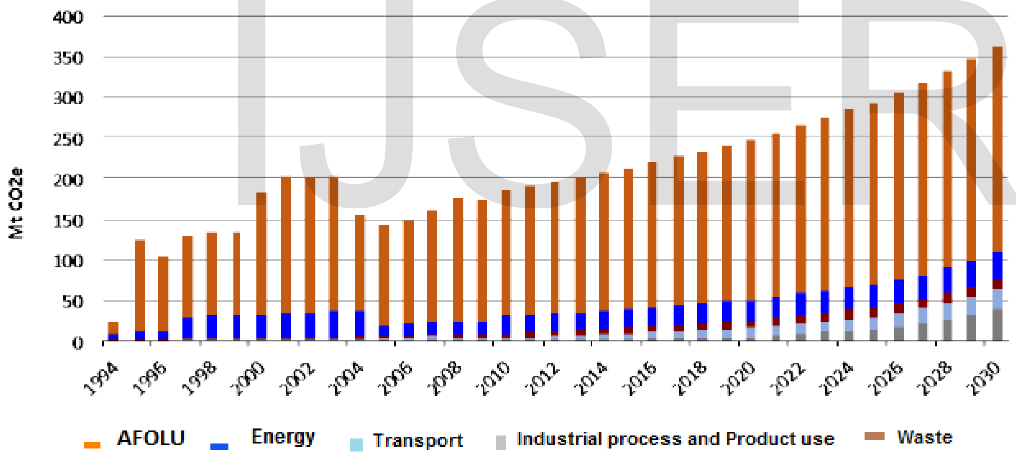

Figure 3: Historical emissions 1994-2009 and projected emissions 2010-2030 (Mt CO2e) [26].

3.3 Wastewater Treatment Plant and Greenhouse Gases Emission

The principal objective of wastewater treatment is generally to allow human and industrial effluents to be disposed of without danger to human health or unacceptable damage to the natural environment. In the past years most efforts to improve wastewater treatment plants (WWTPs) performance have been focused on obtaining a good effluent quality [1, 3, and 4]. However nowadays, new challenges are under consideration, concerned with to ensure the sustainability of WWTPs in terms of their economic feasibility and environmental impact. Energy consumption and greenhouse gases (GHG) emissions are among the aspects that have become key-factors concerning the overall performance of the WWTPs [2]. The amount of energy needed for operations varies depending on effluent characteristics, treatment technology, required effluent quality, and plant size [5]. Energy is required at every stage of the treatment plant, including pumping, mixing, heating, and aeration. The one of the largest energy consumers in the treatment plant are aeration equipment [6].

The demand for energy is increasing in many treatment processes and so WWTPs are considered as a sector that consume a significant amount of energy derived from fossil fuels, this is due to more strict treatment requirements and/or poorer quality source water options, among other reasons [4-5].

Latest researchers have acknowledged the WWTPs as potential sources of anthropogenic GHG emissions, contributing to climate change and air pollution [8–10]. WWTPs produce carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) during the biological wastewater treatment processes and CO_2 is also emitted during the production of the energy required for the plant operation [5-10]. Due to these facts, wastewater processing sector is acknowledged to be seen and taken as a significantly impact producer on the global environment and economy in terms of its contribution to greenhouse gases. In other word; from an energy point of view, wastewater treatment works (WWTW), with the recent climate change focus, the escalating cost of electricity and the need to reduce the carbon footprint of an organization or an activity, the wastewater treatment works is viewed dualistically as a challenge and an opportunity.

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3.3.1 Carbon dioxide CO_2

CO_2 is produced both indirectly as a result of fossil fuel combustion for energy generation that is required for the operation of waste water treatment plants (WWTPs), and it is produced during the degradation of organic matter during the treatment process [12-16].

The CO_2 released in wastewater treatment works due to the energy demand can be directly reduced by enhancing the energy efficiency of the WWTPs. In this way both the reduction of environmental impacts and the decrease of treatment costs by enhancing the energy savings can be accomplished simultaneously [5-7]. But the latter emissions are considered as short-cycle CO2 that does not contribute to increasing atmospheric CO2 concentrations; that means it is taken as biogenic origin. Studies pointed out that up to 20% of the carbon present in wastewaters can be of fossil origin [18-20] and fossil CO_2 emissions from wastewater treatment believed were underestimated previously [19].

3.3.2 Nitrous oxide (N_2O)

N_2O is mainly released during biological nitrogen removal in biological nutrient removal (BNR) plants. It is emitted by nitrification and denitrification processes used to remove nitrogenous compounds from wastewater. Its production occurs mainly in the activated sludge units (90%) while the remaining 10% comes from the grit and sludge storage tanks [11]. N_2O gas is an intermediate of biological processes such as heterotrophic denitrification and nitrification.

Nitrifying bacteria are able to produce N_2O under aerobic or anoxic [15] conditions. In anoxic conditions, both ammonia- and nitrite-oxidizing bacteria are able to produce it, while only ammonia-oxidizing bacteria do it in aerobic conditions. In the latter case, the production is stimulated by the presence of low DO concentrations and presence of nitrite or organic matter in the liquid media [12, 13]. Nitrous oxide can be produced also from chemical reactions taking place in the presence of hydroxylamine and nitrite [16].

In practice nitrous oxide is emitted in the WWTP predominantly in the aerobic tank [17]. However, the contribution of the anoxic and aerobic reactors to this production remains still unclear since it can be produced in the anoxic stage and be subsequently stripped to the gas phase in the aerated compartment [18]. Ammonia-oxidizing bacteria have been identified as the main N_2O producers while heterotrophic denitrifying bacteria contribution is only relevant when nitrite and/or oxygen are present in the anoxic stage [19]. According to Tallec et al. [20], under common operational conditions, the N_2O production occurs mainly via denitrification by nitrifying bacteria. However hydroxylamine oxidation pathway can be the main process responsible for the production of N_2O emissions at high ammonia and low nitrite concentrations, when a high metabolic activity of ammonia-oxidizing bacteria is present (at 2 to 3 mg O_2/L) [19].

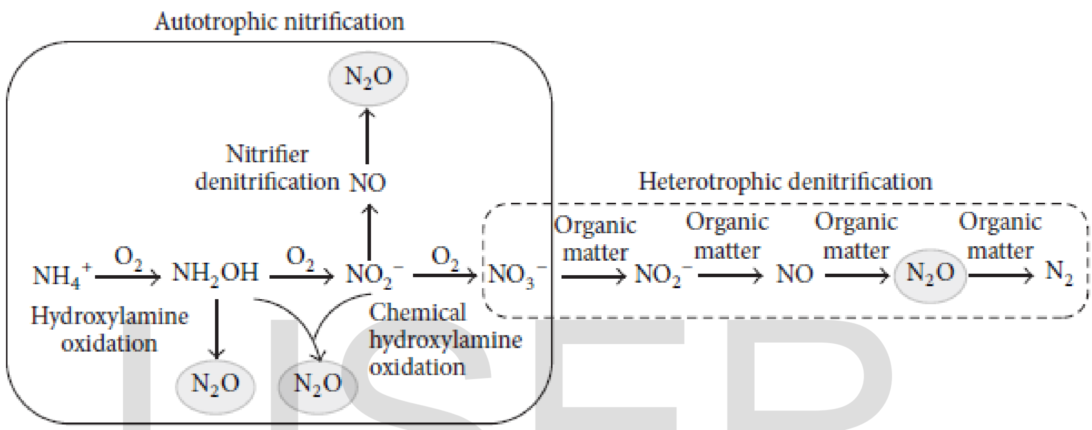

Figure 4: the Biological and chemical pathways of nitrification and denitrification production of processes of N2O production.

Comparing the process with the nature; the microbial nitrogen transformation processes in a wastewater treatment plant are fundamentally the same as in other environments such as soil, marine and freshwater habitats. However, unlike most other environments, wastewater treatment plants are engineered systems designed to achieve high nitrogen conversion rate.

There are several key features that distinguish these plants from other environments:

- Domestic wastewater usually contains relatively high concentrations of nitrogen, around 20–70 mg l^{-1} total nitrogen as N. In order to attain almost complete nitrogen removal within 3–8 h, high nitrogen loading rates are applied, incurring relatively high nitrification and denitrification rates [10]. These are expected to impact on the rate of N_2O production.
- Bacterial communities in the plants are subjected to rapid changes in process conditions that are applied to promote aerobic or anoxic microbial reactions. Such rapid changes in

environmental conditions probably cause physiological stress to both the nitrifying and denitrifying communities, with the potential to induce transient behaviors.

- Active aeration is used to induce aerobic conditions. The aeration systems are engineered to efficiently provide oxygen to the bioreactor, which also enables efficient transfer of N_2O from the liquid phase to the gas phase. Therefore, any temporary imbalance between N_2O production and consumption could result in accumulation and then stripping of N_2O during aeration.
- Given that wastewater treatment systems are highly engineered systems, there are opportunities to mitigate N_2O emissions by improving process design and/or operational conditions

To remove nutrient from the wastewater in order to reduce the eutrophication of water bodies; countries are putting strict regulation to adopt better technology for BNR. And also; there are various configurations of BNR plants that can achieve high levels of nitrogen as well as phosphors removal from wastewater by promoting nitrification, denitrification and biological and non-biological phosphors removal technics in different reaction zones [8].

Other studies have highlighted the trade-offs between eutrophication and global warming impact categories caused mainly by effluent discharge, sludge treatment and disposal, and electricity use [2, 8]. Driven by more stringent wastewater discharge standards aimed at improving the aquatic environment by alleviating eutrophication arising from anthropogenic nutrient source, BNR is being increasingly applied at WWTPs. The overall trend, in the finding therefore is toward increasing energy consumption and chemical dosage per unit of wastewater treated.

2.3.3 Methane CH_4

With regard to CH_4 emissions, Daelman et al. [29] found out that about 1% of the incoming chemical oxygen demand (COD) to the WWTPs was emitted as methane. This amount exceeds the amount of carbon dioxide emission that was avoided by utilizing the produced biogas in anaerobic digestion. The main sources of methane detected by these authors were related to the sludge line units where anaerobic digestion is carried out: the primary sludge thickener, the centrifuge, the exhaust gas of the cogeneration plant, the buffer tank for the digested sludge, and the storage tank for the dewatered sludge. These units contribute to around 72% of methane emissions of the WWTPs while the remaining emissions come from the biological reactors and can be mainly attributed to the CH_4 dissolved in the wastewater which is not totally removed by the biological system. Research works of Chunyan Chai et al. [20] and Rodriguez-Garcia et al. [23] also showed that most of the methane emissions from WWTPs are closely related to processes involved in the sludge line.

With respect to CO_2 its production is attributed to two main factors: biological treatment process and electricity consumption. In the main stream of the WWTP the organic carbon of wastewater is either incorporated into biomass or oxidized to CO_2. In the sludge line, it is converted mainly to CO_2 and CH_4 during anaerobic digestion and, finally, methane is oxidized to CO_2 during biogas combustion.

And also Methane is expected to be detected in sewer network lines and at the entrance of the treatment plant. That means; wastewater treatment facilities that receive wastewater from collection systems, particularly pressurized sewers and gravity-fed sewers that are closed can liberate CH_4 in aerobic systems from dissolved CH_4 that enters the treatment system [21].

In wastewater facility, burning of waste is practiced in handling of the screening from screen unit. The burning of the solid waste might be carried out in open burning or controlled burning. Open burning of waste can be defined as the combustion of unwanted combustible materials such as paper, wood, plastics, textiles, rubber, waste oils and other debris in nature (open-air) or in open dumps, where smoke and other emissions are released directly into the air without passing through a chimney or stack [10-15]. Open burning can also include incineration devices that do not control the combustion air to maintain an adequate temperature and do not provide sufficient residence time for complete combustion. This waste management practice is used in many developing countries while in developed countries open burning of waste may either be strictly regulated, or otherwise occur more frequently in rural areas than in urban areas [13]. Relevant gases emitted include during the process are CO_2, methane (CH_4) and nitrous oxide (N_2O). Normally, emissions of CO_2 from waste incineration are more significant than CH_4 and N_2O emissions. As per 1996 Guidelines (IPCC, 1997), only CO_2 emissions resulting from oxidation, during incineration and open burning of carbon in waste of fossil origin (e.g., plastics, certain textiles, rubber, liquid solvents, and waste oil) are considered net emissions and is included in the national CO_2 emissions estimate. Other traditional air pollutants from combustion - non-methane volatile organic compounds (NMVOCs), carbon monoxide (CO), nitrogen oxides (NOx), and sulphur oxides (SOx) are also expected to be generated in the solid waste handling system of the wastewater treatment plant. Biomass materials (e.g., paper, food, and wood waste) contained in the waste is biogenic emissions and is not included as GHG.

3.4. Boundaries to Estimate GHG Emissions in A WWTP

Assessments of Greenhouse Gas emissions generally divide facilities emissions into three areas or "scopes"

Scope 1: includes the direct greenhouse gas emissions, "Direct GHG emissions occur from sources that are owned or controlled by the company" (The Greenhouse Gas Protocol Initiative 2004). The CO2 emissions from combustion of biomass are not included in this scope.

Scope 2: includes beside the direct GHG emissions from Scope 1 also the GHG emissions that occur from the use of electricity. By the Greenhouse Gas Protocol Initiative, 2004 the extra emissions are described as: "GHG emissions from the generation of purchased electricity consumed by the company". The purchased electricity is the electricity bought by the plant or brought into the organizational boundary of the plant. The actual GHG emissions occur during electricity generation and thus not at the plant. However due to the use of electricity of the plant these emissions need to be added to the emissions of the plant according to Scope 2. For a WWTP this would include for example the emissions of the power used for aeration.

Scope 3: includes besides the GHG emissions of Scope 1 and 2, also other indirect GHG's. This is applicable to emissions from "sources not owned or controlled by the company" For WWTP this is for example the GHG emissions that occur during the production of the chemicals that are used in the WWTP.

To estimate the GHG emissions of the wastewater treatment plants (WWTP) in a comparable way the considered emissions have to be listed. Bridle Consulting, 2007 indicated the better boundaries in WWTW are from Scope-3 are listed below:

- CO_2 and N_2O emissions at bio treatment, endogenous respiration, BOD oxidation nitrification CO_2 credit and nitrogen removal
- Energy use of plant, for aeration, mixing and pumping which leads to CO_2 emissions
- Sludge digestion, biogas CH_4 and CO_2
- Sludge disposal, truck emissions trip to reuse/disposal site, CO_2 emissions mineralization
- GHG emissions from chemical use

3.5 UCBP-WWTPS of Ethiopia

3.5.1 Overall Process Description

In the UCBP- generally; the Universities wastewater treatment plant is employed the activated sludge technology with anaerobic sludge digestion, followed by sludge drying.

The first stage in the wastewater treatment plant is the screening for the removal of coarse material that, if not removed, would damage the subsequent equipment and reduce process effectiveness. Generally, the screen is installed before grit removal units (Sand trap). The Sand Trap removes grit consisting of sand, gravel and other heavy solid materials that have subsiding velocities or specific gravities substantially greater than organic putrescible solids.

A primary sedimentation is used to remove the un-dissolved organic material from the wastewater and therefore reduces the pollution load in the following biological process steps. The removed organic material, named as primary sludge, mainly contains of readily biodegradable agents and is perfectly suited for further anaerobic digestion due to its high methane yield.

The second stage in the wastewater treatment plant is the activated sludge process. This process is a common treatment method and has been implemented worldwide. The aeration tanks are dimensioned for the carbonaceous BOD and COD removal (removal rates up to 90 - 95%) and for nitrification and de-nitrification for the nitrogen removal.

After some time, the mixture of biological solids is passed from the aeration tanks into the final sedimentation tank, where some of the settled sludge is recycled to maintain the desired concentration of organisms in the reactor. The remaining sludge is removed from the system and discharged to the Imhoff Tanks for the digestion and ultimately to SDBs for the dewatering prior to the composting.

The final sedimentation tank is designed under the following considerations:

- Good separation of activated sludge from the aeration tanks effluent.
- Partial consolidation of the settled solids for return to the aeration tank.
- Intermediate storage of activated sludge which is expelled from the aeration tank.

The sludge treatment has the following units:

- Anaerobic stabilisation of sludge in the Imhoff Tanks.
- Dewatering of sludge in sludge drying beds.

The sludge collected from primary and secondary sedimentation is allowed to digested and stabilized anaerobically in the Imhoff Tanks. The digested and stabilized sludge is then sent to sludge drying beds where sludge dewatering and drying takes place. The dewatered sludge is further composted and used as fertilizer or land filled.

See figure 5 and 6 for detail

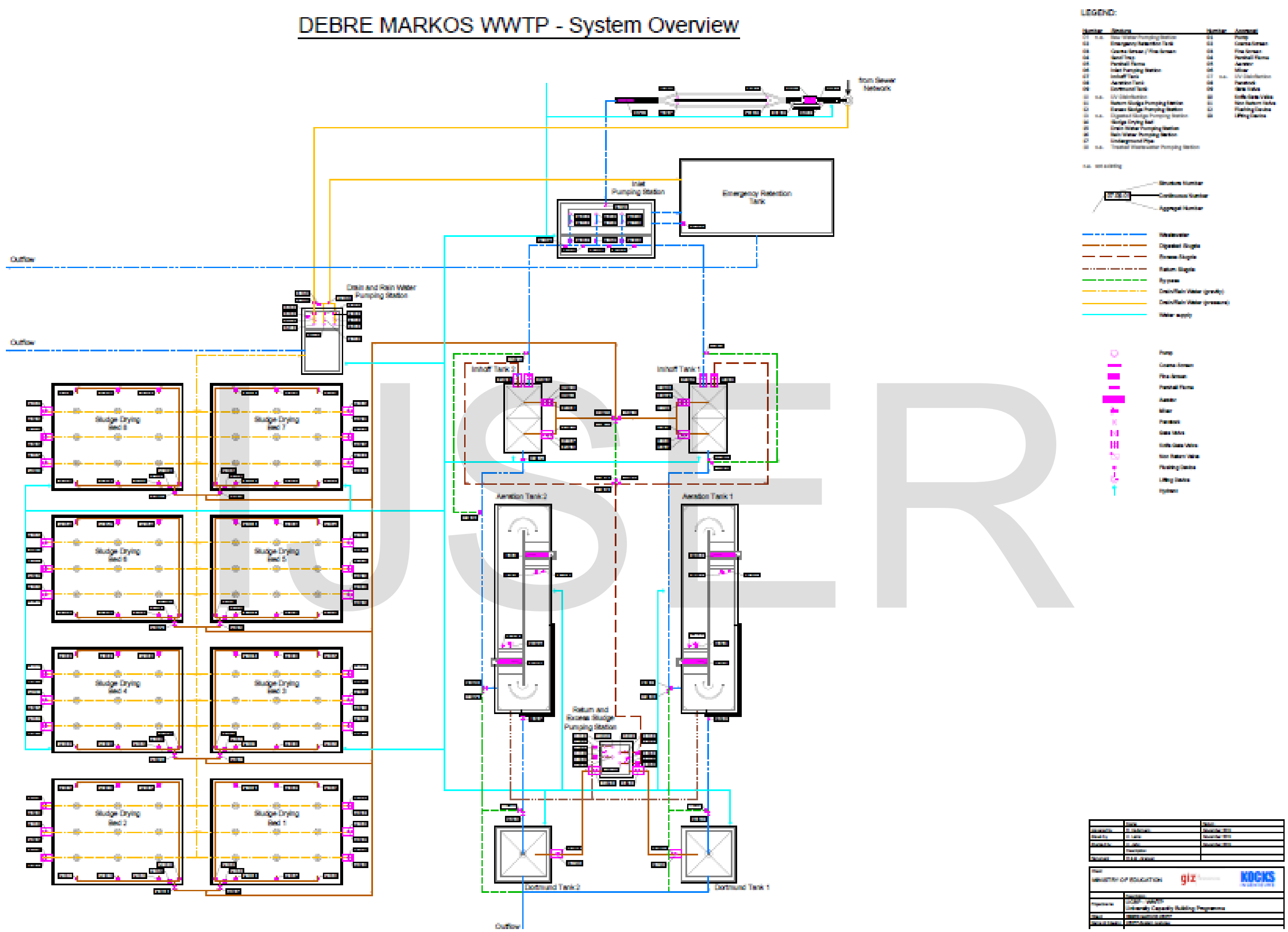

Figure 5: System Overview of the 14,000P.E WWTP of the UCBP –Debremarkos University

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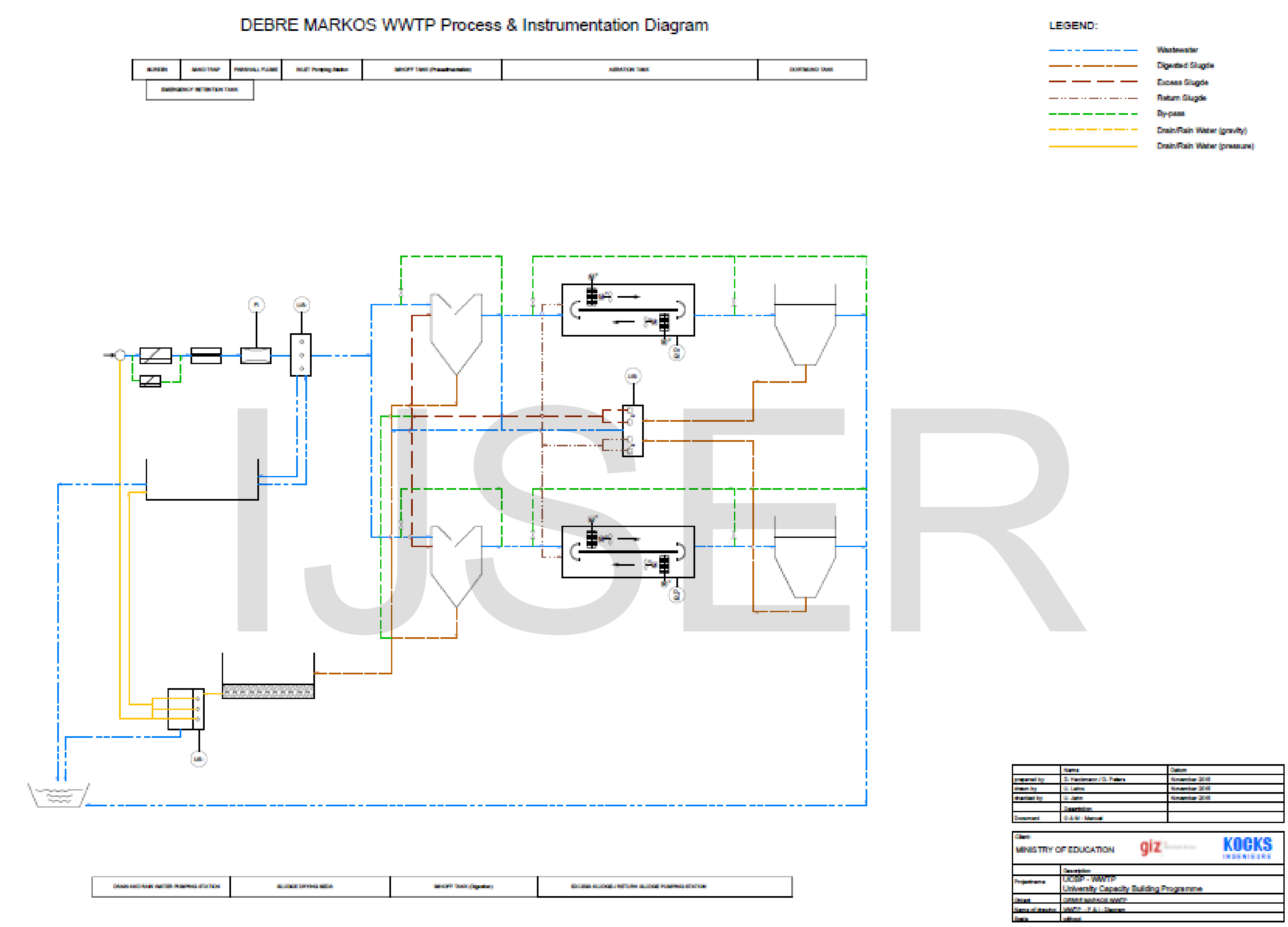


Figure 6: Process Flow Diagram of the 14,000 P.E WWTP of the UCBP without UV-Disinfection Unit–Debremarkos University

3.5.2 Power source for the treatment plants

The wastewater treatment plant is connected to the public grid. A transformer with 315 kVA is installed to delivere the requered Electric Power. The total required power of the whole WWTPs ranged from 77.5 to 169 kW depending up of the amount of whater process, the level of treatment and the number of pump installed basing the site/plants layout. In case of shortage in public power supply, a Diesel generating set (100 kVA) with automatic transfer switch is integrated. But due to the power supply problem from puplic grid, in a numbers of the TPs ; the energey demand is mostlly covered by Diesel generater (Aksum, DB, DM,)

4. MATERIALS AND METHODS

4.1 Definition of Carbon Footprint and System Boundary

The figure7 below indicates the selected system boundary of the study. Except the polishing pond; the boundary includes all unit operation involved in the treatment of the wastewater. The pond is isolated because the unit mainly acts for storage of the treated wastewater before discharged to the environment; no major reaction is expected to takes place.

The carbon footprint in this study was defined as direct and indirect GHG emissions caused by wastewater and sludge treatment within the given boundary. All relevant forms of the energy demand (electricity, heat, fossil fuels) and GHG emissions (carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) are accounted in the carbon footprint assessment.

The accounted GHG emissions converted into carbon dioxide equivalents (CO_2-eq) by global warming potentials (GWPs) over 100 years, namely, 1 for CO_2 28 for CH_4 and 310 for N_2O. It is necessary to be noted that although CO_2 emissions from biological wastewater treatment is generally not considered in GHG inventory of wastewater treatment because of its biogenic origin, some studies pointed out that up to 20% of the carbon present in wastewaters can be of fossil origin [17] and fossil CO_2 emissions from wastewater treatment were underestimated [18]. So; 20% is taken into account when quantifying the associated impact. Within the defined system boundary several flows of GHG emissions were estimated and compared among different treatment scenarios.

The calculation included:-

- Direct GHG emissions from wastewater treatment (e.g., CO_2 emissions from organic matters degradation and N_2O emissions from the nitrification/de-nitrification process) and sludge treatment (e.g., CH_4 and N_2O emissions from anaerobic digestion),
- Indirect GHG emissions from sludge final disposal, indirect emissions from production and transportation of construction materials, electricity use and chemicals consumption during operation, and transport of sludge.

- Studies indicated that the environmental impacts of construction are much less than those of operation in the case of wastewater treatment works and are usually are neglected in most life cycle assessment (LCA) studies, therefore the generation of GHG emission is neglected in this study. The function unit is defined as the treatment of wastewater in one year.
- Emissions from electricity consumption are calculated by applying an “emission factor” to the quantity of electricity consumed by the TPs. It is assumed that for 5/months the grid power supply is replaced by the stand-by generator. I.e. for 5 days/month*12month= 60 days. The emission factor For Ethiopia Electricity-specific factors (kgCO2/kWh) is 0.118948451 or IEA composite electricity/heat factors 0.1185277 (kgCO2/kWh) [22].
- To consider the CF of power generations using the Diesel stands by generator; it is assumed the generator is used to replace the grid power supply for 4 hrs/ days for all TPs in spite of the fact that the disruption of the main line for some of the TPs worse than the other and some TPs like Semera found full power supply from the grid. I.e. the generator is working rough estimated for 5 days per month (4 hrs*30days=120 hrs, 120/24 =5days). The emission factor considered for a diesel generator in the literatures is 1.27 kg, CO2/kWh [6], 3.15 kgCO2/l [6] and 3.50 kgCO2/l [6]. Based on the power demand of the TPs ;the Diesel Fuel Consumption is taken at different load

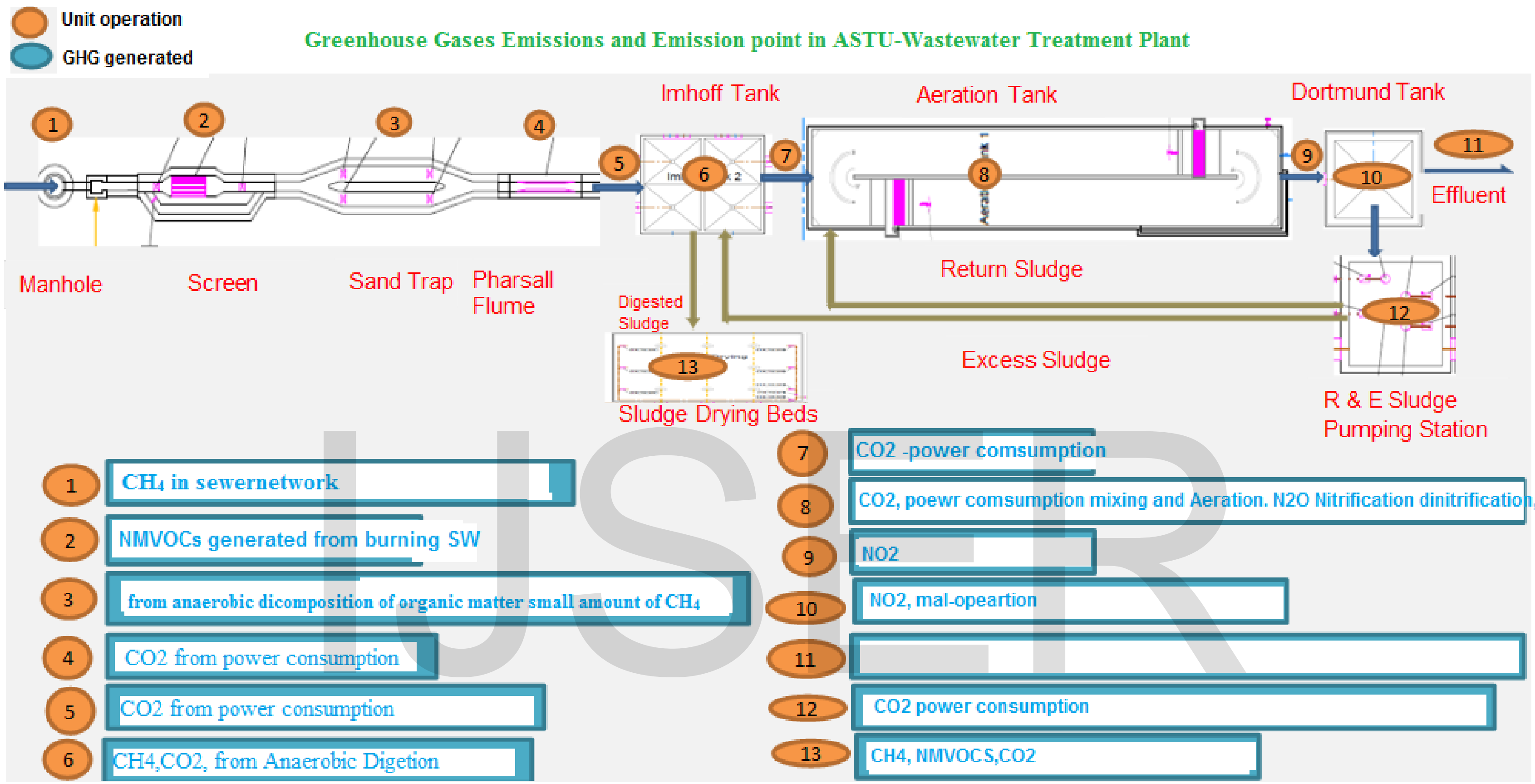


Figure 7: Greenhouse Gases Emission process units in the WWTPs

4.2 Data and Assessment

- The 15 wastewater treatment plant is sub-divided in to 4 types of treatment plant based on the flow rate accommodated in to the system or population equivalent as shown in Table 3.
- Parameters of process configurations were developed from WWTPs design documents and other standard documents.
- The treatment plants have also some difference in the unit operations. Some of the treatment plant use more pumps to operate other use less number of pumps. There is an additional unit operation, which is UV-disinfection unit in four of the treatment plants. These differences will only bring in the amount of CO_2 emission from power consumption. Therefore it is incorporated while handling each plant separately.
- Four different flow rates are considered table
- To estimate or calculate the GHGs; 2006 IPCC Inventory Guidelines is used which follows a top–down approach, for which technology-specific emission factors are not taken into consideration
- The total GHG emissions from wastewater and sludge treatment were calculated by using the method of emissions factors, as shown in Equation (1).
- Emission factors were mostly taken from literature table. But emission factors of electricity used in this study is taken based on national electricity in Ethiopia [22],

Table 3: Flow rate and PE of the treatment plants

Type	PE	Flow rate (m^3/day)	Plant
1	25,000	5616	Adama
2	14,000	3144	Aksum, Diredawa, Nekemte, Sodo, Dila, Debremarkos, Debre biran
3	10,000	2256	Jijiga
4	7,000	1584	Kombolcha, Desi, Robe, Tepi, Mizan, semera

Table 4: Influent Criteria

Parameter	Load in the inlet
BOD_5	1,875 kg/d
COD	3,750 kg/d
SS	1,500 kg/d
TKN	235 kg/d
TP	40 kg/d

Table 5: Effluent Criteria

Parameter	Unit
BOD_5	15 mg/ l
NH_4	10 mg N/ l
NO_3	10-13 mg N/ l
N_{tot}	15 – 23 mg N/ l
DS	25 mg/ l

$$E_{i,j} = \sum AD_{i,j} \times f_{i,j} \qquad (1)$$

Where, $E_{i,j}$ Emissions of type *i* GHG from source *j*;

$AD_{i,j}$, activity data of type *i* GHG from source *j*, e.g., fuel consumption, electric power consumption, materials consumption;

$f_{I,j}$ emission factors of type *i* GHG from source *j* activity;

i, types of GHGs, three types of GHGs are considered in this study, CO_2, N_2O, CH_4;

j, categories of GHG emission sources, e.g., electric power consumption, organic matters degradation from wastewater treatment

Table 6: Emission Factors for Greenhouse Gas (GHG) Calculation Used In This Study.

Parameter	Value and Unit	Reference
Wastewater Treatment		
CO_2 from OM oxidation	1.375 kg CO_2/kg BOD removed	[25]
CO_2 emissions from COD oxidation	0.08 kgCO_2/kg COD	
N_2O from de-nitrification	0.035kg N_2O-N/kg N denitrified	[23]
N_2O emissions from nitrification de-nitrification units	0.6% of the nitrogen treated or 0.01kg N_2O-N/kg N influent	[23]
CH_4 emissions from leakages	0.85 % of COD treated	[24]
Solid waste/ Sludge Treatment and Disposal		
N_2O from composting	0.700 g N_2O-N/kg DS	[25]
N_2O from landfill	8.200 g N_2O/kg $N_{applied}$	[9]
CH_4 from landfill	13.400 g CH_4/kg sludge	[20]
CO_2 from landfill	35.120 g CO_2/kg sludge	[20]
Emission factor for screenings & grit/ Emission factor for screenings & grit	kg CO_2-e/ kg waste Assumed similar to general municipal solid waste	[23]
Energy		
Electricity	0.118948451 kgCO_2/kWh	[22]
Diesel	3.50 kgCO_2/l	[6]

Table 7: Typical Composition of Biogas

Compound	%
Methane	50–70
Carbon dioxide	30–40
Nitrogen	0-10
Hydrogen	0–1
Hydrogen sulfide	0-3

Table 8: power consumption data for the 15-Wastewater and Sludge Treatment Scenarios.

WWTP	ASTU	Dire-Dawa	Dilla	Sodo	Nekemte	Robe	Aksum	Jijiga	Tepi	Mizan	Kombolcha	Dese	Semera	Debre Birhan	Debre-Markos
Power consumption (kw)	165	169	166	166	128	98.0	177	138	98.0	95	77.9	108	98.0	196	143
Load	full	full	full	full	3/4	1/2	full	3/4	1/2	1/2	1/2	3/4	1/2	full	full

Table 9: Approximate Diesel Fuel Consumption [7]

	¼ Load (liters/hr)	½ Load (liters/hr)	¾ Load (liters/hr)	Full Load (liters/hr)
80kW / 100kVA	7.2	12.5	18.0	24.0

Table 10: Operating Parameters and Inventory Data for the 15-Wastewater and Sludge Treatment Scenarios.

Wastewater Treatment Alternatives / Parameters	Type-1	Type-2	Type-3	Type-4
Flow rate	5616 m^3/day	3144 m^3/day	2256 m^3/day	1584 m^3/day
COD in	3,750 kg/d/	1,428 kg/d	1,020 kg/d	714 kg/d
COD eff	125 mg/ l	125 mg/ l	125 mg/ l	125mg/ l
BOD in	1,875 kg/d	714 kg/d	510 kg/d	357 kg/d
BOD	20 mg/ l	20 mg/ l	20 mg/ l	20 mg/ l
TN in	235 kg/d	132 kg/d	94 kg/d	66 kg/d
TN eff	46 mg N/ l	46 mg N/ l	46 mg N/ l	46 mg N/ l
MLSS	3.15 g/l	3.15 g/l	3.15 g/l	3.15 g/l
ASR	6.86 g/l	6.86 g/l	6.86 g/l	6.86 g/l
Volume of screening	0.48 m^3/d	0.27 m^3/d	0.19 m^3/d	0.14 m^3/d
Volume of grit		0.12 m^3/d		0.06 m^3/d
Raw Sludge Production	97.56 m^3/d	173.91 m^3/d	235.13 m^3/d	333.33 m^3/d
Sludge Treatment and Disposal	Anaerobic digestion + sludge drying and composting	Anaerobic digestion + sludge drying and composting	Anaerobic digestion + sludge drying and composting	Anaerobic digestion + sludge drying and composting

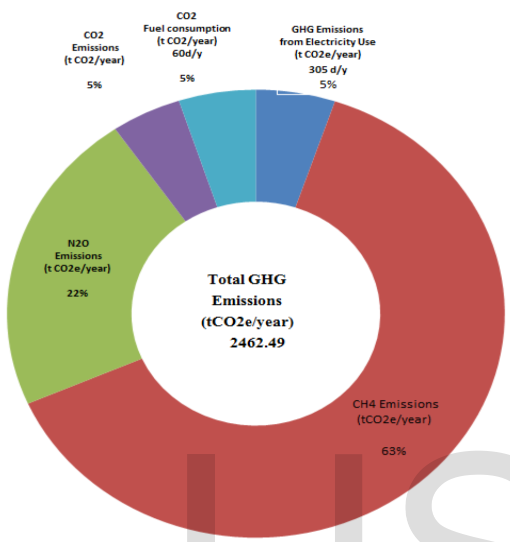
Biogas production	350 m^3/d	196 m^3/d	140 m^3/d	98 m^3/d
Digested Sludge production	41 m^3/d	23 m^3/d	17 m^3/d	12 m^3/d
Water content	92%	92%	92%	92%
Dried sludge	3 g/l	3 g/l	3 g/l	3 g/l

Notes: COD in = influent COD concentration; COD eff = effluent COD concentration; BOD in = influent BOD concentration; BOD eff = effluent BOD concentration; TN in = influent TN concentration; TN eff = effluent COD concentration; ASR = Activated sludge recycling; DS = dry sludge.

5. RESULTS AND DISCUSSION

1. Carbon Footprint

(The figure is for Debremarkos University)



- Total GHG emissions were 2416.34 tCO2e
- The largest sources of emissions for the
  - ✓ Direct emission of CH_4 in the anaerobic digester/Imhoof tank/
  - ✓ Direct emission of N_2O in biological process
- Carbon footprint from fossil fuel consumption for only 60 days per year is almost equal to carbon footprint of electric consumption from grid source.
- The oxidation of COD to CO_2 is accounted for 5% carbon footprint origin

Figure 8: Percentile Contribution In The Total CF Of 2019

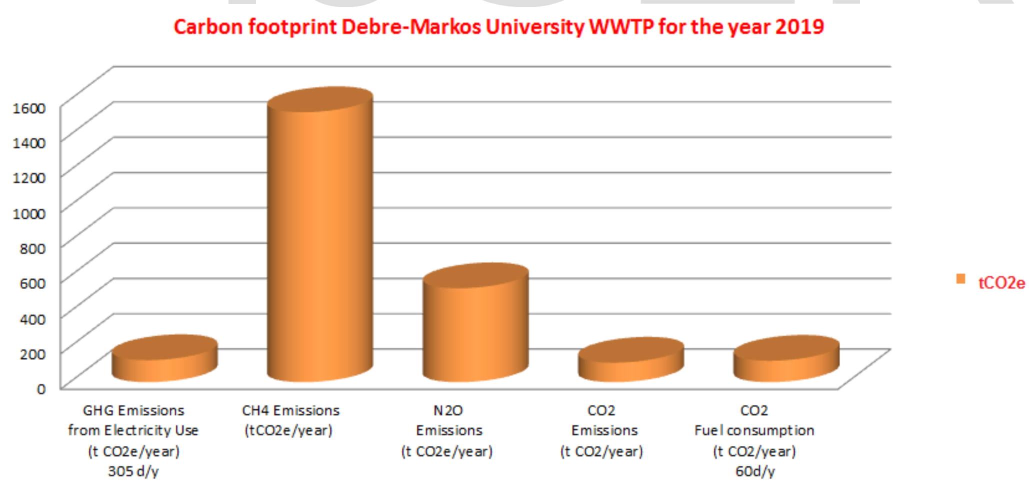


Figure 9: CF Registered From Each Sector with In the Defined Boundary

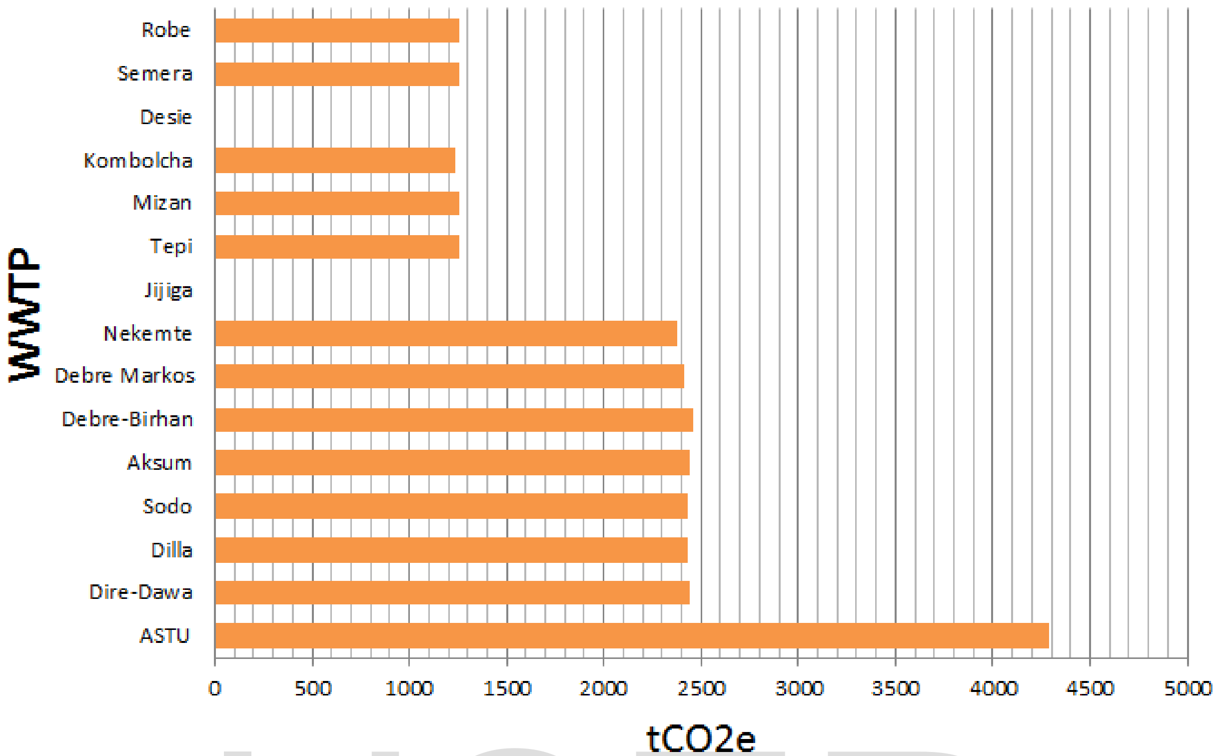


Figure 10: Carbon Footprint of the 13- Wastewater and Sludge Treatment Plants in the Year 2019.

From figure-3 it is observed that Adama University contribute higher amount of GHGs due to the fact that the size of the plant is bigger than the other, and also consume more power that the other site with lower processing capacity.

Out of type-2 treatment plant with the processing capacity of 14,000 P.E, Debre-Dirhan, create the highest CF due to its power consumption related to aerator size installed.

Figure shows GHG emitting points in the treatment plant and their proportional amount. CH_4 is basically generated in anaerobic digestion process and Wastewater collection system. N2O is entirely produced in the BNR system. CO2 from organic matter oxidation that is taken as 20% of COD entered in the treatment plant is generated mainly in BNR and the remaining in anaerobic digestion unit.

The table 11 shows the CF of all treatment plants from each source.

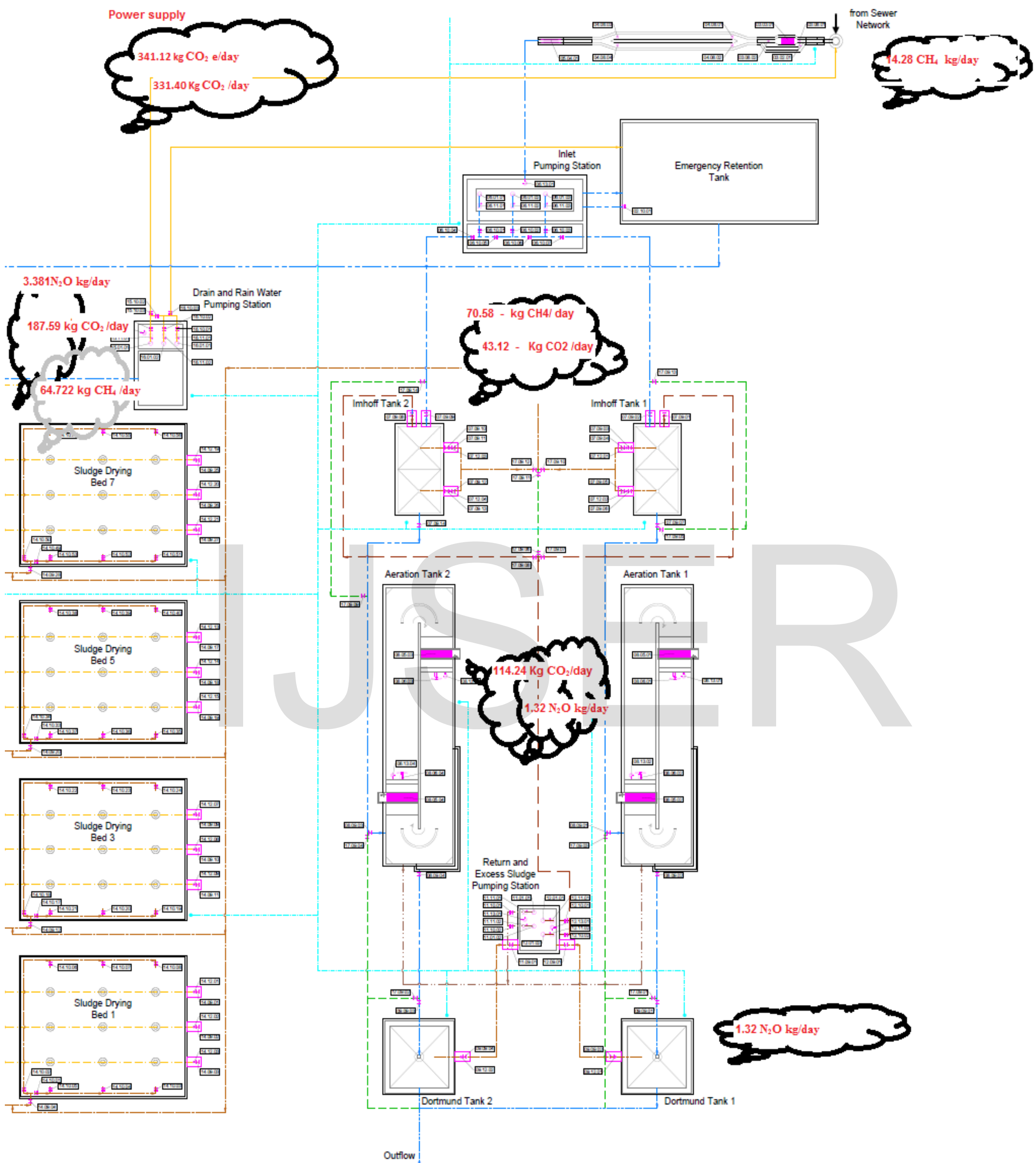


Figure 11: Daily GHGs emission from Debre-Markos WWTP with the system boundary

Table 11: Carbon footprints and GHG emissions from different sources for the 15 wastewater treatment plants.

Treatment plant	Total GHG Emissions (tCO2e/year)	GHG Emissions from Electricity Use (t CO2e/year)/60days	GHG Emissions from Electricity Use (t CO2e/year) 305 d/y	GHG Emissions Based on P.E (kgCO2e/year)	CH4 Emissions (tCO2e/year)	N2O Emissions (t CO2e/year)	CO2 Emissions (t CO2/year)	CO2 Fuel consumption (t CO2/year) 60d/y
ASTU Type-1	4291.93	28.95	143.67	171.68	2850.45	947.86	228.99	120.96
Dire-Dawa Type-2	2438.98	28.95	147.15	174.21	1528.72	531.92	110.23	120.96
Dilla Type-2	2436.37	28.95	144.54	174.03	1528.72	531.92	110.23	120.96
Sodo Type-2	2436.37	28.95	144.54	174.03	1528.72	531.92	110.23	120.96
Aksum Type-2	2445.95	30.32	154.11	174.71	1528.72	531.92	110.23	120.96
Debre-Birhan Type-2	2462.49	33.57	170.66	175.89	1528.72	531.92	110.23	120.96
Debre Markos Type-2	2416.34	24.49	124.51	172.59	1528.72	531.92	110.23	120.96
Nekemte Type-2	2373.04	21.92	111.45	169.50	1528.72	531.92	110.23	90.72
Jijiga Type-3	1444.77	23.64	120.16	144.48	767.53	389.12	77.23	90.72
Tepi Type-4	1257.34	16.79	85.33	179.62	778.74	274.28	55.99	63
Mizan Type-4	1254.73	16.27	82.72	179.25	778.74	274.28	55.99	63
Kombolcha Type-4	1239.84	13.34	67.83	177.12	778.74	274.28	55.99	63
Desie Type-3	1293.77	18.50	94.04	184.82	778.74	274.28	55.99	90.72
Semera Type-3	1257.34	16.79	85.33	179.62	778.74	274.28	55.99	63
Robe Type-3	1257.34	16.79	85.33	179.62	778.74	274.28	55.99	63

Remark: No chemical use in any of the treatment Process, except small laboratory chemical consumption. Jijiga and Desi sites are not functional. The estimation is made entirely from design data and by bearing in mind similar situation will exist in the sites too (power supply).

6. CONCLUSION AND RECOMMENDATION

Using the off grid power supply system in the WWTPs is currently creating a CO2 footprints. Since the treatment plants are running seven days a week and 24 hours a day; to function the TP is consuming a huge amount of fossil fuel at the diesel generator, which is result a carbon foot print of 4 times if the power supply was grid. So the responsible parties must give attention to resolve power disruption to the TPs.

And also the results from carbon footprint analysis show that the direct emissions from N_2O and CH_4 significantly affect the CO_2 eq. of the Wastewater treatment plant. This effect was even more magnified if the power supply was fully from grid, which is appreciated and known for entire production from renewable energy sources. From the studies it is shown, careful design at the design face and optimized operation reduce the direct emissions of N_2O and CH_4.

Seeing this imaginably, the most efficient way, in terms of costs, to reduce GHG emissions is to adjust the operational conditions of WWTPs units but this is not always possible due to the operational limitations of the installed units. Here after it is tried to highlight the possible actions to put in practice to operate WWPTs in order to reduce GHG emissions:

1. CH_4 emissions can be minimized in the plant if Imhof tanks properly covered to avoid leakage and the generated methane is tried to recover to be used as energy source. The collected CH_4 can also put to burn to convert in to carbon dioxide. Since the global warming potential of CH_4 is 28 fold CO_2 . Therefore; the treatment plants should adopt a mechanism to use the CH_4 generated by the plant and avoid direct release of the gas to the atmosphere.

2. Theoretically, the energy contained in the wastewater is far beyond the energy required [3], thus carbon neutrality should be possible. Energy content in wastewater, in the form of chemical oxygen demand (COD), is converted into CO_2 or CH_4 and bio-solids through aerobic treatment in the aeration tank and/or anaerobic treatment in sludge handling process. Therefore, after adopting a methane recovering system; it is possible to decreasing the degree of aerobic treatment and maximizing energy recovery from CH_4 and bio-solids are crucial to lower carbon footprint.

3. Methane also enters the plant from outside via the influent since it contains CH_4 that has been formed in the sewer. The methane load is 1% as of COD load. To avoid the conversion of COD anaerobically in to CH_4 in the sewer network system; the network should be carefully constructed with a possibility of air circulation in the line.

4. The N_2O emissions from the wastewater treatment significantly affect the footprint of carbon emissions. The amount of N_20 produced varies depending up of the operating situation in the plant. Having this in mind decreasing the amounts of N_2O emitted from activated sludge processes presents a great potential for improvement, by avoiding those operational conditions identified as responsible for its production. Some identified conditions are
   - Low dissolved oxygen concentration in the nitrification and the presence of oxygen in denitrification stages, carefully control the aeration process/ proper aeration.
   - high nitrite concentrations in both nitrification and de-nitrification stages, proper aeration and mixing ration should be kept
   - low COD/N ratio in the denitrification stage, making sure that the amount of COD enter in to the aeration tank is as per the design value and the flow rate of the wastewater to the primary settling tank is constant though of the operation.
   - Sudden shifts of pH and dissolved oxygen and ammonia and nitrite concentrations, by trying to make smooth operation. and further
   - Transient anoxic and aerobic conditions [12, 13]. To minimize N_2O emissions, the wastewater treatment plants should be operated at high solid retention times (SRT) to maintain low ammonia and nitrite concentrations in the media. Large bioreactor volumes are recommended to dispose of systems able to buffer loadings and reduce the risk of transient oxygen depletion.N_2O emissions can be also reduced if nitrous oxide stripping by aeration is limited since microorganisms would have more time to consume it [37]. Table 12 indicate summarized recommendation to reduce the GHGs generation in WWTPS

Table 12: miner improvement for the reduction of GHGs generation in the WWTP

Wastewater collection network and treatment	○ Introducing Simple sewer ventilation system ○ Performing Correction works the line to reduce the introduction of solid waste in lines ○ Creating awareness about waste segregation to avoid the receiving of unexpected solid waste volume and type ○ Integrate the university solid waste management with the TP solid management for better solid waste management direction (composting, incineration, biogas etc.) rather than landfilling. ○ better management systems: aeration of the activated sludge process ○ Improving the anaerobic digestion system to reduce emission and recover the energy from biogas ○ Introduce best anaerobic digester Other plant or never use Imhoof for biogas generation ○ better to base Wastewater sludge for sustainable bio-energy production avoids/offsets conventional energy use
Power consumption	○ Energy, GHGs awareness movements
	○ Compressed air systems: use blowers for aeration instead of motorized aerators ○ Introduce variable speed drives for pumps and aerators

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APPENDIX -1

Table –Appe-1-1 Calculated CH_4 Emission Value

CH_4 Emission in the Wastewater Treatment plants

	Unit Operation	Value	Unit	Type-1		Type-2								Type-3		Type-4						
				ASTU			DDU	Aksum	Nekemte	Sodo	Dilla	Debre-Brihan	Debre-markos	Jijiga			Semera	Robe	Kombolcha	Dese	Mizan	Tepi
				Value																		
1	CH4 generation inSewernetwork	1% KgCOD /day	kg/d	3,750	0.01	1,428	0.01							1,020	0.01	714	0.01					
			kg CH4/day		37.5		14.28	14.28	14.28	14.28	14.28	14.28	14.28		10.2		7.14	7.14	7.14	7.14	7.14	7.14
2	CH4 from landfill	Remark:																				
	Grit and Screaning	the total solids (TS) of grit and Screaning is calculated																				
		as kg CO2-e/ kg waste in CO2 generation sheat																				
3	Sludge Handling																					
3.1	Sludge landfill/composting	13.400 g CH_4/kg sludge	m3/d of digested sludge	41	7	23	7							17	7	12	7					
			m3 /d of solid content		2.87		1.61								1.19		0.84					
			g sludge/dried solid content		8.61		4.83								3.57		2.52					
			kg CH4/day	13.4	115.374		64.722	64.722	64.722	64.722	64.722	64.722	64.722		47.838		33.768	33.768	33.768	33.768	33.768	33.768
3.1	Anaerobic Digestion		m³/d	350	65	196	65							140	22	98	65					
					227.5		127.4	127.4	127.4	127.4	127.4	127.4	127.4		30.8		63.7	63.7	63.7	63.7	63.7	63.7
			CH4 weighs0.554 kilogram per cubic meter	0.554	126.035		70.58	70.5796	70.5796	70.5796	70.5796	70.5796	70.5796		17.0632		35.2898	35.2898	35.2898	35.2898	35.2898	35.2898
	Total kg CH4/day				278.909		149.58	149.5816	149.5816	149.582	149.582	149.5816	149.5816		75.1012		76.1978	76.1978	76.1978	76.1978	76.1978	76.1978
	Total kg CH4/year	365			101802		54597	54597.284	54597.284	54597.3	54597.3	54597.284	54597.284		27411.9		27812.197	27812.197	27812.197	27812.197	27812.197	27812.197
	Total KgCO2- e/year	28			2850450		2E+06	1528724	1528723.95	1528724	1528724	1528723.952	1528723.95		767534		778741.52	778741.52	778741.516	778741.516	778741.516	778741.516

Table –Appe-1-2 Calculated CO_2 Emission Value

CO_2 Emission in Wastewater Treatment Plants

	Unit Operation	Value	Unit	Type-1		Type-2								Type-3		Type-4						
				ASTU			DDU	Aksum	Nekemte	Sodo	Dilla	Debre-Brihan	Debre-markos	Jijiga			Semera	Robe	Kombolcha	Dese	Mizan	Tepi
				Value																		
1	COD Oxidation in areation	0.08 $kgCO_2$/kg COD	kg/d	3,750	0.08	1,428	0.08							1,020	0.08	714	0.08					
			KgCO2/day		300		114.24	114.24	114.24	114.24	114.24	114.24	114.24		81.6		57.12	57.12	57.12	57.12	57.12	57.12
2	landfill of SW (grit and screening)																					
2.1	Grit		m³/d	0.2		0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.19		0.14	0.14	0.14	0.14	0.14	0.14	0.14
2.2	Screaning		m³/d	0.48		0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.08		0.06	0.06	0.06	0.06	0.06	0.06	0.06
			household rubbish weighs 481 kilogram per cubic meter		0.68		0.39	0.39	0.39	0.39	0.39	0.39	0.39		0.27		0.2	0.2	0.2	0.2	0.2	0.2
			481		327.08		187.59	187.59	187.59	187.59	187.59	187.59	187.59		129.87		96.2	96.2	96.2	96.2	96.2	96.2
3	Sludge Handling	kg CO_2-e/ kg waste	kg CO2/day		327.08		187.59	187.59	187.59	187.59	187.59	187.59	187.59		129.87		96.2	96.2	96.2	96.2	96.2	96.2
3.1	Anaerobic Digestion		m³/d	350	22	196	22							140	22	98	22					
					77		43.12	43.12	43.12	43.12	43.12	43.12	43.12		30.8		21.56	21.56	21.56	21.56	21.56	21.56
			Carbon dioxide weighs1.836 kilogram per cubic meter	1.836	141.372		79.1683	79.16832	79.16832	79.16832	79.16832	79.16832	79.16832		56.5488		39.58416	39.58	39.58416	39.58	39.58	39.58
3.2	Sludge landfill/composting	0.03512kg CO_2/kg sludge	m3/d of digested sludge	41	7	23	7							17	7	12	7					
			m3 /d of solid content		2.87		1.61								1.19		0.84					
			g sludge/d dried solid content		8.61		4.83								3.57		2.52					
			kg CO2/day	0.035	0.30135		0.16905	0.16905	0.16905	0.16905	0.16905	0.16905	0.16905		0.12495		0.0882	0.088	0.0882	0.088	0.088	0.088
	Total kg CO2/day				627.38135		301.999	301.99905	301.99905	301.9991	301.99905	301.99905	301.99905		211.595		153.4082	153.4	153.4082	153.4	153.4	153.4
	Total kg CO2/year	365			228994.19		110230	110229.653	110229.65	110229.7	110229.65	110229.6533	110229.6533		77232.16		55993.993	55994	55993.99	55994	55994	55994

Table –Appe-1- 3 Calculated NO_2 Emission Values from Each Universities

	N_2O Emission in Wastewater Treatment Plants																					
	Unit Operation	Value	Unit	Type-1		Type-2								Type-3		Type-4						
				ASTU			DDU	Aksum	Nekemte	Sodo	Dilla	Debre-Brihan	Debre-markos	Jijiga			Semera	Robe	Kombolcha	Dese	Mizan	Tepi
				Value																		
1	N_2O emissions from nitrification de-nitrification	0.01kg N_2O-N/kg N influent	kg/d	235	0.01	132	0.01							94	0.01	66	0.01					
			kg N2O-N/day		2.35		1.32	1.32	1.32	1.32	1.32	1.32	1.32		0.94		0.66	0.66	0.66	0.66	0.66	0.66
2	N2O from landfill	Remark: The nitrogen content of MSW is up to 4.0%																				
	Grit and Screaning	of total solids (TS) But kg CO2-e/ kg waste																				
		is in CO2 generation sheat																				
3.2	Sludge landfill/composting	0.700 g N_2O-N/kg DS	m3/d of digested sludge	41	7	23	7							17	7	12	7					
			m3 /d of solid content		2.87		1.61								1.19		0.84					
			g sludge/dried solid content		8.61		4.83								3.57		2.52					
			kg N2O-N/day	0.7	6.027		3.381	3.381	3.381	3.381	3.381	3.381	3.381		2.499		1.764	1.764	1.764	1.764	1.764	1.764
	Total kg N2O-N/day				8.377		4.701	4.701	4.701	4.701	4.701	4.701	4.701		3.439		2.424	2.424	2.424	2.424	2.424	2.424
	Total kg N2O-N/year	365			3057.605		1715.865	1715.865	1715.865	1715.865	1715.87	1715.865	1715.865		1255.235		884.76	884.76	884.76	884.76	884.76	884.76
	Total Kg CO2/year	310			947857.55		531918.2	531918.2	531918.15	531918.15	531918	531918.15	531918.15		389122.9		274275.6	274276	274275.6	274276	274276	274276

Table –Appe-1- 4 Calculated GHG Emission in the WWTPS Resulted From Electricity Use

GHG Emission in the Wastewater Treatment Plants from Electricity Use															
WWTP	ASTU	DDU	DU	SU	NU	RU	AU	JJU	MTU	MU	WKU	WDU	SMU	DB	DM
Power consumption (kwh)	165	169	166	166	128	98	177	138	98	95	77.9	108	98	196	143
$kgCO_2/kWh$	19.6264944	20.1022882	19.7454429	19.7454429	15.2254017	11.6569482	21.0538758	16.4148862	11.6569482	11.3001028	9.26608433	12.8464327	11.6569482	23.3138964	17.0096285
GHG Emissions from Electricity Use (kgCO2-e/year)	171928.091	176096.045	172970.08	172970.08	133374.519	102114.866	184431.952	143794.403	102114.866	98988.9009	81170.8988	112534.751	102114.866	204229.732	149004.346
GHG Emissions from Electricity Use (t CO2e/year)	171.928091	176.096045	172.97008	172.97008	133.374519	102.114866	184.431952	143.794403	102.114866	98.9889009	81.1708988	112.534751	102.114866	204.229732	149.004346