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Article

Unraveling Green Information Technology Systems as a Global Greenhouse Gas Emission Game-Changer

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Abstract: Green information technology systems (Green ITS) are proposed as a strategy to reduce greenhouse gases (GHGs) emissions and other environmental impacts while supporting ecological sustainable development. The Green ITS concept combines both Green information technology (IT) and Green information system (IS) applications. The Green ITS concept has the potential to combat the carbon emission problem globally, beyond simply Green IT, because it combines management, organizational, and technology dimensions of climate change mitigation and adaptation, especially if supported by global policy. Examples include life cycle assessment software for measuring GHG emissions, and software for monitoring GHG emissions. Previous studies on environmental burdens such as GHGs, water and air pollution, energy losses and other forms of waste alongside socio-economic dependent variables including renewable resources and climate change policies are reviewed and synthesized. The research analysis conjointly points to the usage of renewable resources such as solar and wind as a critical strategy to scale back GHG emissions and enhance green growth. Empirical evidence shows that developed countries can reduce their carbon emissions while developing countries can utilize carbon emission-free technologies as they aspire to achieve development. The two significant benefits of the Green ITS strategy are first, to provide the environmental benefits of reducing greenhouse emissions and other environmental impacts and second, to enhance global green growth, which supports achievement of ecological sustainable development. Green ITS tools support achievement of the UN SDG 7, 13 and 15, which emphasize clean energy, climate action and ecological sustainable development, respectively. Future research directions include the formulation of a strategy to combat GHGs and design of a system to monitor carbon emissions and other waste remotely.

Keywords: information and communication technology; green information technology; greenhouse gas emission; green information systems; carbon dioxide (CO_2) emissions; people, planet and profit; legislation; ecology; green growth and sustainability

1. Introduction

Greenhouse gases (GHGs) including carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4), facilitate to balance the Earth's temperature through a thermal heat exchange. However, because of fossil fuel burning, the GHG concentration within the atmosphere has increased, with consequent global climate change. This calls for reducing GHG emissions by the use of renewable energy resources, efficient energy utilization, transforming GHGs to non-greenhouse compounds and capture or perhaps storage of GHGs (Liu 2012). Since carbon dioxide (CO_2) makes up the vast majority of GHG emissions, this research study will focus on carbon dioxide (CO_2) emissions and also address the other GHGs, pollution and waste footprints. Therefore, the authors use CO_2 emissions as a synonym for GHG emissions.

According to the United Nations, the world today is more united than before on the goal of combating CO_2 emissions to achieve sustainable development. The global trend today concerning the earth's finite resources consumption is unsustainable and has resulted in environmental issues including a loss of biodiversity, depletion of resources, air pollution and climate change. Sustainable development aims to meet current needs without compromising the future (Boudreau et al. 2008; Imasiku 2018). Therefore, ecological sustainable development is critical for sustainable development. "Ecological Sustainable Development (ESD) is conserving and enhancing the community's resources so that ecological processes, on which life depends, and the quality of life for both present and future generations is maintained" (Business Dictionary 2019).

As more people become wealthy, they tend to adopt affluent lifestyles that incorporate complex technologies and machinery, which consume more resources. Technology is therefore both a cause of the environmental burdens and conjointly a possible solution. Since controlling population growth and wealth accumulation is always a challenge, there is a need to invest in technologies that have smaller carbon footprints. Examples of technologies capable of reducing carbon emissions and petroleum use include Fischer–Tropsch (FT) techniques for chemical bio-refineries to produce biomass-derived transportation fuels with lower life-cycle greenhouse gas emissions (Joelsson and Gustavsson 2012). These technologies are capable of facilitating reductions in carbon footprints if biomass replaces coal or oil in stationary applications (Olivier et al. 2016; Imasiku 2018; Lin and Lin 2014). In the transport sector, the use of electric cars can replace some use of fossil fuels and public transportation is a low-cost approach to reduced emissions.

Other notable technologies that can lower carbon footprints include Green information technology (IT), Green information system (IS) and IT. Information technology is a technology that transmits, processes and/or stores information (Boudreau et al. 2008). Information technology plays a double role of a polluting agent and as a powerful tool that can scale back the environmental impact of different products, operations or businesses (Bachour 2012). Green IT refers to introducing innovative IT products together with their associated application services and practices to reduce the impact of IT on the environment (Zaman and Sedera 2015). Although information technology (IT) contributes to about 2% of the world's GHGs, it has potential to provide solutions to the other 98% of GHG emissions using information technology applications such as green information systems (Imasiku 2018; Vella 2018; Bachour 2012). In contrast, Green IS is the design and implementation of information systems that contribute to sustainable business processes (Boudreau et al. 2008). Green IS may have greater potential than Green IT because it tackles issues that are capable of making entire systems more sustainable, compared to merely reducing the energy required to operate computer systems (Zaman and Sedera 2015). Previous research work by Daqing Zheng established linkages between organizational theories of green information technology and information systems as technologies that can reduce energy consumption and carbon footprints in computer systems and other business operation (Zheng 2010; Khor et al. 2015). To easily understand the differences between the IT, information and communication technology (ICT), Green IT, IS and Green information technology systems (ITS) terminologies, the authors have provided several definitions below (Table 1) to differentiate them from one another comprehensively and further highlighted the technical variations between them in Table 2 (Zeng et al. 2018).

Table 1. Terms and definitions of Green information technology (IT) associated terms for Green information technology systems (ITS) conceptualization.

Term	Definition	Source
IT	IT is an information technology (IT) that transmits, processes or stores information.	Boudreau et al. 2008
IS	An information system (IS) provides a solution to a problem or challenge facing a firm and represents a combination of management, organization and technology components.	Laudon and Laudon 2014
ICT	ICT is a diverse set of technological tools and resources used to transmit, store, create, share or exchange information. These technological tools and resources include computers, the Internet (websites, blogs and emails), live broadcasting technologies (radio, television and webcasting), recorded broadcasting technologies (podcasting, audio and video players and storage devices) and telephony (fixed or mobile, satellite, Visio/video-conferencing, etc.).	UNESCO 2019
ICT	ICT refers to technologies that provide access to information through telecommunications. ICT is like information technology (IT) but focuses primarily on communication technologies. This includes the Internet, wireless networks, cell phones and other communication mediums.	Tech Terms 2019
Green IT	The practice of applying environmental sustainability (including pollution prevention, product stewardship and sustainable development in managing IT) as principles.	Molla and Abareshi 2011
Green IT	An integrated and cooperating set of people, processes and IT that aims at pollution prevention, product stewardship or sustainable development, for the purpose of enhancing environmental and economic performance.	Barney 2014
Green IT	The practice of designing, manufacturing, using and disposing of computer servers and associated subsystems efficiently and effectively with minimal or no impact on the environment, and focusing strongly on using information systems to enhance sustainability across the economy.	Deng and Ji 2015
Green IS	Green IS refers to the design and implementation of information systems that contribute to sustainable business processes.	Boudreau et al. 2008
Green IS	Green IS refers to information services as opposed to information systems. From the perspective of an institution of higher learning, Green IS is described as "a sustainable management system that manages data and information as an output to support specific research, scholarly and/or decision-making activities".	Chowdhury 2012
Green IT and Green IS	Green IT integrates and cooperates with sets of people, processes, software and information technologies to support individual, organizational or societal goals. Green IS incorporates a great variety of initiatives to support sustainable business processes.	Watson et al. 2010
Green ITS	Green ITS a sustainable information technological design of a business information system that monitors carbon, energy, water and waste footprints to enhance green growth and avoid a merry-go-round syndrome using a global legislature.	

Table 2. Green ITS decision matrix, authors' design.

Technology	Technical Requirement						
	2% CO_2 emission contribution	Industry or Sector Addressed	Smart Integration with other Technologies	Utilizes Technology, Organization and Dimensions	Capable of Addressing 98% CO_2 emissions	Addressing CO_2 Emission Merry-go-round	Addressing SDG 7 and 13
IT	√	All	√	No	No	No	No
ICT	√	All	√	No	No	No	No
Green IT	√	Computer	√	No	No	No	√
IS	√	All	√	√	No	No	No
Green IS	√	Business	√	√	√	No	√
Green ITS	√	All	√	√	√	√	√

Note: Sustainable development goal (SDG) 7 focuses on providing affordable and clean energy while SDG 13 focuses on climate action (United Nations 2019).

Table 1 shows that although ICT is the mother terminology for all the other technologies, it is limited to communication technologies and does not incorporate some critical dependent variables like GHG emissions, technology management and GHG emission global policies that govern and prescribe GHG emission cuts and management. Lack of stronger policies concerning GHG emissions reductions has resulted in a GHG emission merry-go-round.

The trend of the GHG emissions preceding 2015 shows that the highest emitter, China, along with the United States, cut back their GHG emissions in 2015 by 0.7% and 2.6%, respectively. Russia and Japan also decreased their emissions by 3.4% and 2.2%. However, all these efforts to decrease the GHG emissions globally were counter-balanced by the GHG emissions increase in India by 5.1% and 1.3% in the European Union (Olivier et al. 2016). The impact of such activities concerning GHG emissions on a global scale renders these efforts to combat GHGs null and void (Imasiku 2018). This presented a global 'merry-go-round' scenario, where some countries strive to scale back the carbon emissions while others nullify the global decrease by increasing their emissions. While the western world tries to cut back GHG emissions, the emerging countries are mostly in contrast because they increase their emissions as they strive to attain a developed nation status. The online learner's dictionary defines a merry-go-round as "a set of recurrent activities that are fast, confusing, or troublesome to leave" (Learners Dictionary 2017; Imasiku 2018).

The following Green ITS Matrix table distinguishes the technologies in Table 1 according to technical capabilities of IT, ICT, Green IT, IS, Green IS and Green ITS.

Table 2 shows that the two most competitive technologies are Green IS and Green ITS. Green ITS stands out to be better because it focuses on all sectors of society while Green IS focuses on the sustainable business sector alone. Furthermore, Green ITS also addresses SDG 7 and 13 and the CO_2 emission merry-go-round. Green ITS shows a higher potential to enhance green growth.

While adopting green growth has paid off in some regions, a CO_2 emission crisis looms on a global scale because the CO_2 emission merry-go-round works against green growth. Many governments, international organizations and members of civil society and academia have so far built a case for green growth to address the crisis (Bina 2013; Imasiku 2018), but without stronger global policy, this green response may not be workable (Mead 2018). The Paris Agreement of 2015 still depends on individual country/regional corporate social responsibility (CSR) and this has resulted in a global CO_2 emission merry-go-round.

However, some regions and organizations have respected the Paris Agreement on Climate Change (Olivier et al. 2016; Imasiku 2018). For example, the US and the EU through an executive order number 13,423, instructed the implementing agents to conduct their carbon-intensive related activities in an environmentally and economically sound manner that integrates continuous improvement for an efficient and sustainable economy. The U.S. Department of Agriculture committed itself to implement its activities in a sustainable manner that enhances energy efficiency and cuts down CO_2 emissions by using renewable energy, conserving water, acquiring green products and services, managing waste and recycling non-degradable material like plastics, reducing usage of toxicant and unsafe chemicals and materials, deploying sustainable technologies in buildings and using low-CO_2 electric vehicles (United States Department of Agriculture Office of the Chief Information Officer 2009; Imasiku 2018; Lin and Lin 2014; Simboli et al. 2014). The aforesaid provides logical indication that the CO_2 emissions should have been reduced by 2018 but this has not been the case. According to the Earth System Research Laboratory, the global average CO_2 concentration in October 2018 was 406.41 parts per million-ppm (Earth System Research Laboratory 2019). Further reference with the daily updated website, the current records stand at 413.96 ppm as of 22 January 2019[1].

While the literature review shows the effort that has been made so far concerning governing policies and technological advancement, evidence showing CO_2 emissions decrease remains missing. What is clear in the lack of cooperation regarding CO_2 emission reduction is that a global environmental crisis looms if drastic mitigation measures are not taken. Another trend is that while the western world struggles to cut back on GHG emissions, the developing nations are not concerned with such measures as a result of their bid to achieve development (Olivier et al. 2016). There is a need to address this looming crisis from a global point of view. This research paper focuses on finding a solution to resolve the GHG emission merry-go-round that has prevailed since 1959 (Carbon Brief 2018).

The research paper proceeds as follows; Section 2 summarizes the literature on greenhouse gas emissions and its impacts, the governing policies of CO_2 emissions, the significance of Green IT applications to enhance a green economy, the environmental benefits of CO_2 emission cuts and the way to use renewables resources to reduce CO_2 emissions and promote ecological sustainable development and sustainable development at the same time. This section ends with the authors' conceptualized framework to guide the research. Section 3 presents the problem background and synthesizes it and offers a road map to resolve this issue using stronger global policy to drive the concept—Green information technology system (Green ITS) approach by all stakeholders to reduce CO_2 emissions. It then identifies and states the global problem that has been prevalent since 1959 concerning the CO_2 emission increase. Section 4 provides an in-depth explanation of the research method employed, and the requirements to resolve the CO_2 emission problem. The proposed method uses both mathematical approaches and suggested software as a more practical industrial method considering the complexity of the existing systems. This method is scientifically supported with previous research studies and benchmarks by the 2016 Intergovernmental Panel on Climate Change (IPCC) revised report on method guidelines for estimating national inventories of CO_2 emissions using higher tier methods for complex systems or plant-specific measurements and estimations. The selected method of validation uses a sustainability design that allows a fair business climate to prevail and highlights the significance of CO_2 emission monitoring. Section 5 presents the results for the research study. Finally, a combined discussion and conclusion in Section 6 to address the results and provide insight into the Green ITS concept; the impact of CO_2 emissions; the importance of global policy compared to the prevailing corporate social responsibility (CRS) approach; the significance of usage of renewable energy to combat CO_2 emissions and how all these can support the sustainability transitions in both developing and developed nations.

2. Literature Review

The key factors that are vital to unraveling Green IT as a possible greenhouse gas (GHG) emission game-changer worldwide are the GHG emission policy status, the significance of green growth, GHG impacts and the role of IT and its interaction with the business world. The utilization of ICT applications like Green IS would facilitate resolution of the CO_2 emission issue and indirectly promotes renewable energy technologies (RETs) and a green economy (Lin and Lin 2014).

[1] https://www.co2.earth/daily-co2.

The world's green growth policy status decentralizes into different regions and countries but is guided by one overall global policy framework, the Paris Agreement of 2015. The authors argue that this agreement is efficient but may not be effective enough to combat or reduce the CO_2 emissions, which have been on the increase since 1959. Green growth is the development of or transitioning to a low-carbon or a sustainable economy while cutting back pollution and CO_2 emissions in a manner that is environmentally friendly and is defined according to a country's or a region's green policies (Bina 2013). The country-specific or regional-specific policies are usually in two extremes but often overlap with the aim of promoting an efficient or productive low-carbon economy (OECD 2012; Imasiku 2018). This emphasis to varying degrees of dematerialization, decoupling of resource utilization, valuing ecological system services or innovative power systems with technologies that have high-efficiency in different nations. Increased capital utilization has implications on for long-term economic growth and improved human welfare that has increased its recognition by international and local organizations (Bina 2013; Imasiku 2018). This scenario of policy variations fuels the prevalence of CO_2 emission global merry-go-round scenario, whereas some nations reduce their emissions other nations tend to increase theirs, leading to a zero impact in terms of worldwide CO_2 emission reductions. This indicates that the planet presently is governed by less stiff policies because several companies and countries influence climate change policies to safeguard their investments. There is a need for the world to adopt a lean six sigma thinking approach to help cut back emissions of greenhouse gases, volatile organic compounds and waste and boost energy efficiency (Caldera et al. 2018; Slack et al. 2013; O'Neill 1996; Imasiku 2018).

The current existence of a carbon emission global merry-go-round creates a green response deficiency that sadly is not being viewed as a worldwide crisis in the face of humanity, because of the individual, organizational and country gains from their investment. However, protecting these personal gains is temporary because it would not be long before the planet stops to support plant and animal life. It is thus vital to embrace green growth globally (Imasiku 2018).

According to the Organization for Economic Co-operation and Development (OECD), a green economy or green growth implies fostering economic growth and development while guaranteeing that the natural resources are exploited in an environmentally friendly manner. Green growth cannot replace sustainable development but is a pragmatic and versatile way of attaining measurable progress within the green economy with special attention being given to the environmental pillar of sustainability without neglecting the social consequences of the green growth process (OECD 2013; Imasiku 2018).

Green growth is important and matters to both developing and developed nations. While the emerging countries have a vital role to play in reducing global warming and easing the slow-approaching climate change crisis by deploying CO_2 emission-free technologies like renewable energy technologies, the western world conjointly has a vital role to scale back CO_2 emissions and promote green economies worldwide (Lin and Lin 2014).

The developing nations are key to achieving global green growth in two major ways. First, the socio-economic impacts of environmental degradation are vital to the developing countries as they are the foremost vulnerable to climate change and lack the technological and financial ability to mitigate climate change although they are well endowed with unexplored natural resources. Additionally, many developing countries face severe socio-economic and ecological threats from energy poverty, and food and water insecurity caused by extreme weather risks that are a consequence of climate change. They conjointly face risks of high premature deaths because of air pollution, unclean water supply and diseases related to the ever-changing climate. These factors undermine their pursuit of development. Second, although nowadays least developed nations contribute minor shares to the global CO_2 emissions compared to the Organization for Economic Co-operation and Development (OECD) and major emerging economies, they are likely to scale up their carbon footprints if they follow conventional economic growth patterns of the developed nations concerning fossil fuels. This is because developing nations are embarking on rapid economic growth programs without paying attention to CO_2 emissions and environmental degradation as they explore their natural resources (European Union 2013; Imasiku 2018).

However, despite the good initiatives to monitor and control CO_2 emissions by the developed nations, in their respective regions, their efforts will be in vain, nullified or offset if they do not get complementary efforts from the developing nations to use carbon-free technologies. A good initiative worth noting is the regulation of the European Parliament and of the Council of 21 May 2013, which came up with a mechanism of monitoring GHGs and reporting them at the country level and regional level to repeal against member states if their activities enhanced climate change (European Union 2013; Imasiku 2018).

Since 1959, projections of how the CO_2 emissions are likely to increase over the succeeding 20 years, by regions, facilitated the predictions of expected premature deaths due to compromised water supply, air pollution and diseases related to a changing climate (OECD 2012). Figure 1 below shows the CO_2 emission trend from 1959 to 2018.

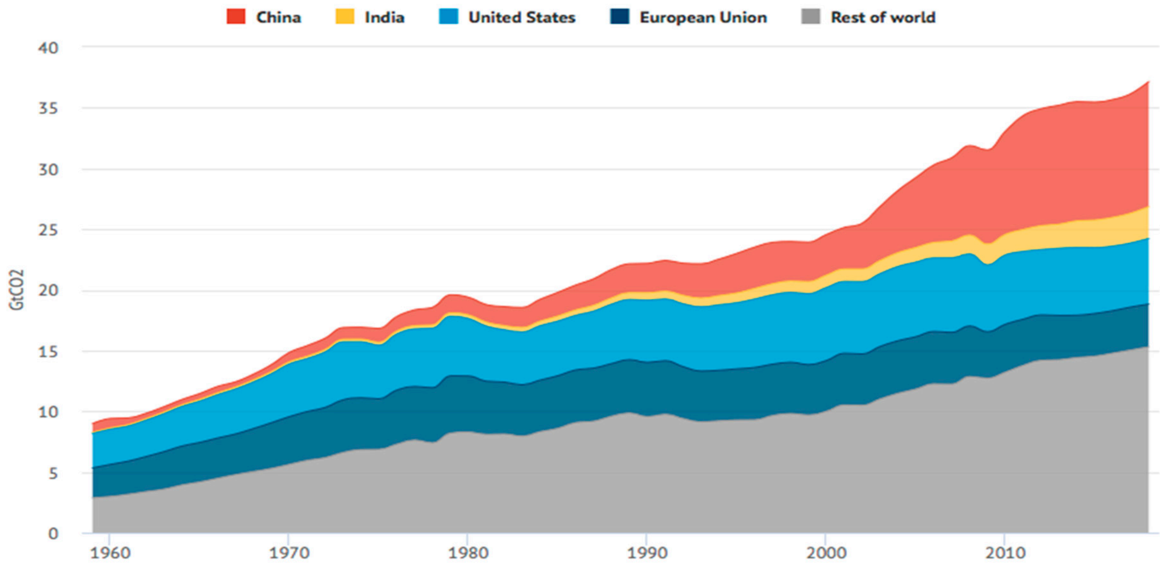


Figure 1. The annual CO_2 emission from fossil fuels by Country, 1959–2018 (Hausfather 2018).

Figure 1 above shows that CO_2 emissions have been increasing since 1959 to 2018. According to the Carbon Brief, the Gigatonnes of CO_2 equivalent ($GtCO_2e$ of CO_2) emissions will have risen to about 37.15 billion tonnes of CO_2 ($GtCO_2$) by 2018 with China and the US being the two largest emitters.

The projection is supported by the prevailing CO_2 emissions trends since 1959, shows in Figure 2, that the CO_2 emissions will still increase even by 2050. However, the worrying reality is that these significant increases also translate into ruinous impacts on plants, animals and humans. The figure below shows the global premature deaths associated with a CO_2 emission increase.

Figure 3 shows that by 2050, the world expects to record about eight million premature deaths because of risks associated with CO_2 emission pollution and climate change related risks. In 2015, the world estimated about seven million premature deaths[2].

Both developed and developing countries ought to be committed to resolving the GHG emissions issue. However, the lack of commitment by both blocs, including the G20 is the cause of the present CO_2 emissions crisis. The authors deduce that developing countries fall short of the commitment to promote green response and justify their poor cooperation, citing that they have more pressing problems like high impoverishment among the people and poor development levels. The authors argue that ensuring that a sustainable planet prevails is more important than shortsighted national

2 https://www.businessinsider.com/carbon-dioxide-record-human-health-effects-2018-5?IR=T.

interests and gains. Furthermore, it is essential that as more emerging countries strive to develop or become greater, there is a higher chance that their activities will make the planet less habitable. On the other side, the developed countries tend to focus on trying to safeguard their investments, gains and interests and this presents a threat on their adherence or commitment to global climate change policies concerning CO_2 emission-free technologies deployment.

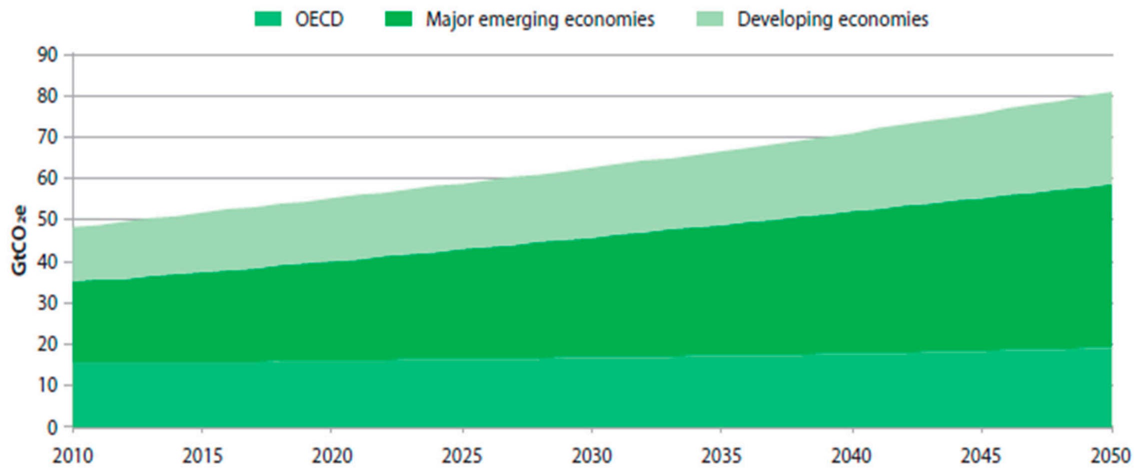
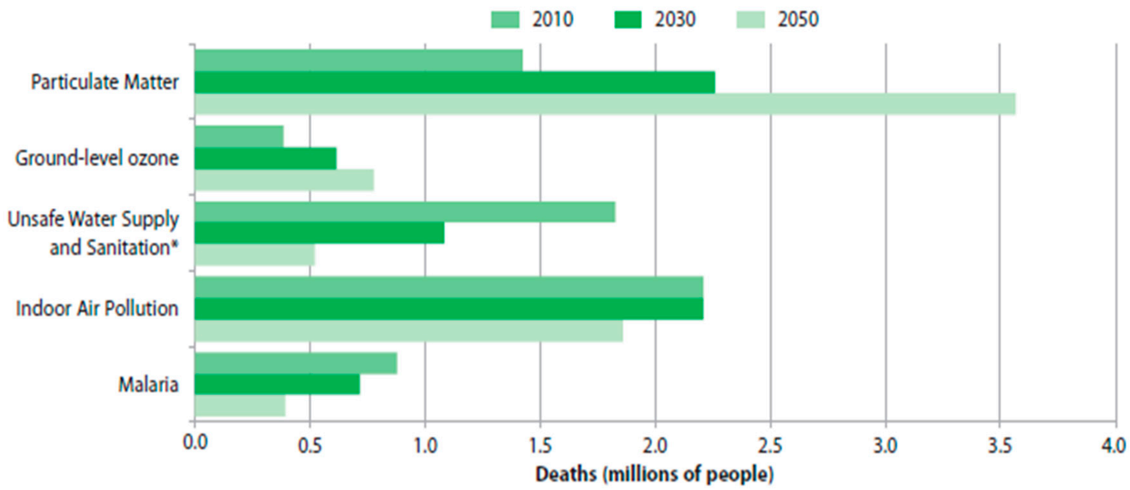


Figure 2. Greenhouse gas emissions global bloc projection from 2010 to 2050 (OECD 2012).



* Child mortality only

Figure 3. Selected environmental risk global bloc projections of premature deaths, 2010 to 2050 (OECD 2012).

To address the CO_2 emissions issue, Green IT applications are capable of offering some practical solution because their impact is far less than 2% of the global share of total CO_2 emissions. Green IT is defined as the act of implementing policies and procedures to improve the efficiency of computer resources in a manner that cuts back the energy consumption and environmental impact of their utilization. As a compound noun of environment and information technology, Green IT deals with environmental issues such as pollution, energy consumption, disposal and recycling of material resources. Since information technology (IT) is the driving technology for information and communication technology (ICT) applications, it is also capable of managing enterprise activities in an environmentally sustainable manner throughout the product life cycle and its associated services and resources (Zaman and Sedera 2015; Imasiku 2018). However, since information technology will run information systems to support sustainable business practices, technology becomes an important means by which the world will address its problems. Leveraging technologies that are carbon free to produce goods and services that are environmentally friendlier is a significant endeavor that presents smart opportunities for the commerce and trade sector (Boudreau et al. 2008; Imasiku 2018; Lin and Lin 2014).

From a business point of view, the information systems approach gives solutions to the problem faced within the firm because it combines management, organization and technology elements. The management dimension comprises elements of strategy, leadership and management behavior while the technology dimension comprises computer hardware and software including Internet, data management and telecommunications technologies. Last, the organization's hierarchy, functional specialties, business processes, organizational culture and business politics are the main elements of the organization dimension (Laudon and Laudon 2014; Imasiku 2018). Owing to the afore stated facts, the authors combined the Green IT and Green IS concepts to develop the Green ITS concept as an approach to address the global carbon emission issue. Authors define Green ITS as "a sustainable information technological design of a business information system that monitors carbon, energy, water and waste footprints to enhance green growth and avoid a merry-go-round syndrome using a global legislature". This definition implies that the term CO_2 emission henceforward will incorporate carbon, energy, water and waste footprints in this research paper. Figure 4 below shows the authors' conceptualized framework derived from the literature review to guide the study.

The conceptual framework in Figure 4 shows the implementation of Green ITS programs on the right-hand side to be pursued simultaneously with the development of socio-economic indicators on the left-hand side. Green ITS provides environmental benefits, which contribute both to socio-economic development, green growth and sustainable development.

Furthermore, the framework shows that the use of renewable energy contributes towards achieving sustainable development through increased business hours and opportunities, improved health, education and technology and enhances energy accessibility by all. The framework also introduces the synergies of carbon emissions with renewable energy, as they are both dependent variables of a green economy and sustainable development. The role of renewable energy in a green economy enhances a clean hygiene environment with less waste, and less pollution by fossil fuels. This contributes to people's socio-economic wellbeing through access to clean energy, better health and more business opportunities.

In summary, this literature review provides a baseline for this study by foremost presenting many previous studies and policy documents, and analyzing their impact on the overall aim of reducing CO_2 emissions. Until today, the world has built a case that there is a need to transform to renewables and enhance green growth. The authors also emphasize the need to have stronger global governing policies on climate change. NASA graphs by Robert Simmon supported by knowledge from the NOAA Paleoclimatology and Earth System Research Science Laboratory show that there has been a rise in concentrations of CO_2 and CH_4 emissions that coincided with the Industrial Revolution since 1750 (Riebeek 2010). While this paper does not focus on the policies that have governed CO_2 emissions until today, the authors argue that the current climate change policies have been efficient but have not been effective enough to combat CO_2 emissions. At present, the world has recorded over 410 ppm at an annual growth rate of about 2 ppm. Going by this growth rate, the authors predict a looming global crisis, unless mitigation techniques to slow down or stop the emissions are put in place worldwide. In alignment with this research, the United Nations Environment Program (UNEP) released a report on how the global carbon dioxide (CO_2) emissions rose again by 2017 citing failure to deliver on the Paris Agreement by most countries as the cause. The Paris Agreement emphasizes keeping global warming to below 2 °C from pre-industrial levels (UN News, United Nations Environment Programme UNEP). The authors infer that there is a need for stronger global policies so that countries may import the agreed Paris Agreement targets into national laws and policies and translate them into measurable climate action (Boudreau et al. 2008; Mead 2018).

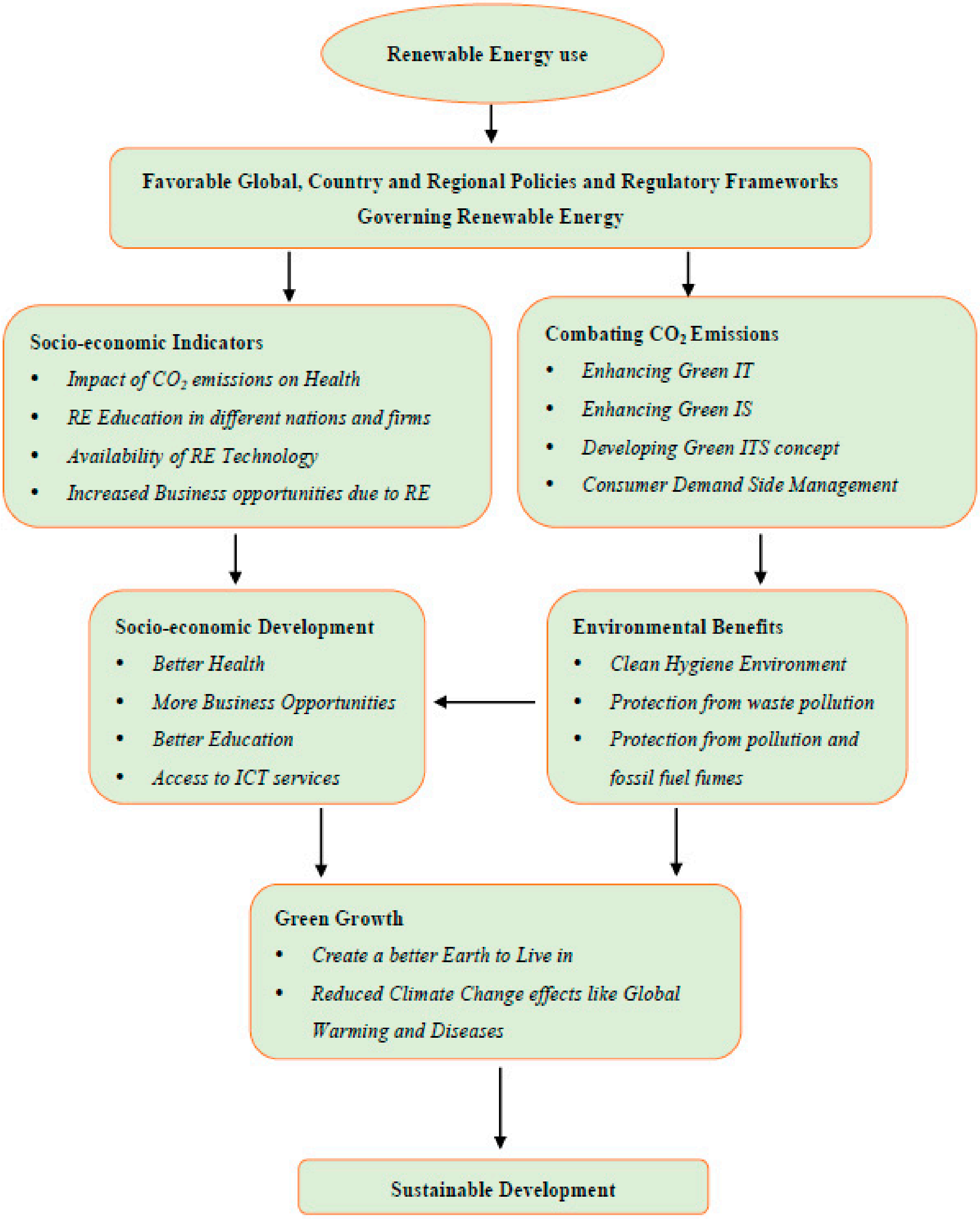


Figure 4. Authors' conceptual framework of the study.

Although global governance policies like those formulated by the IPCC and the Paris Agreement are in situ, the current set-up does not have follow-up mechanisms in place on who is complying with the Paris Agreement policies in terms of the prescribed carbon emission reduction factors or other benchmarks like those established at the 2006 IPCC Guidelines for National Greenhouse Gas Inventories of 2016, held at Minsk, Republic of Belarus (IPCC 2016; NCASI 2005).

The literature review outlined a prevailing trend that the authors describe as a GHG merry-go-round where, while some nations reduce their CO_2 emissions, other nations increase theirs, leading to a zero net impact on worldwide CO_2 emission reductions. The authors are highlighting that the planet is facing a policy crisis because companies and nations are re-defining these Paris Agreement policies to suit their interests and gains. The authors point to the need for all nations to embrace a lean six sigma thinking way to promote the values that are beyond mere corporate social responsibility (CSR) to combat GHG emissions worldwide. The authors stress the need to have stiffer global policies and presumably a monitoring body as well to ensure compliance with the Paris Agreement deliverables by all. While this may sound over-ambitious and challenging to achieve, it is only workable if the stakeholders cooperate.

The authors developed a conceptual framework which shows that the use of renewable energy will contribute towards reducing carbon emissions because it is a dependent variable that affects both green response and climate change. There is a need to improve the manufacturing technologies so that fewer CO_2 emissions are experienced worldwide (Simboli et al. 2014).

By combining Green IT and Green IS principles to develop the Green ITS research approach, the authors suggest that Green ITS is a more viable solution to combat the CO_2 emission problem than the Green IT approach because Green ITS combines management, organizational and technology dimensions of climate change to mitigate and adapt, especially if supported by global policy. The Green ITS concept shows the potential to combat the CO_2 emissions that are impacting the ecological systems of the earth, disturbing the natural food chain supply systems by altering the life-supporting climate. Successful control of CO_2 emissions could be achieved if the world establishes stronger climate change global policies and an improved CO_2 emissions monitoring system, using the Green ITS concept, would benefit the worldwide pursuit to achieve a global green economy that promotes ecological sustainable development. The succeeding section presents the problem background and a problem statement of the study.

3. Problem Background and Statement

3.1. Problem Background

According to the Center for Global Development, Figure 5 below shows that as of 2015 the first world countries account for 63% of carbon emissions whereas the developed nations account for 37% (Center for Global Development 2015). Despite such a huge contribution to the total global CO_2 emissions by emerging countries, they are more struck by the GHG emission impacts because of inadequate adaption means. The authors infer that the majority of the emerging countries feel that they might rather consider easing impoverishment and attempt to realize the developed nation standing at the expense of renewable energy usage and green growth. This points to the need to have stronger global policies and a monitoring organ of the UN to combat excessive carbon emissions that cause climate change. A key strategy to address this is by using renewable energy technologies (RETs) and green information technology (IT) applications such as a green information system (IS) to reduce CO_2 emissions (Vella 2018; Lin and Lin 2014). Information technology has the potential to support a reduction of the remaining 98% of CO_2 emissions because it easily integrates with other technologies and provides system intelligence while emitting a minimal CO_2 emission of about 2%, compared to other technologies (Bachour 2012; Chowdhury 2012).

Based on the empirical evidence and CO_2 emission trends, the authors infer that CO_2 emissions will continue to increase unless a monitoring mechanism that is backed up with a global agreement to achieve effective CO_2 emission reductions by all nations, regardless of their social, political or economic position, is implemented. Against this background, the authors narrowed down to the following problem statement.

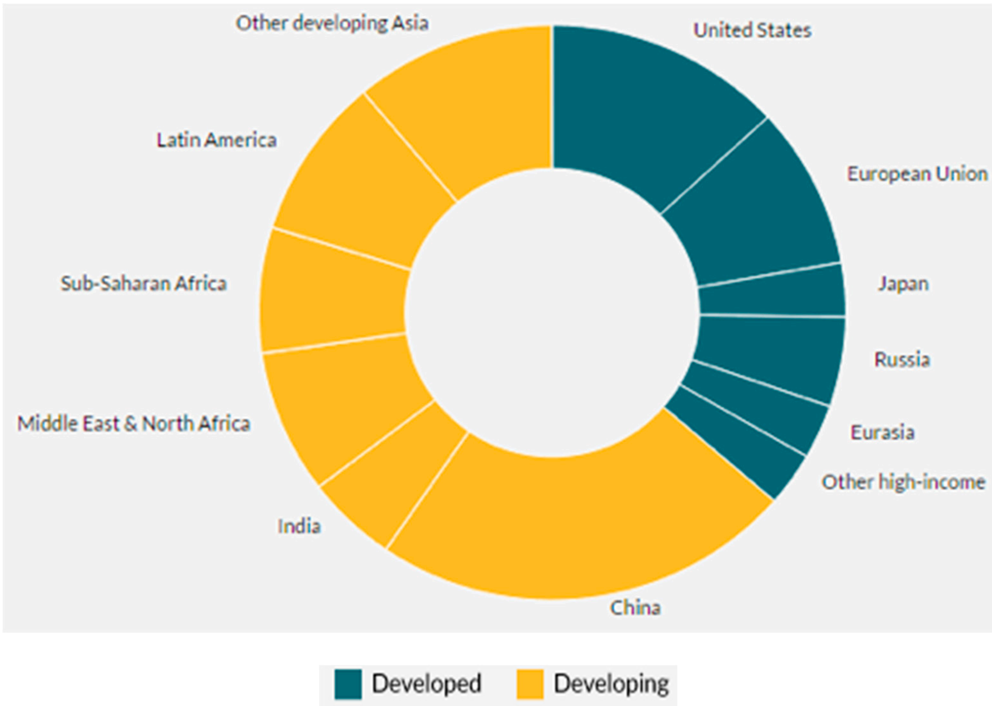


Figure 5. Percentage of CO_2 emissions of developed and developing nations (Center for Global Development 2015).

3.2. Problem Statement

As more people and nations accumulate more wealth, they adopt affluent lifestyles that exploit sophisticated tools and technologies that consume resources excessively or in an unsustainable or wasteful manner, stronger global policies are necessary to enforce CO_2 emissions reduction through the usage of renewable resources and less CO_2 emission intensive technologies to enhance green growth and ecological sustainable development globally.

Since Green IT has the potential to support reductions of CO_2 emissions globally and reduce the environmental burden of global warming and climate change. Green IT conjointly serves as a function of population growth and wealth because as the population grows, the more resources it consumes, the greater the impact it has on the planet (Boudreau et al. 2008).

Although technologies like coal-fired power plants provide electricity, they create carbon emissions that contribute to climate change. To address this issue, the authors point to the utilization of renewable energy technologies based on renewable resources like wind and solar to enhance green growth and achieve ecological sustainable development. However, since the world already hosts considerable CO_2 emissions, the authors propose that technologies like green information systems (Green IS) utilized to reduce CO_2 emissions (Khan et al. 2019). In order to coordinate all these elements of the Green ITS, the following section shows the methods and materials involved.

4. Methods and Materials

The major stakeholders in this research study included water and sewerage utility firms, electricity utilities and the mining or manufacturing firms. Monitoring carbon emissions using Green IT will enhance green growth, which fosters sustainable socio-economic development. The proposed method focuses on addressing the UN sustainable development goal—SDG 7, that emphasizes access to affordable, reliable, sustainable and modern energy for all and adopts a two-fold approach of first measuring the CO_2 emissions and second monitoring the CO_2 emissions to calculate carbon footprints.

4.1. Carbon Emission Measurement

According to the 2016 statistical review, the method for calculating CO_2 emissions from energy is modernized and made easier using software applications. The use of software to estimate CO_2 emissions is done by applying specified emission factors at the country or company level for oil, gas and coal as specified by international regulatory authorities like the IPCC or International Energy Agency (IEA). A well-designed software application accounts for the oil consumption used for non-burning functions, like the use of gas within the petrochemicals sector or oil processed into hydrocarbons that are used for the construction of roads. In keeping with the IEA, the estimates of the share of non-burning fossil fuels deducted from the total consumption of fossil fuels before applying the allocated emission factors would help measure the carbon emissions. While the IEA and the IPCC considers biofuels not to be a CO_2 emitter because of its ability to recapture the same amount of CO_2 through photosynthesis (British Petroleum Statistical Review 2016; IPCC 2016), a full accounting of the life-cycle emissions will include the recognition that in some developing nations the consumption rate of biofuels is too high and leads to deforestation, a recipe for environmental degradation and climate change. To determine the CO_2 emissions measurements, tediously computational mathematical expressions were used but a smart and modern way was by deploying ICT application software.

4.2. Mathematical Expression of CO_2 Measurements

To determine the energy consumption or carbon emissions for an entire lifecycle of the ICT product, mathematical expressions play a critical role as long as country-specific carbon emission factors are pre-determined. Table 3 shows some matching rate between energy consumption and CO_2 emission in electricity production for a few European countries.

Table 3. Factors for kilogram of CO_2 Per kWh, IEA 2017.

Country	CO_2 Factors
Sweden	0.04
France	0.09
Finland	0.24
Italy	0.59
Germany	0.6
Ireland	0.7
Luxemburg	1.08

Reference (Rondeau et al. 2015), for equipment manufactured in one country, but used in another country and dismantled elsewhere, used the following equation to estimate the CO_2 emissions.

We estimated the Φ using:

$$\Phi = \Phi_m + \Phi_u + \Phi_d = \alpha_m E_m + \alpha_u E_u + \alpha_d E_d \quad (1)$$

where the gain α relates to the stage of the life cycle, α_m corresponds to the factor during the manufacturing stage, E_m represents the manufacturing of equipment, E_u is the use of the ICT-based design and E_d represents the dismantling stage of the design.

Equation (1) takes into consideration the location of produced energy to enhance the use of energy close to the network installation that limits energy-transport losses. To integrate this parameter, it is necessary to make that part of the CO_2 emission caused by energy transportation visible.

$$\Phi = \sum_{s=m,u,d} \frac{\alpha_s}{\tau_s} \times E_s \quad (2)$$

Therefore, adding a factor τ to (1) yields Equation (2). The factor τ is the extra rate required to transport energy in a particular country.

Extending Equation (2) to incorporate different sources of energy locally, like the oil required to drive generators to produce power for emergency purposes. A good example of such a system is the global system for mobile communications (GSM) system. Equation (3) may also be extended to solar panels that are installed locally and dedicated to the network. The impact depends on the energy type and in this case either electricity or oil, and this results in the following general metric for CO_2 emission:

$$\Phi = \sum_{s=m,u,d} \sum_{energysource} \frac{\alpha_{s,i}}{\tau_{s,i}} \times E_{s,i} \tag{3}$$

where $E_{s,i}$ is the energy-source component, the equipment Φ is consumed during the manufacturing, use or dismantling stages.

Equation (3) is appropriate for smart micro-grid applications to locally encourage the use of renewable energy.

Simple methods to estimate GHG emissions and reductions are often unsatisfactory due to their failure to capture more complex and diverse systems and practices, resulting in an increase in GHG emissions and reductions. This has made a greater number of inventories opt for more sophisticated methods that use models to directly measure and improve inventory accuracy and resolution. Measurements are the cause on both models and facility-level data at an individual plant covering the sectors. Therefore, modeling has the potential to increase the power of data. The 2016 IPCC Guidelines state: "Although models are frequently used to assess complex systems and can be used to generate data, models are means of data transformation and do not remove the need for the data to drive them".

The 2016 IPCC guidelines and scoping meeting for these methods was refined at Minsk, Belarus to simplify all these mathematical expressions to the following (IPCC 2016; NCASI 2005);

$$\text{Emission} = (\text{Emission Factor}) \times (\text{Activity data}). \tag{4}$$

Note: In Equation (4) it is assumed that the units of activity individually or on average, carries an identical emissions burden.

However, if this calculation seems to be inadequate, we adopt more complex models. A good example of a complex application is the sigmoid growth of a stand of trees, which implies that one cannot multiply the removal rate by the stand space to induce emission removal from the atmosphere. Furthermore, the age of the equipment conjointly matters. Most importantly is the existing linkages between processes; measuring the emissions at the manufacturing stage in a specific country but used in another country with a different emission factor makes the process of calculation more sophisticated than Equation (4).

4.2.1. Calculating Complex CO_2 Emission Measurements

Greenhouse gases (CO_2 emissions) mainly comprise carbon dioxide (CO_2) with some methane (CH_4) and nitrous oxide (N_2O). These gases have the potential to cause global warming. Global warming potentials (GWPs) is a unit for measuring the impact of non-CO_2 greenhouse gases, which may also be expressed as a weight of CO_2-equivalent universally. The GWP for CH_4 is 21, which represents an equivalence of 21 g of CO_2 for every gram of CH_4, whereas that of N_2O is 310.3 CO_2-equivalents. Either CO_2-equivalents or MTCEs (metric tons carbon equivalent) units are acceptable universally (IPCC 2016; NCASI 2005). Since this research aims at unraveling ICT applications as a potential tool to reduce CO_2 emissions, the authors analyzed Green IT's shortcomings and realized that Green IS is in a better standing to provide the required solution. Further diagnosis narrowed down to a hybrid concept green information system technology (Green ITS) combining Green IT and Green IS concepts. The following mathematical expressions of CO_2 emissions measurement will also further illustrate the typical industrial applications of the Green ITS concept.

The Content of Fuel in Heat (HHV) and the Lower Heating Value (LHV)

One of the first technical challenges in evaluating greenhouse gas emissions is to correctly quantify the energy and carbon content of fuel used in manufacturing processes. Fuel energy content can be expressed as a higher heating value (HHV) or gross calorific value (GCV) or lower heating value (LHV) or net calorific value (NCV), with the following equation (IPCC 2016; NCASI 2005):

$$LHV = (1 - M_{wet})\,[HHV_{solids} - \lambda(M_{dry} + 9H)], \tag{5}$$

where LHV represents the net calorific value at any moisture content, HHV_{solids} represents the gross calorific value of dry fuel (zero moisture content), λ represents the latent heat of the vaporization of water (2.31 MJ/kg at 25 °C), M_{wet} represents the moisture content of fuel wetly (expressed as a fraction), M_{dry} represents the moisture content of fuel drily (expressed as a fraction), H represents the mass fraction of hydrogen in dry fuel (expressed as a fraction and, LHV is expressed as dry fuel or as dry solids in the fuel, similarly, the HHV of the dry fuel is given by HHV_{solids} (IPCC 2016; NCASI 2005):

$$LHV_{solids} = HHV_{solids} - 9\lambda H, \tag{6}$$

where LHV_{solids} is equal to the zero moisture content or the net calorific value of dry fuel.

Burning of Resin-Containing Wood Residuals

Some wood products like methyl alcohol, created from agricultural feedstock or biomass, burn wood residuals that contain resins that are formed from raw materials that are fossil oil or natural gas by nature. These resin-containing wood products emit CO_2 as they burn as biomass fuels. Since these wood products and wood residuals are not in the CO_2 emission inventory, there is a need to capture their emissions (British Petroleum Statistical Review 2016; Liu 2012). To calculate the emissions based on the specific emission factor for such resin-containing wood products, the following Equation (8) is used (IPCC 2016; NCASI 2005):

$$\frac{lbCO_2}{lbresinated\text{-}wood} = \left\{ \frac{\begin{matrix} \left[\left(\frac{lbresin}{lbresinated\ wood}\right)\times\left(\frac{lbcarbon}{lbresin}\right)\times\left(\frac{44lbCO_2}{12lbC}\right)\right]+ \\ \left[\left(\frac{lbresin}{lbresinated\ wood}\right)\times\left(\frac{lbcarbon}{lbresin}\right)\times\left(\frac{44lbCO_2}{12lbC}\right)\right]+ \end{matrix}}{\left[\begin{matrix} \cdots\cdots \\ \left(\frac{lbresin_m}{lbresinated\ wood}\right)\times\left(\frac{lbcarbon}{lbresin_m}\right)\times\left(\frac{44lbCO_2}{12lbC}\right) \end{matrix}\right]} \right\} \tag{7}$$

Simple Combined Heat and Power System

If we divide the emissions from a combined heat and power (CHP) system between the heat and power outputs, according to the efficiency ratios, we get Equations (8) and (9) (IPCC 2016). The IPCC recommends this technique for manufacturing facilities that do not have or choose not to use detailed designs and operational data from the CHP systems (NCASI 2005).

$$E_H = \left\{\frac{H}{H + P + R_{eff}}\right\} \times E_r;\ R_{eff} = \frac{e_n}{e_p} \tag{8}$$

where E_H represents the emissions share resulting from heat production (t GHG/y), E_T represents the total emissions from the entire CHP plant usually expressed as t GHG/y, H is the heat output usually expressed as GJ/y, P is the power output expressed as GJ/y, R_{eff} is the efficiency ratio of heat production to that of power production, e_H has an efficiency of 0.8 by default in a typical heat production system and e_P has an efficiency of 0.8 by default in a typical electrical production system.

The relation for the emission share attributed to electric power production is:

$$E_P = E_T - E_H, \tag{9}$$

where E_P is the emissions share attributed to the electric power production.

Complex Combined Heat and Power System

In typical industrial applications, the CHP systems combine both heat output streams and electric power production from multiple generators. Manipulation of Equations (8) and (9) to measure the GHGs for the CHP industry results in (IPCC 2016; NCASI 2005):

$$E_{H\,1} = \left\{ \frac{\frac{H_1}{e_{H1}}}{\frac{H_1}{e_{H1}} + \frac{H_2}{e_{H2}} + \ldots + \frac{P_1}{e_{P1}} + \frac{P_2}{e_{P2}} + \ldots} \right\} \times E_T \quad (10)$$

and;

$$E_{P\,1} = \left\{ \frac{\frac{P_1}{e_{P1}}}{\frac{H_1}{e_{H1}} + \frac{H_2}{e_{H2}} + \ldots + \frac{P_1}{e_{P1}} + \frac{P_2}{e_{P2}} + \ldots} \right\} \times E_T \quad (11)$$

where E_{H1} represents the emissions caused by heat production from steam stream 1, E_{P1} represents the emissions caused by electric power production through generator 1, E_T represents the total emissions from the entire CHP plant, H_1 represents the heat output from steam stream 1, H_2 represents the heat output from steam stream 2, P_1 represents the power output from generator 1, P_2 represents the power output from generator 2, e_{H1} represents the overall efficiency of producing heat in steam stream 1, e_{H2} represents the overall efficiency of producing heat in steam stream 2, e_{P1} represents the overall efficiency of producing electric power through generator 1 and e_{P2} represents the overall efficiency of producing electric power through generator 2.

Estimating Methane Emissions from Landfills

To estimate CH_4 emissions from landfills, the USEPA recommends a 75% default value of collecting efficiency (1998). The IPCC acceptable protocols stipulate that solely the CH_4 emissions are measured owing to having too many uncertainties of CO_2 emissions composing biomass carbon are an insignificant part of the GHG inventory whereas the N_2O emissions remain negligible.

Using default values, assumptions and estimates of CH_4 generated from landfills, the subsequent expression is employed to estimate the emissions from landfills (IPCC 2016; NCASI 2005):

$$\text{CH}_4\ (\text{m}^3/\text{y})\ \text{released to the atmosphere} = [\text{REC}/\text{FRCOLL}) \times (1 - \text{FRCOLL}) \times \text{FRMETH} \times (1 - \text{OX})] + [\text{REC} \times \text{FRMETH} \times (1 - \text{FRBURN})] \quad (12)$$

where REC is the amount of landfill gas collected or determined on a site, usually expressed as m^3/y, FRCOLL is the fraction of collected generated landfill gas, with a default value 0.75, FRMETH is the fraction of CH_4 in landfill gas, with default value 0.5, OX is the fraction of CH_4 oxidized in the surface layer of the landfill, with a default value of 0.1, and FRBURN is the fraction of collected CH_4 that is burnt on site.

To estimating landfill CH_4 emissions at landfills without gas collection data, the following expression is used (IPCC 2016; NCASI 2005):

$$\text{CH}_4\ (\text{m}^3/\text{y})\ \text{generated from all waste in landfill} = \text{R}\ \text{L}_0\ (\text{e}^{-\text{kc}} - \text{e}^{-\text{kT}}), \quad (13)$$

where R is the average amount of waste sent to landfill per year, expressed as Mg/y, L_0 is the CH_4 generation potential, expressed as m^3/Mg waste, k is the CH_4 generation rate constant, expressed as 1/y, C is the time since landfill stopped receiving waste, expressed as y, and T is the number of years since landfill opened, expressed as y.

Note: R and L_0 can be in units of wet weight, dry weight, degradable organic carbon or other units but the units for R and L_0 must be the same.

Since not all the generated CH_4 is released to the atmosphere the following expression estimates atmospheric releases (IPCC 2016; NCASI 2005):

$$CH_4\ (m^3/y)\ \text{released} = [(CH_4\ \text{generated} - CH_4\ \text{recovered}) \times (1 - OX)] + [CH_4\ \text{recovered} \times (1 - FRBURN)] \tag{14}$$

where CH_4 generated is equal to the one from Equation (14), CH_4 recovered is equal to the amount of CH_4 collected on site, OX is equal to the fraction oxidized in the surface layer of the landfill before escaping usually assumed to be 0.1 and FRBURN is equal to the fraction of collected CH_4 that is burnt on site.

Overall, the expression below helps to measure the annual generated CH_4 emissions (IPCC 2016; NCASI 2005):

$$CH_4\ \text{generated}_T = \text{DDOCm decomp}_T \times F \times 16/12 \tag{15}$$

where DDOCm is equal to the product of $W \times DOC \times DOC_f \times MCF$; W is equal to the mass of waste deposited, DOC is equal to the fraction degradable organic carbon in waste (based on the same units as used to measure the amount of waste sent to landfill), DOC_f is equal to the fraction of DOC that degrades into landfill gas, 16/12 is equal to the conversion factor from carbon to CH_4, 0.5 is equal to the default value of the fraction CH_4 in gas from a managed landfill and MCF is equal to the amount of CH_4 in landfill gas relative to a managed landfill (if managed landfill MCF is equal to 1).

The following expression calculates the CH_4 annually (IPCC 2016; NCASI 2005):

$$\text{Methane released} = (\text{Methane generated} - REC) \times (1 - OX) \tag{16}$$

where REC is equal to the amount of CH_4 converted to CO_2 by burning and OX is equal to the fraction of CH_4 converted to CO_2 by oxidation in the landfill cover (default value is zero but IPCC's May 2000 Good Practices document shows that 0.1 applies for well-managed landfills in industrialized countries).

Estimating Methane Emissions from Wastewater

IPCC's approach for estimating CH_4 from wastewater treatment or sludge digestion is just like the all-in-one-year technique used for estimating CH_4 emissions from landfills. The CH_4 emissions from wastewater are (IPCC 2016; NCASI 2005):

$$\text{Methane emissions} = (TOW\ \text{or}\ TOS) \times B_0 \times MCF \tag{17}$$

where TOW or TOS is equal to the measure of the organic content of anaerobically treated wastewater or sludge, B_0 is equal to the CH_4 per unit of organic matter, in units consistent with TOW or TOS, and MCF is equal to the fraction of CH_4 not recovered or flared, varies from 0 to 1 depending on the treatment unit.

These complex energy economic analyses are better done and stipulated by policy governing bodies instead of the implementing agents, firms or individual countries to avoid bias analysis. This again points to the existing gap of a governing body. However, ICT applications facilitate to simplify these calculations through Green IT software to ensure that a sustainable and fair business climate prevails.

4.3. Green IT Software

While many software applications exist together with the geographical information system (GIS) based applications, some examples of software systems that may assist companies and countries to measure, manage and possibly cut down their carbon, energy, water and waste footprints are the (Carbon Trust 2019; Imasiku 2018):

(1) Footprint Manager—it is a cloud-computing based reporting tool that enables an organization to measure, manage and cut down the carbon footprints.
(2) Footprint Expert—this is a desktop-based software system tool capable of helping organizations to produce accurate carbon footprint readings quickly for different products and services.
(3) Data Analytics Manager—this tool can assist organizations to move to advanced big data analytics to evaluate choices of sustainable strategy.

Besides the above software systems, some obtainable open source software that can be used to design artificial intelligence (AI) based systems for monitoring carbon footprints and to trace carbon emission-cut defaulters or any other statistical computing, remotely include:

(1) Open-source Data Inventory for Anthropogenic CO_2 (ODIAC; Oda et al. 2018),
(2) Open source software R (QGIS 2019),
(3) RStudio (R Project 2019), and
(4) QGIS (R Studio 2019).

An achievable measuring process of CO_2 emissions is workable if a global measuring framework for green growth exists (OECD 2012). However, the establishing monitoring framework does not go with no challenge especially within the developing nations owing to different pressing priorities including impoverishment, weak institutional capability, food insecurity, gender inequality, poor infrastructure and consequently have policy priorities that differ from developed nations (OECD 2012).

4.4. CO_2 Monitoring Method

The monitoring of CO_2 emissions at an organizational or firm level reflects an overall country-specific emission reduction once aggregated in alignment with country-specific policies and regional policies. Figure 6 below shows the key steps in calculating an organizational carbon footprint are (Carbon Trust 2019; Imasiku 2018):

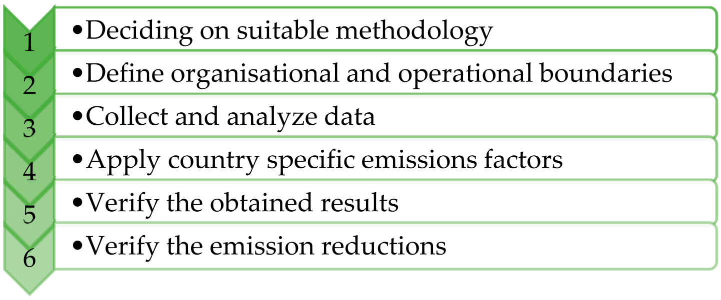


Figure 6. Key steps for calculating carbon footprint sourced from the Carbon Trust website, 2019 (Carbon Trust 2019).

These six key steps to monitor CO_2 emissions are further explained as follows:

- Step 1: Deciding on the methodology to follow—it is vital to use a consistent method that would give accurate results, especially if the method depends on many people to assist the collection and interpretation of the data. The GHG Protocol is one amongst the foremost commonly used standards. It provides elaborated guidance on methods and is offered free online. Another recognized standard is from the International Organization for Standardization, ISO 14064, which builds on several concepts introduced by the GHG Protocol. Both provide an additional explanation of the steps lined here. The 2016 IPCC policy document has provided a flowchart to assist select appropriate methods.
- Step 2: Define organizational and operational boundaries—set clear boundaries for the elements of the organization to incorporate within the footprint. This could be complicated if a firm has many

subsidiaries, joint ventures or hired assets. The operational boundary determines the emission sources to quantify together with the complete range of emissions from activities under the firm's operational control. It may help to fit in with a reporting system and legislative requirements like the Carbon Trust Standard.

- Step 3: Collect and analyze the data—the accuracy of the footprint depends on collecting and analyzing the consumption data for all the emission sources within the organization's established boundary. For gas and electricity, collect data in kilowatt hours (kWh) from meter readings or bills. This may include data for other fuels in other units, like liters, kWh or mega joules (MJ).
- Step 4: Apply emissions factors—the carbon footprints are usually given in tonnes of CO_2 equivalent (tCO_2e) and are obtained by getting the product of the activity data collated and applicable emissions factor.
- Step 5: Verify the results—in order to confirm the country or firm-specific carbon footprints, the results are verified by an independent third party verifier.
- Step 6: Verify the emission reductions—firms ought to take up this step for reporting. Carbon footprint cutbacks usually enhance investor confidence, credibility and confidence.

4.5. Method Validation

Since the study approach adopted was socio-economic, political and technical by nature, the validity of the chosen methodology depends on many factors. For a fair business climate to prevail, it is advisable that the three pillars (3Ps) of sustainability are utilized as critical design parameters of calculating and monitoring CO_2 emissions even if software approaches are used.

4.5.1. Design Specifications for Sustainability and a Fair Business Climate

The design of Green ICT solutions ought to integrate all the pillars of sustainability; the people, the planet and the profit (3Ps; Slack et al. 2013). Figure 7 below shows the three pillars (3Ps) of sustainability (Imasiku 2017).

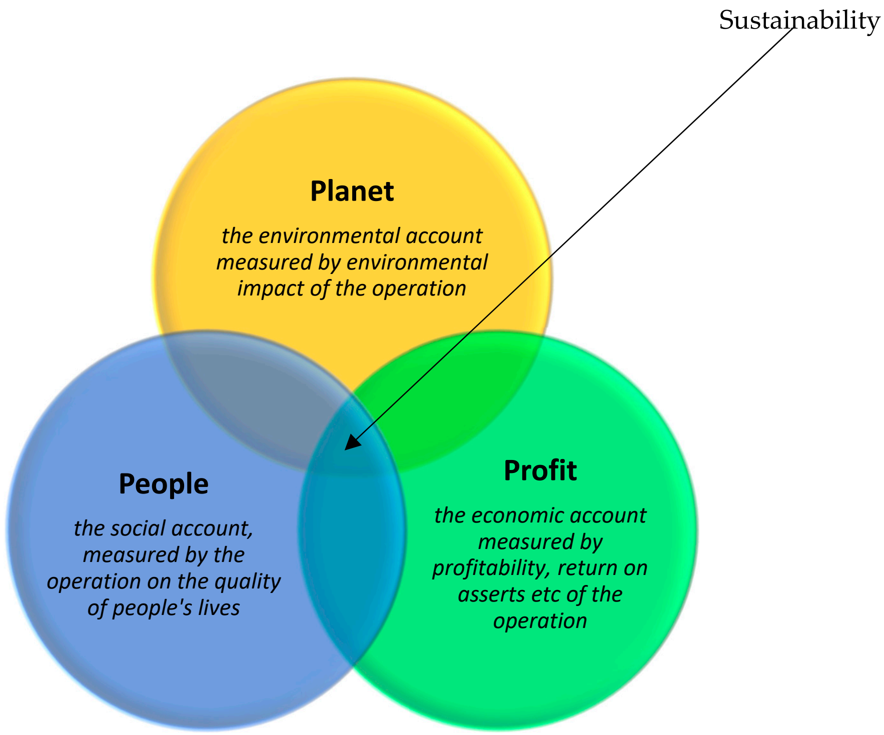


Figure 7. The three pillars of sustainable development (Slack et al. 2013; Imasiku 2017).

Most research studies on Green ITs focus on environmental issues and neglect human issues like ethics. The basis of ICT development has helped many people perform their work activities with well-defined ethical guidelines to produce ICT-based solutions in compliance with the International Telecommunications Union—Telecommunications (ITU-T) regulations. Since this ethics approach is people-centric, it impacts positively on the choices realized in the planet pillar (environmental ethics) and in the profit pillars (economic ethics) to promote fair business (Rondeau et al. 2015). From this analysis, the authors infer that fair business is critical because of previous high capital investments in the fossil fuel technology by most top CO_2 emitters. With this business acumen in place, the CO_2 cutbacks can consider the planet, profit and the people (3Ps) before allocation and over appropriate durations with the amount of investment for a fair practice.

The proposed method capable of unraveling Green ITs as a greenhouse gas emission game change in the world is two-fold. First, it involves a CO_2 measurement and second, it involves CO_2 monitoring methodologies. Instead of calculating the CO_2 emissions manually using mathematical Equations (1)–(17), given in Section 4.2, software systems like the Footprint Manager, Footprint Expert and Data Analytics Manager can perform these operations with ease (Section 4.3). One of the major input data to this software are the CO_2 budget-cut factors so that the software could determine whether one has reduced or exceeded the allocations. These pre-determined factors defined by the IPCC (2016), ensure that a fair business climate prevails while taking the three pillars of sustainability (3Ps) into consideration.

4.5.2. The Importance of Carbon Emission Monitoring

Some reasons for calculating and monitoring CO_2 emissions using software applications is to assist firms in (Carbon Trust 2019; Imasiku 2018):

(1) Identifying the cost savings across the business supply chain network.
(2) Identifying the opportunities to reduce environmental impact through reductions in material use, water usage, general waste and increase sustainability and energy efficiency.
(3) Promoting product innovation for low carbon emissions for sustainable product design.
(4) Understanding the business supply chain risks for mitigation techniques application.
(5) Since there is already a substantial level of pollution, there is a need to adapt by combating the prevalent climate change and prepare for future legislation.
(6) Enhancing the firm's brand and acquire new business opportunities through improved environmental credentials concerning carbon footprint labeling and communications.

All these benefits contribute to the firm's sustainability and this culminates to any country's, region's and therefore the world's success.

Acceptable levels of CO_2 emissions are calculated and monitored before being reduced to ensure that a fair business climate prevails. However, the authors would like to stress that while Green IS is the umbrella for this task, the technology behind the game-changing task is IT since it is a driving technology for information systems (IS). With these facts in situ, Green ITS stands a greater success chance because it combines both Green IT and Green IS concepts and interacts with the socio-economic factors that characterize the business world.

4.5.3. Scientific Justification

The method used to estimate carbon emissions from energy consumption is regularly under review. The IPCC revised CO_2 emission factors in 2016 has some advantages over the old ones. This new method does not use default CO_2 emission factors for the combustion of each energy product type but rather each product type has its own specified CO_2 emission factors. However, biofuel emissions were exempted from this capture because of the net effect of their contributions resulting from the process of photosynthesis. The new method is 8% more effective than the old method (British

Petroleum Statistical Review 2016), (Liu 2012) because the 2016 IPCC new procedures encourage all countries to take steps that increase the perceived transparency of tier 3 models. This includes use, evaluation, review and documentation of models such as the COPERT (computer program to calculate emissions from road transport); New Zealand's enteric CH_4 inventory model; the CBM-CFS3 (carbon budget model of the Canadian Forest Sector) and the models of CH_4 emissions from rice paddies (IPCC 2016). The selected method adheres to the revised 2016 IPCC procedures[3] and considers all the emission factors throughout the life cycle of the equipment, from manufacturing, through usage to equipment failure and decommissioning.

The following elaboration shows the impact of CO_2 factors on system efficiency (British Petroleum Statistical Review 2016).

Illustration: To calculate the carbon emission of the ICT architecture life cycle for a product manufactured in China with a CO_2 factor per kWh at 0.97, and recycled in France with a CO_2 factor per kWh at 0.09, the carbon emissions can be calculated using Equation (1) in Section 4.2.

Given that:

- Situation A: The energy consumption at manufacturing, utilization and dismantling is 11,700, 22,849 and 2600, respectively.
- Situation B: The energy consumption at manufacturing, utilization and dismantling is 12,600, 24,382 and 2800, respectively.
- Situation C: The energy consumption at manufacturing, utilization and dismantling is 11,700, 25,915 and 3000, respectively.

Recalling Equation (1); where α is the gain related to the stage of the life cycle, α_m corresponds to the factor during the manufacturing stage, E_m represents the manufacturing of equipment, E_u is the use of ICT-based architecture and E_d the dismantling of ICT-based architecture.

We obtained the following solutions:

Solution A: $(11{,}700 \times 0.97) + (22{,}849 \times 0.09) + (2600 \times 0.09)$
$= 11{,}349 + 2056 + 234$
$= 13{,}639$ kg CO_2

Solution B: $(12{,}600 \times 0.97) + (24{,}382 \times 0.09) + (2800 \times 0.09)$
$= 12{,}222 + 2194 + 252$
$= 14{,}668$ kg CO_2

Solution C: $(13{,}500 \times 0.97) + (25{,}915 \times 0.09) + (3000 \times 0.09)$
$= 13{,}095 + 2332 + 270$
$= 15{,}697$ kg CO_2

Plotting the results of the solutions A, B and C yielded a visual perspective of how CO_2 emission factors can impact on the overall carbon emissions of the equipment life cycle from manufacturing through usage and up to the dismantling or decommissioning stage. Figure 8 below shows the effect of different carbon emission factors on a product life cycle.

These results are of interest to authors because they display the ratio between the manufacturing usage and dismantling stages. The carbon emission cuts of any equipment should be accounted for both the manufacturing and the usage stages within or outside the country of manufacture and usage so that the design engineers may decide on the best solution. To achieve sustainable development, all three pillars (3Ps) of sustainable development (Section 4.5.1) should be considered. From Figure 8, the highest carbon emissions are recorded at the manufacturing stage. This shows that the 'planet pillar' is greatly affected at the manufacturing stage than at the usage or dismantling.

[3] https://www.ipcc.ch/site/assets/uploads/2018/05/1608_Minsk_Scoping_Meeting_Report.pdf.

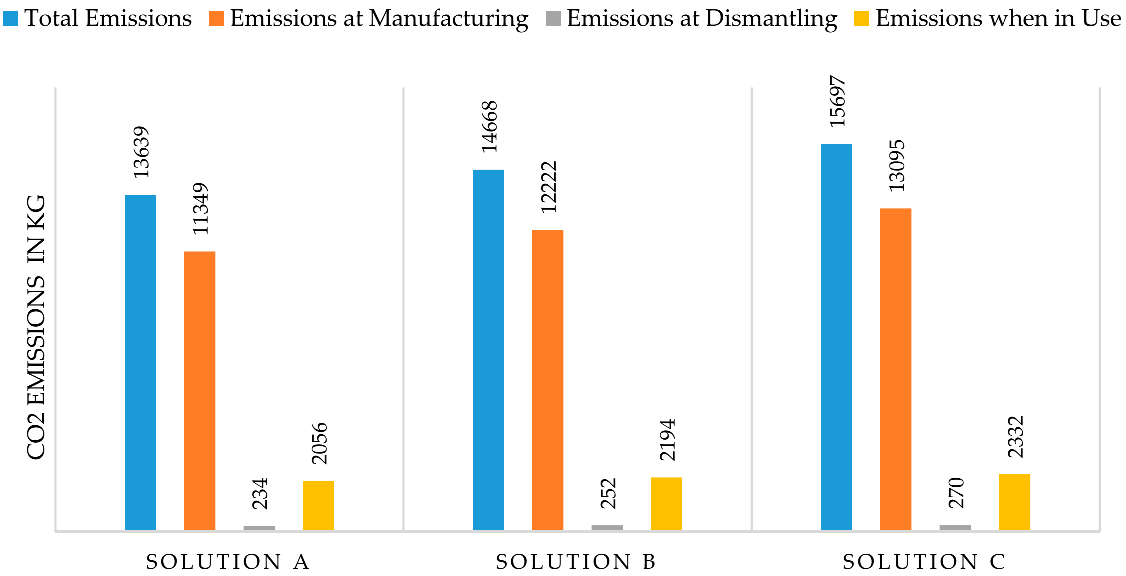


Figure 8. Effect of different carbon emission factors on a product life cycle.

5. Results

As opposed to the simpler idea that Green IT is the game changer, it is now clear that Green ITS is the real game changer capable of reducing CO_2 emissions globally because it combines management, organizational and technology dimensions, hence meeting the demands of sustainable development pillars—the planet, the people and profits.

Green IT is the practice of implementing policies and procedures that improve the efficiency of computing resources in a way that reduces the energy consumption and environmental impacts of the utilization of computer systems. Information technology (IT) is the focal point and driving technology of information and communication technology (ICT) applications like Green IT and Green IS. Information technology helps to manage enterprise activities of products, services and resources in an intelligent and sustainable manner throughout their equipment life cycle (Zaman and Sedera 2015; Vella 2018). This points to information technology as core skills for running the information systems in order to support sustainable business activities. Technology is a vital tool that the world can use to address its global problems. The leverage behind technologies to produce goods and services that are environmentally friendlier translates into viable business opportunities (Boudreau et al. 2008; Imasiku 2018).

To accommodate all sectors other than the computer systems alone, a business perspective and approach to combat GHG emissions is inevitable. The information systems (IS) approach has the potential to resolve the GHG emissions problem because it provides a technical approach, which addresses broader issues faced by firms by combining management, organization and technology elements. The management dimension comprises of leadership, strategy and management behavior while the technology dimension comprises computer hardware and software, data management technology and computer networking (including internet) and telecommunications technology. The organization dimension involves issues like the organizations' hierarchy, functional specialties, business processes, culture and political issues (Laudon and Laudon 2014; Imasiku 2018). Chowdhury introduced sustainability to IS and defined Green IS as a sustainable management system that is designed to manage data and information as an output to support specific research, scholarly and/or decision-making activities (Chowdhury 2012; Table 1). The authors conjointly utilized the concepts of Green IT and Green IS to develop the green information technology system (Green ITS) concept as the technique that is capable of combating GHG emissions worldwide. The authors define Green ITS as a sustainable information technological design of a business information system that monitors carbon, energy, water and waste footprints to enhance green growth and avoid a merry-go-round syndrome using a strong global policy.

While many developing nations concentrate on improving the country's human development index (HDI) without paying much attention to the energy development index (EDI), they may find themselves making little progress because HDI and EDI have socio-economic synergies. The HDI shows in so many ways that access to reliable energy has positive effects on human development. Access to energy is a primary need and an enabler to other service industries such as rural clinics and schools and manufacturing industries. This includes access to clean water and sanitation services. The 2012 World Energy Outlook report showed that the EDI scores for most developing countries remain low and Sub-Saharan African as a region scores the least[4].

Energy forms a foundation for modern economies and therefore is a focal need for modern life. It is a prerequisite for improved living conditions, poverty alleviation and economic growth as stipulated by the UN—SDG 7, which emphasizes access to affordable, clean energy for all. Although renewable energy technologies (RETs) can offer the desired clean energy and directly resolves the CO_2 emission problem, this is not easily achievable because the energy infrastructure in most countries are fossil fuel-based and the renewable technology infrastructure is still not affordable by all. Other challenges surrounding the use of renewables are poor accessibility and the lack of large-scale storage facilities so they are used when needed (The Fundamental Limitations of Renewable Energy 2019).

Most governments and international organizations like the IPCC, the UN, civil society and academia have contributed to enhancing green growth by advocating for the deployment of renewable energies as a strategy to resolve the CO_2 emission problem (Bina 2013), but without stronger policies and merely depending on CSR, all CO_2 emission cut back efforts would be null and void and cause a global CO_2 emission merry-go-round.

The Green ITS framework in Figure 9, showing the interplay between the global policy, Green ITS and carbon emissions, serves as a good summary of our research findings.

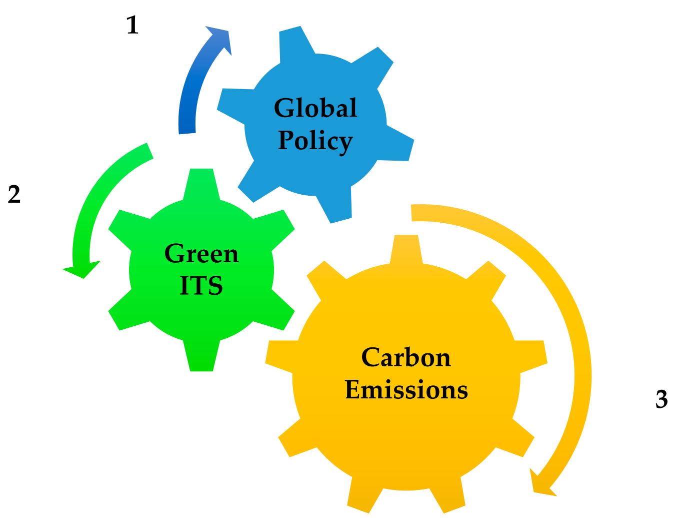


Figure 9. Authors' own-conceptualized Green ITS model.

The author's own-conceptualized Green ITS model in Figure 6 shows that there is a need for the world to consider adopting a worldwide policy to avoid the prevalent CO_2 emission merry-go-round. The order of importance in the Green ITS model is 1, 2 and 3 implying that global policy is a priority for driving the Green ITS to reduce the CO_2 emissions merry-go-round worldwide.

4 International Energy Agency 2012.

Because of the observation in Section 4.5.3, in Figure 8, that the highest CO_2 emissions stage, in the life cycle of some pieces of equipment is during manufacturing and in the context of the 'planet' pillar, the authors recommend that greater engineering efforts are made at the manufacturing stage to reduce the emissions increase without neglecting the profit pillar. Additionally, the CO_2 emissions budget cuts and the ambition by mankind to replace fossil fuel infrastructures with renewables should ensure that a fair business climate prevails with all individuals, firms or countries competing favorably.

The world has today exceeded the threshold of 410 ppm[5] and is experiencing climate impacts already and health impacts associate with burning of biomass and fossil fuels. By 2015, seven million people died prematurely from pollution-related diseases, accounting for about 16% of all deaths worldwide (OECD 2012). It is also projected that about eight million people will have died prematurely by 2050 because of impacts associated with pollution and climate change (Figure 3). Having a strong global policy and possibly a UN organization to monitor and implement the global green growth project through Green ITS would assist the reduction of CO_2 emissions worldwide and save lives.

6. Discussion

The authors advocate for the adoption of the Green ITS concept as a game-changer capable of resolving the carbon emission merry-go-round that is impacting the ecological systems on earth and food chain systems by altering the life-supporting climate on earth.

Adopting the Green ITS, fostering green growth through renewable energy usage, must not be seen as being a costly activity of doing business but as an opportunity for organizations and nations to cut back their carbon footprints, reduce costs, improve productivity for increased profitability and sustainability. Failure to use resources effectively, having energy inefficiency, noise, heat and other emissions are all forms of waste products, which lead to environmental burdens that consequently deduct from the potential for economic growth in most nations. A lean six sigma production should be everyone's approach because it would yield a reduction in waste and translate into more efficient enterprising firms. Pursuing Green ITS to create more sustainable businesses would benefit the local communities, customers, investors and future generations. However, this is achievable if stronger policies exist because the CO_2 emission cutbacks have been left to be addressed through corporate social responsibility (CSR) and this approach has to date yielded little or no positive result. The annual growth rate of CO_2 in the atmosphere is 2 ppm and as of January 2019, the total CO_2 concentration stands at 413.96 ppm.

Although the formulation of stronger global policies or a legislature is not an easy task because most stakeholders in the world today have different interests, gains and motives, the exercise of cutting back the CO_2 emissions must not be viewed as an expensive activity but as a chance for the world to scale back its carbon footprints, which present risks to humanity. Some benefits of such an exercise are improved productivity, reduced waste, increased profitability and sustainability on a global scale (Boudreau et al. 2008).

Since renewable energy resources and RETs can reduce significantly carbon emissions through displacing fossil power generation, a cutback on CO_2 emissions would indirectly encourage a high usage of renewable resources and the associated technologies. Although CO_2 emissions have not exploded from 2015 to 2017, a 2% increase was experienced in 2017.

So far the present GHG emission policies that place confidence in CSR have not managed to curb the GHG emission increase that has prevailed since 1959. The authors deduced that the current policies guiding the climate change problem are efficient, but not effective enough to manage the worldwide CO_2 emissions To resolve the current GHG emission crisis, diplomatic approaches like CSR is not adequate but with a bit of force, a new collective approach like the corporate shared value (CSV) may

[5] https://www.co2.earth/daily-co2.

be cultivated in all stakeholders (Foschi and Bonoli 2019; Amor-Esteban et al. 2018). CSR is subjective to political will.

Although renewable energy technologies (RETs) present a good solution, they are still not yet affordable to all. The current international policies are not very favorable to the existing coal power plants, nuclear power plants and hydropower plants because they tend to give a lot of economic energy for many nations with fossil fuels offering an alternative for base-load power. Within Europe and conjointly the United States, the leveled cost of producing power from a new gas turbine is currently less costly than from a new coal-fired unit and this is increasing the popularity of deploying new gas-fired and making the coal-fired plants to skew towards coal in mostly the developing countries due to their dependence on expensive imports for gas supply resources. The struggle to establish a balance between environmental sustainability, financial gain and energy equity poses a serious sustainable development challenge, which is even worsened by the absence of a global price on air pollution and carbon emissions[6]. The world has abundant renewable energy resources especially wind and solar energy although they are not available everywhere and at all times. This research points to a need for further research work on energy storage systems so that renewables could be utilized where it is not available and when needed. Though photovoltaic (PVs) prices have fallen, the PVs with high efficiencies of about 43% are still uncommercialized[7] while the commercialized PVs have low efficiencies, in the range of 20%. There is a need to find a way to reduce the cost of more efficient PVs so that the entire solar spectrum is harvested. In 2017, a US-based firm, SkyThrough Solar Concentrator reported having produced the world's most efficient concentrator PVs with efficiencies of about 73% but again, this PV is not yet commercialized, still expensive and thus not affordable by the poor majority[8]. Since there is a correlation between having access to affordable, reliable energy and development, it also follows that the human development index (HDI) depends on the energy development index (EDI). This is true because the most underdeveloped nations in the world also experience energy poverty. Renewables can reduce energy poverty and enhance green growth and sustainable development.

Sustainable development is not just for the developing world alone but for the developed world as well because the environmental impacts manifesting as global warming and climate change do not spare the developed nations. However, the authors recommend that developing nations over-embrace green growth than developed nations because they suffer greater consequences than developed nations due to both financial and technological inadequacy to deal with climate adaptation and mitigation. However, this does not mean that climate mitigation and adaptation is just for developing nations, but for both worlds. To achieve a sustainable energy development, we recommend the enforcement of the efficient use of electricity through sustainable development licenses or renewable energy certifications (REC certification) as a global criterion of awarding business opportunities.

To ensure that a fair business climate prevails, and to allow the countries to make a smooth transition from fossil fuel investment and infrastructure to renewables, a cost-benefit analysis should always be conducted before determining the country-specific emission reduction factors because of the high capital investment on the current fossil energy infrastructure. The CO_2 emission reduction process should consider the people, planet and profits (3Ps) before allocated over reasonable durations and fair CO_2 budget cuts or CO_2 emission factors like those shown in Table 3 in Section 4.2 to enhance sustainable development through green growth. Apart from CO_2 emissions, reduced environmental impacts through reduced material usage, water usage and general waste would increase sustainability and energy efficiency.

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[6] World Energy Council Resources, 2016.
[7] https://www.nrel.gov/pv/assets/pdf/cell_efficiency_chat_explanation.pdf.
[8] https://inhabitat.com/skyfuels-skytrough-is-worlds-most-efficient-solar-concentrator/.

From Section 4.5.3, Figure 8, it is observed that the highest CO_2 emissions stage, in the life cycle of some types of equipment, is at manufacturing. In a contextual view of the 'planet' pillar of sustainable development, we recommend that greater engineering effort to reduce emissions should be adopted at the manufacturing stage. However, this should not be done without considering the profit pillar as this may motivate manufacturers to seek more financial gains in the pretext of developing sophisticated engineering equipment.

Of great importance is that the authors advocate for the formulation of global policy and a UN organization whose primary aim will be to implement the global green growth projects through the ICT applications like the Green ITS concept to monitor and cut back the CO_2 emission and stop the CO_2 emission merry-go-round worldwide. The Green ITS concept combines management, organizational and technology dimensions of climate change mitigation and adaptation. This makes it capable of not just being a greenhouse gas emission game changer in the world but a future planet and lifesaver to humans, animals and plants. Besides this, the authors are calling for a more united and centralized governing body whose main role would be to monitor and evaluate the CO_2 emissions cuts worldwide because global CO_2 emissions have continued to increase. The energy economics analysis and CO_2 emission budget compliance role is not supposed to be left to individual firms or countries to calculate but rather be monitored in a coordinated manner that does not disadvantage those that are compliant to the allocated CO_2 emissions cuts or budgets.

The allocation of emission-cuts should not be left to the implementing agents, firms or countries to avoid bias analysis and non-compliance. This existing gap in today's climate governance system also makes the authors point to a more aggressive business approach of adopting the renewable energy certifications (REC certification) system as a global criterion of awarding business opportunities.

This insight by the authors concerning the need for a global policy is in agreement with a US-based thematic expert, Leila Mead, who explained in the article on climate change and sustainable energy, the recommendations by a team of climate experts from the Grantham Research Institute on Climate Change and the Environment and the Centre for Climate Change Economics and Policy at the London School of Economics and Political Science, UK, in partnership with the University of Leeds, UK and the Sabin Center for Climate Change Law at the Columbia Law School, New York, US, that stronger laws and policies are needed to implement the Paris Agreement because most governments are failing to import the agreed Paris Agreement targets into national laws and policies, and translate them into action (Mead 2018).

7. Conclusions

While developing nations over-exploit their natural resources in an unsustainable manner to attain a developed nation status, some developed nations protect their investments in fossil fuels at the expense of sustainable development. Some developed nations trade off their carbon emissions with cleaner investments and others put their gains and interests first. Stronger laws and policies are needed to implement the Paris Agreement because most governments are failing to import the agreed Paris Agreement targets into national laws and policies, and translate them into action.

In another dimension, as more people and nations accumulate more wealth, they adopt affluent lifestyles that exploit sophisticated tools and technologies that consume resources excessively or in an unsustainable or wasteful manner, stronger global policies are necessary to enforce CO_2 emissions reduction through the usage of renewable resources and less CO_2 emission intensive technologies to enhance green growth and ecological sustainable development globally.

Future research is therefore encouraged on designing an artificial intelligence (AI) based software system to monitor carbon footprints and trace carbon emission budget-cut defaulters. Furthermore, in order to deliberately cultivate corporate shared values in most firms and nations, the allocation of emission-cuts should not be left to the implementing agents, firms or countries, to avoid bias analysis and non-compliance. There is a need to formulate a strategy to combat global GHGs. This existing gap in today's climate governance system also points to the need for a more aggressive business approach of adopting a renewable energy certifications (REC certification) system as a global criterion of awarding business opportunities.

Green ITS technology can be taken advantage of to provide the technology services to reduce persistent carbon emissions. Green growth can be every nation's pursuit alongside the utilization of renewable energy resources and renewable energy technologies to achieve ecological sustainable development.

Unless carbon emissions are discontinued or reduced, the world lies in a corridor of GHG crisis because of the GHG emission merry-go-round syndrome where some nations reduce their CO_2 emissions, while other nations increase theirs, leading to a zero net impact on worldwide CO_2 emission reductions. There is a need for all nations to embrace lean six sigma thinking to enhance the values that go beyond mere corporate social responsibility (CSR) to reduce GHG emissions worldwide. A corporate shared value (CSV) approach is recommended.

The overarching conclusion is that there is a need for the world to formulate a strong global policy or policies that will emphasize the use of renewables and drive the Green ITS concept to combat the CO_2 emission merry-go-round and achieve ecological sustainable development.

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