Carbon offset as a tool to achieve carbon neutrality in building

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Abstract

One of the most debated topics in recent years corresponds to the increasing phenomenon of Global Warming, which is directly linked to a sizable amount of the carbon emissions emanated from the building sector. In the last decades, after the future predictions of recognizable scientists, governments around the world denoted their significance to combat the pollutant, by addressing to numerous researchers and organizations to discover aspects of lessening effectively the Greenhouse Gas (GHG) emissions. As an initial step for the reduction of the building's pollutant to the atmosphere, the development of the building envelope by the usage of wood-based materials, in parallel with the participation on forthcoming and revolutionary environmental projects and especially carbon offset schemes, was signified as essential. The greatest challenge of existing governments is the persuading methods concerning the contribution of people to the fundamental race of reducing the CO_2 emissions, involving the financial part. Hence, in order for the specific target to be achieved, governments and private organizations worldwide, collaborated to fund carbon offset programs related to energy efficiency interactions, along with the usage of low-carbon materials, concluding to the mitigation of GHG emissions in the building sector. However, for the accurate detection of the carbon emissions, and the appropriate selection of construction materials concerning the building envelope, the application of Life Cycle Assessment (LCA) is compulsory. Predominantly, the current dissertation supervises one case study, focusing on the building construction materials, along with the examination of the most impactful environmental categories, by the usage of an LCA software, the so-called OpenLCA. In addition, the construction materials were assessed in all the life cycle phases and illustrated in diagrams.

Keywords: LCA, carbon offset, construction materials, carbon reduction, Global Warming

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1 Introduction

Mainly Green House Gas Emissions(GHG) dominate today's world, considering the high quota of impact on Global Warming. The necessity of GHG emissions mitigation, along with scientists' discoveries reflecting on Global Warming, has led a variety of researchers and governments across the world to find solutions, covering all the aspects associated with the building sector and determinedly aiming to carbon neutrality over the years. Thus, in recent decades, a new groundbreaking idea has come to the forefront, divulging pioneering carbon offset projects to the world. The majority of the investigations for the reduction of the emitted emissions to the atmosphere consisted of numerous Life Cycle Assessment(LCA) methods, an extensive analysis on the building construction materials, and financial breakdown depending on the interferences.

Furthermore, a significant amount of GHG emissions globally are represented by the entire building sector, concerning the constructions materials and the energy used. A common phenomenon is observed, where either the engineers or the customers indicate for the construction of the building, materials which are used in several cases and mainly for their price, not knowing in detail the alternative and more environmentally friendly – low carbon options that occur in the market, therefore contributing to the maintenance of the already large amount of GHG emissions emanated from the building (Jannik Giesekam, 2016). Hence, the alteration regarding the building envelope is deemed necessary, with the proposed use of wood-based materials instead of concrete and more specifically the usage of timber as the preferable one, lightening the structure and resulting in the reduction of the volume of the unchangeable concrete foundations along with an around 9% lessening of GHG emissions worldwide over time (Austin Himes, 2020). On the other hand, the interventions into the energy use sector of a building differ pondering the location and the climatic zone, distinguishing them in parallel a crucial part of the pre-referred recent conditions, be concerned about the environment (Kneifel, 2009). Overall, the energy efficiency intrusions in the building are composed of the insulation, the solar system, the openings, and the Heating Ventilation and Airconditioning(HVAC) system. Such interventions are predominantly based on the purchase cost, in proportion to the payback period of such an investment, contributing to the overall reduction of energy use by almost 30% and an average of 16% reduction to the carbon footprint of the building (Kneifel, 2009). Additionally, the installation of photovoltaic panels(PV) will automatically lessen the energy use of a building even more, in contrast to the substantial negative effect on the environment, that its manufacture has (Cassandra L.Thiel, 2013).

Moreover, for more beleaguered research, highlighting the reduction of carbon footprint in the building sector, a variety of LCA methods from different researchers followed, aiming at educating mostly consumers wide-reaching about the integrated course of the majority of construction materials, demonstrating evidence that with the accurate intercessions in this specific area, the carbon footprint will be meaningfully condensed and slightly start to becoming the so-called Green Building. The core stages of LCA systems reflecting on low-carbon, arranged by the designing, the construction, the operation, and the most crucial part which is the demolishment, along with specific evaluation methods, resulting in the reduction of complexity regarding the understanding of the consumer, presenting a variation of legible table contents (Jianrong Tang, 2011). Therefore, examinations are focused on the materials that will initially be used along with the construction phase, concluding that as expected the concrete and steel occupy the largest percentages, concerning Global Warming, and surprisingly the construction of PV panels impacting the environment in an identical quota and making the installation of PV to building equally harmful regarding their construction phase (Cassandra L.Thiel, 2013). Overall, the phases that are being used and examined thoroughly by the researchers are the construction phase, the use phase, and the end of life phase, contributing to equal importance in the building sector respectively. `Also, the accurate specification of the Greenhouse Gas(GHG) emissions from the engineers, highlighted by the usage of a diversity of carbon label systems that occurs from the previous years along with some current upgrades, intending to implement an amalgamation filled with precise data, consisting of all the prevailing schemes and concluding to the better empathetic of the carbon labeling concerning building construction materials (Peng Wu, 2014). The goal is the continuous expansion of carbon labeling systems in order for engineers to possess the necessary data for the construction materials and the building sector in general, to make the appropriate modifications, and thus diminish the GHG emissions in parallel with Global Warming (Peng Wu, 2014).

In addition, a key role to the analyses occupies the forest, pondering the ascending but controversial usage of wood-based materials to the building envelope, in combination with carbon storage, and thus reflecting the impact of Global Warming. The comparison between a conventional building with curtailed usage of wood to a mainly wood-based one considering the amount of wood taken from the forest concludes to a significant amount of carbon emissions emitted for the construction of the wood-based building, in contrast to the typical one with an expected lower quota, highlighting the importance of restoring the balance in this segment (James Salazar, 2009). Therefore, having previously intended in utmost cases a discrepancy in the building envelope, that implies the upgrading percentage of the use of wood-based materials and explicitly timber, the examination of alternative harvesting of wood used from short-lived products or even wood that used for burning, transporting into the construction sector of the building, in order for the extraction of wood from the forest to be equalized (Galina Churkina, 2020). In general, the significance of upgrading the sector concerning the course of carbon after the demolishment of timber-based buildings is underlined, utilizing the soil where the wood is retained after the end of life, by employing it as carbon storage (Galina Churkina, 2020).

Moving on, as declared above carbon offsets schemes regarding the building sector are composed of a variety of indorsing actions made such as energy efficiency interpositions, reflecting on the HVAC system or insulation, and in general the modification of building materials, along with the construction of energy and wind wise projects, contributing to the global mitigation of GHG emissions and lessening the percentage of Global Warming. Carbon offsets can be either produced or sold through two key markets, containing Clean Development Mechanism(CDM) associated with the United Nations Kyoto Protocol and the controversial and more flexible Voluntary offset market (Lovell, 2010). Numerous countries across the world either embrace these particular markets or determine their own market, with the UK government in 2009 establishing Quality Assurance Scheme(QAS) associated with the CDM market, resulting in an overabundance of considerations on the subject of this judgment (Lovell, 2010). Additionally, individuals can also purchase carbon offsets credits along with companies, and in combination with the establishment of additional interactions during the day, the percentage of Global Warming, contemplating the lowering of GHG emissions, will be diminished even further (Gupta, 2011). Countries with a low quota of GHG emissions have the possibility to store a significant amount of carbon offset, and consequently emerging at the top of the wanted list with several countries entering the race for purchasing carbon offsets, concluding to a beneficial increment in revenues and more unambiguously in combat Global Warming (Gupta, 2011). Another key parameter in the reduction of GHG emissions and the supplying of carbon offsets is related to the forestry sector and the land-use amendment, arranged by opportunity cost and the accused of the delay in carrying out projects the transaction costs (Oscar J.Cacho, 2013). Every project before the purchase or even the specified opportunity of rental from the buyer goes through an exhaustive investigation to evaluate the profits, resulting in a higher number for the assortment of rental (Oscar J.Cacho, 2013). On the other hand, a variety of people are willing to participate in several carbon projects, aiming to combine ecological and social advantages, believing in the increase of job opportunities and in general the evolvement of the society by such an investment (Catherine J.Robinson, 2015).

On the other hand, in order to be able to illustrate all these critical interventions in the building sector either from people or from companies and build a beneficial collaboration, resulting in the reduction of GHG emissions and contributing positively to the phenomenon of Global Warming via carbon offset projects, the existence of funds from various sectors will play a significant role for such an involvement. Thus, the majority of the researches concentrate on the aid of low-income families and companies, principally with the cooperation of banks and government legislations (Paolo Bertoldi, 2020). Furthermore, a key role regarding the applicable approach to this kind of situation will be played by the flexibility of the bank, recommending loans with reasonable interest rates, intending to have a positive impact on consumers (Paolo Bertoldi, 2020). Governments across the world, willing to consciously contribute to combating the Global Warming effect, intending to the proliferation of carbon offset projects by implementing new innovative funded energy efficiency obligations and converting them subsequently to Green buildings (Siamanta, 2017). Additionally, a significant drawback regarding the taxes is primarily reflected in the most vulnerable categories of people, concluding to abstain from such programs, with a relatively low amount of countries offering a reduction of the taxes from energy efficiency improvements, recommended as an example for other countries to follow, targeting to the sustainability of the economical and environmental segment (Paolo Bertoldi, 2020). In most of the current cases, energy savings and mitigation of Greenhouse Gas(GHG) emissions are requested from governments, with a hasty approach regarding the energy efficiency interventions from the consumers, and therefore a proposed initial income related to energy saving will be extremely beneficial with a positive impact to the final outcome concerning the energy saved (Siamanta, 2017). Overall, the main application of the people is the reassurance from the governments that the balance between the economical and environmental sectors will be restored by upgrading the project's requirements and leading to the common goal of systematically reducing the Greenhouse Gas(GHG) emissions globally (Siamanta, 2017).

In this report, the carbon offset-related interventions in the building construction materials sector regarding the mitigation of Greenhouse Gas(GHG) emissions and the overall impact on Global Warming will be analytically examined through a Life Cycle Analysis(LCA) model. Firstly, a reference to carbon offset will be extensively discussed, focusing on the meaning and its utility worldwide along with a variety of LCA methods, targeting low-carbon materials for the construction and mainly the beneficial usage of wood-based materials. Second, an LCA model will be used for the calculation of the emissions regarding Global Warming, Terrestrial acidification, Terrestrial ecotoxicity, Ozone formation-Human health, Ozone formation-Terrestrial ecosystems, Human carcinogenic toxicity, and Human non-carcinogenic toxicity, with the usage of the main construction materials of a conventional building. Lastly, the results of the calculation will be discussed thoroughly.

2. Literature Review

(Gupta, 2011) analyzed mainly the meaning of the carbon credit and the carbon offset which are two financial ways for individuals or companies to contribute to saving the environment and discussed the role of India considering carbon trading. More precisely, the author referred to Global Warming as a result of the numerous amounts of carbon dioxide emitted in the atmosphere on a daily basis, making it indispensable for governments worldwide to find novelty schemes to combat this phenomenon. Initially, (Gupta, 2011) mentioned the Kyoto Protocol which was an innovative proposal started from the United Nations Framework Convention on Climate Change for the reduction of greenhouse gas emissions, that had the approval of 181 countries and the European Union in 1997 and started to operate in 2005. In general, the previously stated protocol was referring to profitable units whose emissions surpassed the limit, providing them with three possible solutions, the necessity of reducing the emissions, the purchase of carbon credits certificates, or compensating the dept with the so-called carbon tax. Furthermore, according to (Gupta, 2011) carbon credit has named a scheme that companies either were selling to others that had exceeded the limit of the emissions or were purchasing respectively by companies or individuals. In addition, India is one of the countries that have a low under the limit quota of greenhouse gas emission, thus having the opportunity of selling the saved carbon credits to the international market and by increasing the storage of credits, at the same time the earnings will be increased. On the other hand, carbon offset is the second scheme for the lessening of the emissions and has evolved in parallel with carbon credit resulted in many similarities considering the purpose. (Gupta, 2011) stated that the procedure doesn't stop after purchasing the carbon offset, emphasizing the need of individuals acting to extend the quota of the emissions emitted in the atmosphere.

(Lovell, 2010) examined thoroughly the carbon offset market, focusing on the evolvement of the voluntary market in contrast with the compliance market and providing the disputed decision of the UK government over the carbon offset market. The compliance market or CDM started after the formation of the Kyoto Protocol in 1997, composed of a series of time-consuming evaluation procedures in order for a project to be defined as Certified Emission Reduction, filling with reflection the governance in terms of bureaucracy. Moreover, a combination of registration to the Kyoto Protocol and several authorized documents is required for a country to have the allowance of selling or purchasing credits, according to (Lovell, 2010). In contrast to the mentioned above market, the voluntary market is noted as an independent market consisting mainly of informal saving time procedures and entitled as VCO or verified emission reductions (VERs) considering the verification. Overall, VCO organizations from the year 1990 that were first recognized as reputable, concentrating mainly on forestry offsets until 2005 were a relatively low number. Hence, a surprising upsurge in the quota of organizations entering the voluntary market was noted, with 123 million metric tones of carbon exchanged worldwide in 2008, resulting in an astonishing growth of 87% on 2007 volumes. The substantiated international voluntary offset standards with a quota of 79% collectively were Voluntary Carbon Standard(VCS), Gold Standard(GS), The Climate Action Reserve (CAR), and American Carbon Registry(ACR). The included voluntary carbon standards resulted in a significant revolution in the 2008 Market Share compering to 2007, highlighted by the 19% Voluntary Carbon Market increase. Concerning the relationship of the two types of carbon offset market with the governances, the UK government unexpectedly came up with a new system Quality Assurance Scheme(QAS), maintaining only the ideology of the compliance carbon offsets and thus coming into conflict with several voluntary organizations.

(Kneifel, 2009) examined the determination from energy efficiency enhancements of the energy savings and cost-effectiveness, the consequential mitigation of carbon emissions, and the resulting cost of carbon from an energy efficiency investment by using life-cycle cost and life-cycle assessment with a number of very detailed building cost databases, energy simulations of buildings, level of emissions rate and the average utility rates worldwide. Taking into consideration a prototypical building for each category, 12 building types and 3 building designs for each building—design amalgamation were examined in terms of size, number of floors, CBECS occupancy type, and floor space. Moreover, the results from the life-cycle costing and life-cycle assessment concluded from a period of one year, 10 years, 25 years, and 40 years, along with energy simulations for 16 U.S. cities and which have been located in dissimilar climates zones selected from ASHRAE 90.1-2004. The author used the RS Means CostWorks online database for the determination of the building construction cost for the prototypical building, altering the sectors of insulations and windows to scope the gap between the numbers of ASHRAE 90.1-2004 and ASHRAE 90.1-2007. In addition, maintenance, repair, and replacement (M, R, R) cost for each building type, considering the year of service life were taken from (M.Towers, 2008). On the other hand, M.R.R. costs for the interferences in building designs were occupied from RS Means CostWorks, apart from the HVAC in both cases respectively. The energy cost was delivered from the combination of the rates from EIA and energy simulations for 192 building type-location in EnergyPlus 3.0. Furthermore, the building residual value consists of the initial costs of the baseline residual value and the remaining residual value from the HVAC system that was altered during the study period. Inferring from the results obtained from the majority of the buildings types compared to the base case(ASHRAE 90.1-2004), mitigation of 30% in the energy use segment is considered to be doable. The differentiation of the worm and cold climate on the energy cost savings concluded to the low ratio of saving in a cold and higher amount of saving in the wormer climate. Over the perennial study period for the life-cycle cost of the 3 building designs for each type of building, was occasioned an increment of the quota of cost-effectiveness as the period increases for the Low Energy Case(LEC), attaining 93% in the last stage. An AIRR over 10% delivered from 56% and above of the study period collectively, surpassing the 7% fraction of the U.S. stocks. According to the author, a significant lessening was obtained for the majority of the cases, considering the life-cycle carbon emissions. Overall the carbon costs vary from different locations highlighting an intensification on the return of the particular investment.

(Catherine J.Robinson, 2015) explored the coexistence of innovative carbon offset systems mainly for the usage of Australian land field along with Indigenous people and organizations, aiming to a beneficial collaboration which is also consisting of the reduction of the emissions. Overall, the main idea was the examination of Indigenous people considering the movement on contributing in Payment for ecosystem services (PES) and carbon offset schemes in general, considering the ideally positive outcome in the long run. After collecting the data from the interviewed people which was directly implemented for further analysis and coding to NVivo, an evaluation of Carbon Farming Initiative(CFI) carbon projects by their subset composed by the idea of planting native trees was noted. The alteration of the CFI-funded schemes considering association separated to operational and feasibility respectively. In terms of ensuing into beneficial biodiversity conservation by planting, the usage of respectively effective CFI planting schemes was noted. According to the authors, a plethora of views was observed by the results considering the desirable benefits, consisting mainly of two parameters, the sustainability on the cultural, economic, and environmental sectors and upgrading local communities with collaborations which deliver an informative consent and the maintenance of the executive authority.

(Galina Churkina, 2020) examined the relationship of the building materials with the mitigation of the emissions along with the outcomes evaluation of 4 dissimilar building scenarios considering the use of mass timber and pointing mainly to the storage and CO_2 emissions percentages in the long run. In addition, energy efficiency interventions into the HVAC system are not related to the building's envelope in terms of reducing emissions. Thus the usage of bio-based construction materials like wood or mass timber was highlighted as a solution excluding the foundation sector, followed by a significant amount of awareness for the material's durability in extreme situations and the exposure to fire. Moreover, they noted the meaning of the usage of mass timber on new buildings, resulting in a significant quota of storage around 0.01-0.68 GtC yr^{-1} reliant on the scenario and offsetting in the forests a slight percentage of the momentary mitigation of carbon stock. As far as the carbon emissions are concerned, focusing on the number of emissions over the realistic 30 years timeline(2020-2050) of the 4 scenarios a meaningfully decrease noticed, contemplating the impact of mass timber on the foundation, using fewer construction materials due to the lightness of timber (Galina Churkina, 2020). The authors emphasized the influence that the use of timber would have on the forest, demanding a percentage of harvesting over 1 GtC yr^{-1} for the most timber used scenario. Hence, they came up with some alternative solutions of harvesting by the combination of wood and hardwood tree species along with bamboo and the modification of the round wood to the building construction field as the most advantageous one.

(Oscar J.Cacho, 2013) examined the procedure of trading carbon offsets through a designed model consisting of a project developer and a group of landowners, applied to two case studies, an Indonesian case with a farm sized around 2 ha and an Australian case with a farm of 2000 ha correspondingly, by either purchasing carbon flows or renting carbon stocks. The included variables in the model were, the trajectory of carbon offsets, duration, purchase price, sell price, stream of opportunity cost, present values of revenues and costs for buyer and seller, average area, opportunity cost coefficient of variation, carbon revenues, abatement costs, individual transaction costs vectors for buyer and seller, negotiation, approval, project management, monitoring, enforcement and insurance, discount rates for buyer and seller, number of landholders and market price of certified emissions reduction(CER). The diversity on the number of ha required for the feasibility of the two projects considering rental and the purchasing option with numbers higher for the rental one resulted for both projects respectively. Additionally, it was concluded from the graphs that the final value of the two contract options was almost identical as the CER price increased. After a Monte Carlo analysis, consisting of 10000 iterations, it was concluded to continuous mitigation of the minimum project area by the increasement of the CER prices with the greater area presented in the Australian case. Furthermore, the authors deliberated for the mitigation of the transaction costs, pointing to the Indonesian case because of its anticipated profitability in the future.

(James Salazar, 2009) studied the carbon and energy balance of two types of the house consisting of one with frequently used materials and one with mainly wood-based materials-wood intensive, applying a life cycle assessment(LCA) for the results. Three crucial systems are contained within the LCA, the product system including its subcategories, the forest sequestration, and the end of life which have been measured independently, and the results collectively. Moreover, the forest-related products used for the wood-based material house were twice as many as the typical house and the corresponding emissions numbers were even larger for the wood intensive house, as follows by the forest results. Additionally, using the ATHENA Impact Estimator for the life cycle of the two cases, resulted in differentiation in the energy mandatory for the manufacturing of the constituents in each type of house, with the wood intensive house having the lowest ratio. The authors indicated that the construction of the foundation for both cases was with reinforced concrete and thus resulting in a nonlinear correlation of the quota for the wood intensive house with 33% less released emissions and 52% fewer usage of fossil fuel than the typical one. For the End of life system they displayed two scenarios constituted by the retrieval of wood using it as a fuel and additional with the usage of a landfill which exploits average methane capture technology, the products were disposed of. Overall, the emanated emissions for the wood intensive house to the landfill were pointedly lower in comparison to the typical scenario and in combination with the recovery of the biomass, an enhancement for the wood intensive house concluded, considering the carbon balance, followed by an analogous outcome on the fossil fuel balance (James Salazar, 2009).

(Bruce Lippke, 2004) analyzed the outcomes of the CORRIM Phase I research, which was consisted of two typical building types on different locations and climates, composed mainly of wood resources and products. They elevated the pre-existing information by adding more product data from various LCA and LCI fallouts consisting of the variety of building-contraction sectors, followed by the formation of two alternative forms of design for each house type in order for an effective comparison to take place considering the used materials and the influence on the environment in combination with the energy use and the mass. Additionally , an alteration into the mass of concrete materials noticed , with the Atlanta house having the higher total mass percentage, in contrast with the total wood mass, was in the Atlanta house an extremely small quota of more usage of wood concluded in the comparison of the two designs. In the energy used sector, 60% more energy resulted for the Minneapolis house, and a superiority considering the utilization of primary fuels due to low percentages for the wood-frame house in comparison with the alternatives was highlighted. Furthermore, waste emissions from water, air, and solid were detected from the ATHENA Environmental Impact Estimator model(EIE) and a variety of other carbon emissions were concluded from the LCI procedure. For supplementary control of environmental directories, the implementation of the wood frame house as a base type was noticed, followed by interventions on the materials for a more substantial comparison of the outcome. A significant amount of non-bioenergy used resulted in both alternatives in contrast with the wood frame. In combination with the association of the forest management related to carbon, they focused on Pacific Northwest coming into conflict with the Kyoto Protocol.

(Jianrong Tang, 2011) analyzed the necessity of change considering the mitigation of the carbon emissions in the building sector, providing different approaches, along with the usage of LCA on low-carbon buildings, highlighting the importance of the fast switching to low-carbon buildings. For the reduction of carbon emissions, a variation of sectors for intervention was proposed, consisting of energy efficiency improvement, new energy utilization, environmental load reduction, low-carbon management, and carbon sequestration and carbon storage. Furthermore, implementing the double Life Cycle Assessment(LCA) system reflecting on the building's life cycle, which consisted of four main stages, the design, the construction, operation, and the demolishment, in order for the better understanding and evaluation of the building in terms of carbon emissions to reach sustainable development . In addition , the authors highlighted the difficulties prevailing in the aforementioned sector , mainly reflecting the uncertainty regarding the advantageous outcomes of the developer-user collaboration , attaching the importance of having renewed policies in relation to reducing the cost of such interventions and the deepening in the field of information, making the investment for low carbon building more attractive.

(Zaid Alwan, 2014) examined the outcomes from a variety of construction materials considering a typical building design prior to construction, quoting the total amount of energy consumption , embodied energy(EE), carbon emissions, and the cost offsetting through time, resulting in a better understanding of the carbon footprint of a building in terms of the climate change. An assortment of considerations consisting of the design stage material balance, the environmental commitments, the inventories of materials, and the ability to replicate methodology followed for the proper selection of the observed building. Additionally, for the accurate calculation of the mentioned above parameters, a series of various targeted steps, concerning the inventory of basic building materials, the type and volume of materials, the application of Inventory of Carbon and Energy(ICE) for embodied energy, operational values from the Chartered Institution of Buildings Services Engineers(CIBSE) and the impact of embodied energy over 10 years and offsetting in terms of carbon up to 2050, were pinpointed in graphs. A significant amount of difference was noted for the steel and concrete materials with the higher numbers in comparison to the others, regarding the total embodied energy and carbon. Moreover, taking into consideration the key role of the energy consumption of a building, in relation to carbon footprint, a continuous increase observed in contrast with the embodied energy for a ten-year period, concluded to a three-year payoff period with the appropriate interventions. The authors underlined that the cost of offsetting over the years will be increased dramatically and thus resulting in the idea of combining the actions for offsetting and reducing the carbon. For a more targeted and exhaustive study, the implementation of four basic sectors composed by study boundaries of materials, waste, and surplus building materials, the lifetime of the building, and services and maintenance were noted by the authors.

(Austin Himes, 2020) analyzed the importance of change in the building sector, considering the reduction of the emissions, and examined the difference concluded from the materials by addressing a building with commonly used materials in comparison to a wood one, based mainly on the usage of timber. The extraction of data took place through a systematic literature review consisting mainly of the construction phase followed by a variation of LCA studies by different authors. In addition, a statistical analysis was used for the defining of the alternation in construction phase emissions for the mentioned above buildings by implementing a linear mixed model(LMM), composed of the following variables of the estimated CO_2/m^2 emissions of the building from the rth study, the mean emissions of constructing buildings with conventional materials, the incremental effect on emissions of constructing buildings with mass timber, dummy variable equal to 1 for buildings constructed with timber and 0 otherwise, the random effect of the rth study, the random effect of the building size of the tth buildings and the random error associated with the estimate of emissions of the building. For a ten-year period in order to balance the stated quota of minimizing global warming by 2030, an assumption of 50% was taken in the usage of timber instead of conventional materials in the building sector. Moreover, the authors highlighted the superiority of the buildings using timber materials, referring to the low emitted emissions compering to the alternative materials, by highlighting a substantial 69% mitigation of the carbon emissions. Overall, the contribution of the timber used is emphasized by covering other important beneficial aspects considering the emissions and climate change in general.

(Zahra S.Moussavi Nadoushani, 2015) examined the advantageous alternation of using life cycle carbon footprint for the structural system of the building by designing five dissimilar structural systems for each of the three selected heights in comparison to the case building , ensuing in the formation of 15 structures collectively. In addition, the authors gave a piece of more detailed information considering the buildings frame design, for concrete and steel respectively, along with the location of the buildings which was provided by the American Institute of Steel Construction(AISC). Furthermore, in contrast to previous studies, in a variety of phases of the building's life cycle completed an extensive analysis of the carbon emissions , which was executed in all of the designed structures mentioned previously . The phases used for the estimation of the life cycle carbon were material extraction and manufacturing, transportation, construction, operation, and end-of-life. A noteworthy alteration referring to the resulting number from the operating, the life cycle, and the embodied carbon made the consideration of the life cycle carbon footprint as a key parameter for the structural design of the building.

(Andrew Buchanan, 2013) explored the difference of the outcome considering the environmental effects of energy and global warming of a three-story timber-based building in comparison with concrete, steel, and a low energy timber one, by performing life cycle assessments(LCA). The data considering the life cycle inventory for building materials, along with the potential of global warming for New Zealand, were extracted from other authors. The examined stages of the life cycle were manufacturing the building's materials cradle to gate and final disposal of the materials at the end-of-life of the building. In addition, the operational energy consumption for all the building designs was almost identical, in contrast to the low-energy timber one with an expected low number. For the material quantities, a slight difference was noticed between the total numbers of tones for the three designs apart from the concrete one with the higher total number. The separation of materials was placed between two end-of-life scenarios, the current and the future one. Furthermore, for the life cycle of primary energy considering the transport, embodied energy , operation and maintenance , concluded to a similarity on the resulted values in the two scenarios , in contrast to the end of life where a significant alteration was noticed in the future scenario. On the primary energy of building materials through the three stages, the timber-based building was the one with major development, considering the different landfills and the amount of useful energy. On the other hand, on the primary energy of building excluding operational energy throughout the two scenarios , the reduction of the required primary energy was resulted , in parallel with the fewest non-renewable energy required for the timber based building . For the life cycle global warming potential of buildings referring to the two scenarios , the values remained almost identical for all the types of design expect the end of life in each category with slightly differences , highlighting the lowest number for the low-energy timber building. Moreover, in the end-of-life, global warming potential of buildings for the two scenarios, the importance of steel considering the mitigation of the greenhouse gases was noticed. The low values of the timber-based buildings highlighted the global warming potential of buildings excluding operational GWP through the two scenarios. The usage of life cycle assessment based method for the comparison of the materials of the building required the participation by all major material manufacturers, agreement on the system boundaries, derivation of materials effects given as coefficients by life cycle assessment experts, and the adoption of simple methods by green building rating schemes (Andrew Buchanan, 2013).

(Cassandra L.Thiel, 2013) examined the results reflected to the environment, of the building materials phase based on a life cycle assessment(LCA) of a net-zero energy building named Center for Sustainable Landscapes(CSL) in comparison with other commercial building structures. For the life cycle assessment(LCA) of the CSL building, concerning the system boundary, the selected building categories were interiors, exterior wall, plumbing, HVAC, electrical, excavation & foundation, structure and roofing & waterproofing, in contrast to the low mass elements comparing to the building mass which was excluded from the analysis. Additionally, the two impact assessment methods implemented on the life cycle impact assessment(LCIA) were a Cumulative Energy Demand(CED) and a Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts(TRACI). A separation of the results was obtained by the authors, in order for a better understanding of the data. The superiority considering the high percentages of structure, excavation & foundation along with electrical systems to the majority of the impact categories, highlighting mainly the impact of concrete and steel for the majority of the impact categories, thus a series of interventions mainly for concrete, steel, and materials referring to PV panels, regarding other studies followed for the reduction of the emissions. On the other hand, for a more detailed evaluation of the results for the comparison with the five alternative LCA studies, the CSL building presented two options concerning the PV usage. For the global warming potential denoting to the comparison, a high amount of concrete and steel resulted for all the types of structure along with the increment of the quota for the CSL when the PVs were applied. For the embodied energy concluding from the comparison, a lower percentage of concrete for all the structures was noted, in contrast to the high percentage of energy for the CSL due to the PV system.

(Jan Gerrit Geurt Jonker, 2014) analyzed the alternation of the source for the production of wood pellet, placed in the South-eastern United States, using forestry biomass and mainly softwood, aiming to the determination of carbon offset and payback period by addressing three different methodological approaches from the carbon accounting program GORCAM considering three different management intensities, in order for carbon balance to be achieved. The three approaches used for the study were stand-level, increasing stand-level, and landscape-level for the low management intensity, the more intensive forest management, and the most intensive forest management scenarios respectively. Furthermore, a variety of carbon emissions considering the wood pellet supply chain composed of truck transport, pelletizing, international transport, oceanic transport, and cofiring of wood pellets in Dutch power plant, were calculated. The dry biomass number of tones for each of the three productive scenarios was calculated. Additionally, considering the carbon balance for the three productive alternatives, including emissions in supply and avoided coal emissions with the usage of the stand level approach, a significant difference in the value of fossil carbon avoided and on the course of balance was noticed along with the carbon debt, which remained the same from the beginning. On the other hand, for the increasing stand-level approach considering the carbon balanced, a balanced rise for the fossil carbon avoided was noticed, along with the temporary increment of the carbon dept over the years until it balanced at some point after 25 years . For the usage of an landscape approach , referring to carbon balance the differences were noted in the same sectors as on the previous approaches , with the value of fossil carbon avoided starting from a higher starting value followed by a continuous increase, in contrast to the carbon debt which value continued the same over the years. The comparison of the carbon balances of productive scenarios with a no harvest scenario by using the increases and landscape-level approaches resulted in a substantial increase for the tree and litter carbon and higher carbon offset parity points. The average greenhouse gas emissions(GHG) profile of wood pellet fired electricity for the three productive scenarios of the first harvest resulted in the highest value for the low productive scenario and zero net emissions for the highly productive one.

(Jannik Giesekam, 2016) highlighted the importance of changing the current approach considering the mitigation of embodied emissions from the building by providing various of other studies focusing on the usage of alternative materials for the construction sector. Thus, the authors proceeded with an innovative idea by interviewing and using a survey with 17 core questions to a number of people, aiming to understand the reason for the selective materials on construction projects related to the mitigation of embodied carbon emissions. On the survey were approximately 17 questions composed mainly of the influence and responsibility of respective professions, the knowledge of alternative materials, experiences with alternative materials, the barriers, the drivers, and the comments. For the interviews resulted that the majority of the people agreed with the stated quota of the emissions reduction but there was noticed a difficulty considering the responsibility of specific materials during a construction project. Furthermore, they deepen their result from the interviews through numerous sectors consisting of costs, low value of materials, knowledge – understanding and skills, demonstration projects and product testing, early engagement, negative perceptions of low carbon materials, moral convictions, establishment of an embodied carbon community, client requirements, regulation , business opportunities, benchmarks and role of institutions. Overall, they concluded that with the appropriate drivers along with extensive knowledge of the materials in the construction sector, the reduction of embodied emissions will be achieved.

(Peng Wu, 2014) analyzed the importance of upgrading the carbon labeling schemes for construction materials, along with greenhouse gas emission(GHG) standards, in order to better understand climate change by the extensive and accurate measurement of the greenhouse gas(GHG) emissions of the buildings. Additionally, they explored the international GHG standards through time, composed by PAS 2050, WRI/WBCSD: the GHG Protocol, and ISO 14067. The comparison of the three GHG standards resulted in various differences considering the criteria, with the ISO 14067 the one in which guidelines regarding the use and the comparison of carbon labels were provided. On the other hand, the existing carbon label schemes were Singapore Green Labelling Scheme, CO_2 measured label and reducing CO_2 label, CarbonCounted, CarbonFree, and Hong Kong Carbon Labelling Scheme. The evolution of carbon labels for construction materials was achieved by upgrading the regular carbon label at a product level along with the assurance of the company considering the reduction of GHG emissions. Overall, for further improvement in both GHG standards and carbon labeling schemes, some useful tools were discussed extensively composed mainly by benchmarking, raising consumer awareness, standardization, and simulation technologies in carbon labeling.

(Siamanta, 2017) analyzed the importance of change considering the environment and mainly focused on the relationship of photovoltaic projects with the green economy , considering Greece, along with the financial outcome of such an alternation for the companies and the country in general. The data of this study were extracted from a Foucauldian focused on discourse analysis, a variety of sources of information, and essential semi-structured interviews. The summary of oral, written, and video material consisting of speeches and statements by the Greek Prime Minister and Ministers of Environment and Economics, Laws, Ministerial Decisions, Law Bill Explanatory Statements , reports, and press releases by the former Ministry of Environment , Energy and Climate Change(YPEKA) , reports , guides , press releases , statements , official websites and Facebook profiles of large Greek ENGOs , official websites and press releases of RES market bodies and statements by their key representatives , television advertisements by banks and ENGOs and the Greek printed and electronic press , were involved for the discourse analysis . Furthermore , some large companies approached Greece considering the reduction of climate change by suggesting RES systems as a way out of unemployment and resulting to a great contribution to the environment . Wind parks and the placement of PVs on the roofs was the proposed idea from Greenpeace and WWF Hellas. On the other hand, a project named Helios was implemented in 2011 by EU Council, consisting mainly of PVs and extracting their income to Germany and other North European countries, in order for the mitigation of the pre-registered financial support mechanism by the troika. The decisions of the government considering the PVs were in conflict with the majority of the people and along with the crises, it was difficult for them to keep up.

(Buchanan, 2007) analyzed the advantages of the designing of sustainable buildings in New Zealand with the usage of wood-based materials, considering the mitigation of fossil fuel energy consumption and CO_2 emissions. For timber buildings, the materials used to cover the following criteria consisting of renewable, low energy, low CO_2 emissions, sourced locally, reusable and recyclable, minimum waste, and non-polluting. The author highlighted the need for forestry in New Zealand referring to Kyoto Protocol standards. The usage of timber for the construction of buildings reflected the increasement in the pool of carbon in wood-based products, in the mitigation of fossil fuel used in manufacturing wood rather than more energy-intensive alternative materials, and the extraction of fossil fuel by burning of wood waste materials, in order to minimize the emissions. Furthermore, timber materials stored a significant amount of carbon and released it into the atmosphere after tearing down, in contrast to other materials like cement which releases carbon during the manufacturing phase. Wood-based materials considering solar energy, in comparison to alternative materials, used less embodied energy for their manufacture. The author noted that the combination of wood processing, forest harvesting, waste on construction site, and demolition of the building, concluded to wood waste. On the other hand, the construction materials on new buildings lead to the mitigation of heating and cooling energy. For the definition of the system boundaries, concerning the time phases a series of processes preferably composed by design , sourcing of materials , planning , construction , operation of the building, refurbishment, demolition, and recycling. In addition, for wood-based materials planting, growing, harvesting trees, obtaining suitable land, transporting logs and forest products, processing of structural and non-structural wood components, and timber treatment, consider crucial. Overall, it was highlighted by the author the beneficial impact of timber in the construction sector of a building, aiming to the reduction of emissions.

(Paolo Bertoldi, 2020) examined the importance of upgrading the current financing projects for innovative energy interventions to residential buildings by addressing new financing systems considering the fast evolution observed in the construction sector. In addition, the proposed changes in several sectors including the capital structure, the reduction of interest rate, specification considering the sectors of the building that included for the energy efficiency intervention. Making alterations considering the financing, in combination with loans and in general creating flexibility on this sector, ideally concluded to very efficient energy interventions. Furthermore, traditional financing systems composed mainly of Grants and subsidies and tax incentives were explored, with some suggestions over the widespread expansion of their territory of assistance. A further upgrading on financial and testing implemented on financial instrument and tool consisting of Energy Efficiency Obligations(EEOS), Energy Service Companies(ESC) and Energy Performance Contracts(EPC) and Energy Service Agreements(ESAs), along with detailed information for each instrument. In contrast to the mentioned above instrument, they anticipated for the usage of new and innovative financial instruments and tools, in order for the problems reflecting EE financing in the EU to be solved, composed by On-bill finance, property assessed clean energy financing, energy-efficient mortgages, energy efficiency feed-in tariffs, incremental property taxation, one-stop shops, and crowdfunding.

(Karen Valls-Val, 2021) examined the importance of identifying the carbon footprint(CF) in higher education institutions in terms of sustainability in development and on the greenhouse gas(GHG) emissions, by addressing a variety of current calculations of the carbon footprint from different institutions across the world in comparison to their own results, aiming to the production of a common formula. For the calculation of their own formula, the variables were GHG emissions from a specific source, the product between the activity data from that specific source, and the respective GHG emission factor. In addition, the authors implemented four basic stages for the evaluation of the calculation resulting from the other studies, composed of the identification of articles, the general mapping, the methodological aspects, and the comparison of the results. It has resulted that the carbon footprint(CF) for the majority of the studies calculated for the defined boundary along with the usage of forestry as a recommendation for the mitigation of the carbon footprint(CF).

(JoshuaS.Gans, 2009) examined the impact of the implementation of carbon offset considering the carbon dioxide emissions along with the resulting electricity used by a monopolist. In addition, for the outcome of the extracted carbon offset from the consumption activity of the individuals purchasing offsets, the variable used was the quantity of electricity consumed and the number of emissions, the price of electricity, continuously differentiable functions, quilt on the part of the consumer, base case quantity demanded when offsets are not available, offset permit costs, the consumer chooses, the impacts on the guilt component, the quantity demanded when offsets are available, consumption and offsets purchased. It has resulted from the graphs, the increasement of net emissions value when introducing an offset market along with the increment of monopolist profits when an offset was created. On the other hand, they examined the carbon offsets when directly related to the consumption activity by using models for the strategic clean and non-strategic generator cases respectively. The variable used for both models were the same as the initial model, placed in different equations. Moreover, they resulted that in both cases the emissions were reduced.

(Su-Hyun Cho, A Study on Life Cycle CO2 Emissions of Low-Carbon Building in South Korea, 2016) highlighted the willingness of change in Korea, considering the mitigation of GHG emissions mainly by the usage of alternative low-carbon materials in conjunction with the establishment of new carbon emission reduction boundaries. Thus, regarding the criticalness of the current situation for the lessening of the carbon emissions, a comprehensive Life Cycle Assessment(LCA) study of a building with low-carbon construction materials was examined, in comparison to typically constructed buildings, for the identification of the CO_2 emissions. In addition, the authors denoted the construction materials input area as the targeted sector for innovations, by addressing concrete as the preferred material for further examination. For the calculation of CO_2 emissions, a procedure from an LCA perspective view followed, including the enactment of system boundaries along with a selected Korean LCI database involving the construction materials, the separation of production, operation and maintenance, construction, and demolition phase for the placement of the appropriate inputs for the comparison. Furthermore, after placing the applicable inputs in every phase of the LCA analysis, the contribution rate was placed for better acknowledgment of the impact that the construction material would have. According to the results of the study, the authors indicated the importance of using low-carbon construction materials, after a substantial value of 2423004 kg CO_2 was emitted to the atmosphere after a suitable life cycle of 30 years, concluding to a 25% lessening on the carbon emission stage in contrast to the typical buildings.

(Effrosyni Giama, 2021) analyzed with the assistance of an LCA analysis the innovative idea of green roofs, considering the climatic conditions along with the overall environmental impact of such a construction, followed by a sensitivity analysis for the lifespan and thermal insulation, compared to two basic scenarios, reflecting the renovation and maintenance. Additionally, the selected building was placed in Thessaloniki and to the Mediterranean climatic condition correspondingly. Firstly, the authors set the system boundaries including the energy and environmental impact by the examination of two alternative technological green roof systems. Then, after applying the preferable inputs and outputs on the inventory analysis, considering the amount of the construction materials, in parallel with the distance for the transportation phase. Moreover, imported the data to the SimaPro software, they examined the impact categories that were affected from ready concrete, steel-rebar, mastic asphalt, and thermal insulation XPS. After the impact assessment, the results showed a significant percentage for concrete in the Global Warming with 49.65% and Respiratory Organics with 85.88% respectively, referring to the carbon emissions. Overall, after the implementation of sensitivity analysis, along with the Life Cycle Cost(LCC) analysis, the overall cost of Traditional Horizontal Roof(THR) was essentially lower than Extensive Green Roof(EGR).

3. Problem Definition

3.1. The world of carbon offset

In today's world, the collaboration of governments and private organizations that is highly observed regarding the association of a variety of schemes, such as carbon offset projects for the reduction of Greenhouse Gas(GHG) emissions, stemmed from previous judgments and acts correlated to Global Warming captured worldwide. More explicitly, the significance of carbon offset along with the categories of the carbon market and the corresponding financial part will be deliberated profoundly.

Following the detected continual growth in the percentage of Global Warming, the international community enacted the Kyoto Protocol as a solution for effectively diminishing Greenhouse Gas(GHG) emissions globally (Gupta, 2011). The Kyoto Protocol was initially presented to European Union and in a total of 181 countries in 1997 from the United Nations Framework Convention on Climate Change and was established in 2005 (Gupta, 2011). Overall, the main goal of this debutant protocol was the essential mitigations of the emitted GHG emissions to the atmosphere, by implementing limitations regarding the accepted amount of emanated carbon emissions, making carbon taxes, or finding ways of lessening the carbon emissions obligatory for the delinquents (Gupta, 2011).

Additionally, carbon offset developments worldwide are manifested mainly in the effectual mitigation of Greenhouse Gas(GHG) emissions, with a variety of schemes including forestry, methane obliteration, manufacturing gases, energy effectiveness, and renewable energy (www.offsetguide.org). Therefore, carbon offset schemes concerning the building area, mainly addressing energy efficiency enhancements, including involvements on the Heating, Ventilation, and Air Conditioning(HVAC) system along with the building's construction materials and the usage of low-carbon materials, for the lessening of GHG emissions. Furthermore, carbon offsets are allocated in two central categories concerning the purchase and trade, the Voluntary offset market and the Clean Development Mechanism(CDM) market (Lovell, 2010). The CDM indicated a type of carbon offset based strictly on the ideologies of the Kyoto Protocol and initially managed by the United Nations Framework Convention on Climate Change(UNFCCC) (Lovell, 2010). The UNFCCC consists of a variety of commissioners and different ways of management, highlighting the importance of the CDM Executive Board along with CDM Methodology and Accreditation Panel, and a limited number of working groups (Lovell, 2010). In addition, each environmental project goes through time-consuming but exhaustively until it is approved as a Certified Emission Reduction(CER), lasting an immense period of time around 500 days from the first day of examination, and thus instigating strong protests on the part of the governments as a clear indication of its main process steps, characterizing it the famous CDM bureaucracy (Lovell, 2010). A key role in the overall process in order to be successful plays the registration of the formulated documents to the CDM executive board, followed by the examination of World Bank carbon funds for the possibility of financing those environmental projects (Lovell, 2010). Hence, in order for countries to be able to seam CDM projects, their identification to Kyoto Protocol and UNFCCC respectively are deemed mandatory, by addressing a paper entitled as Designated National Authority(DNA) (Lovell, 2010). After the completion of the project evaluation, the CERs or carbon credits can easily be a conveyance to the UNFCCC-based International Transaction Log(ITL), concluding to an accurate operative plan of purchase and trade CERs in the CDM market (Lovell, 2010). On the other hand, the Voluntary market is mainly named as VCO or Verified Emission Reduction(VER) pertaining to the certification, and considered as the most comfortable in terms of the procedural part of the market, with more freedom of movement equated to the CDM market (Lovell, 2010). The major alteration between the two offset markets is highlighted by the quickness of contribution from anyone who indicates the reduction of their carbon emissions through the Voluntary offset market, in which provisionally there are no specific boundaries and lows, based mainly on the directives of neutral and private organizations (Lovell, 2010). Moreover, due to the peculiarity of the autonomy that it represents in combination with the absence of any restrictions or instructions, resulted in informality in relation to the CDM market, while generating numerous disputes regarding the uncertainty of the final outcome from the contribution to this market (Lovell, 2010). Nonetheless, after its initial appearance in the '90s and has focused mainly on the forest sector, it followed a static course in terms of the percentage of participants until 2008 when the percentage of tone launched in the market, noting an 87% increase over the prior year (Lovell, 2010). The CDM offset market also played an important role in the increased percentage mentioned above, from which a large quota of projects was collected considering the dismissals and the delays of examination (Lovell, 2010). Overall, the Voluntary offset market without any boundaries has the advantage of combining ideologies and approaches from other markets, to make possible the operative production and the trade of carbon credits, by investing and persuading countries that are not using the Kyoto Protocol-based CDM market (Lovell, 2010).

On the other hand, for all the environmental projects in order to be considered as a preferred investment for any consumer or company, the actuarial of transaction and opportunity cost is denoted as one of the crucial sectors that should be taken into deliberation (Oscar J.Cacho, 2013). Overall, the opportunity cost is interrelated to the extensive examination of a future project from consumers or companies concluded to a beneficial collaboration of the final selected investment scheme above the others (Fernando, 2021). In contrast to the opportunity cost, the transaction cost is signified as the total cost of the exchange or acquisition of a scheme, highlighting the importance of the price considering the final outcome from the devoted project and the attempt to complementary the price between the transaction cost and the revenue (Downey, 2021). As far as the environmental schemes are concerned, the opportunity cost is mainly characterized by how profitable a project will be and on the contrary, the highly noted transaction cost imitated the total cost considering all the processes from the assessment until the corroboration of a scheme (Oscar J.Cacho, 2013). Thus, a variety of CDM projects are observed to have a severe delay in the project's pre-determined accreditation time, due to the multiple procedures that need to be taken, concluding to high transaction costs (Lovell, 2010). Comparatively to the two main costs mentioned above, concerning the whole process of verification of the environmental projects, it assumed from the majority of the researches that the more complex a project is in terms of procedures, combined with the strict boundaries, thus the higher the construction cost will be, ultimate to the lower quota of transaction costs for the Voluntary offset market due to its informality (Lovell, 2010).

3.2. The usage of low carbon construction materials and energy interpolations in the building sector

In order for an individual or a company to be able to significantly reduce the GHG emissions emitted to the atmosphere of a building, and substantially contribute to the global effort which is implemented for the lessening of the quota of Global Warming, it is denoted the importance of contributing in carbon offset programs, by making modifications to the building envelope, applying low-carbon materials, in combination with fluctuations to the HVAC and energy system. Subsequently, all-encompassing exploration concerning the differentiation in the usage of low-carbon materials associated with the application of wood-based materials, in parallel with the upgrade of the HVAC system, will be reviewed intensely.

Most of the percentage of construction building materials across the world are based on concrete and specifically the foundations of the building with the usage of reinforced concrete to withstand statically, concluding to a high quota of GHG emissions emitted to the atmosphere during the construction phase. In the field of foundations, which occupies the most important part of the building, implementing the usage of the highly harmful to the environment reinforced concrete is mandatory, merely with the replacement of the current materials to low-carbon ones lighten the construction and the use of cement is reduced by constructing a smaller foundation volume, thus reducing the pollutants by a percentage (Austin Himes, 2020). In addition, there has been a lot of discussion about the choice of materials in building construction, regarding the knowledge of consumers and engineers of the usage of alternative materials with less impact on the environment (Jannik Giesekam, 2016). According to many kinds of research, in a large percentage, the choice of materials is made mainly according to their cost and the usual suggestion of engineers since the proposal of using alternatively low-carbon materials is comparatively larger and would probably be rejected from the variety of the consumers (Jannik Giesekam, 2016). Moreover, in order to correctly identify the GHG emissions of each construction material, it is compulsory the existence of an analytical database, which is already being undressed, with several interventions and embellishments to the Standard database, eager to the creation of an informative and more accurate database for both the consumers and engineers, resulting to the inclusive extenuation of the emitted carbon emissions (Peng Wu, 2014). Hence, it is painstaking essential to enlighten consumers in detail regarding the construction materials associated with their environmental footprint, and thus contributing to the use of appropriate low-carbon materials to occur at the same time the mitigation of GHG emissions and more unambiguously the involvement to the lessening of Global Warming quotations worldwide (Jannik Giesekam, 2016).

Additionally, corresponding to a variety of researches, the material that is considered in most cases as a low-carbon alternative of concrete and steel in the construction phase of a building is wood and more explicitly mass timber. Nonetheless, at the same time, there are strong doubts about the harvest of wood from the forests, along with the resistance to fire by using wood-based materials, concluding to the importance of restoring the balance in this sector, along with the reduction of the GHG emissions by the usage of timber (Galina Churkina, 2020). Overall, mass timber as a pioneering solution for the mitigation of the GHG emissions is willing to be established in the building sector in a larger quota, by contributing to the durability of the building, reducing the usage of concrete, and manufacturing greater importance, volume, and durable construction materials like cross-laminated(CLT) panels and glue-laminate beams from lamella or boards (Galina Churkina, 2020). Furthermore, regarding the controversial durability of the timber-based building, the architecture of the building was greatly emphasized, in combination with the selection of the appropriate high fireproof materials, and denoting the examination of even an 18-story building exposed to fire, resulting in a positive outcome compared to a conventional constructed one respectively (Galina Churkina, 2020). On the other hand, a key role for the construction of timber-based materials plays the harvesting of the forest, with the amount of extracted wood assumed to be higher by the usage of wood-based materials, and thus impacting Global Warming (Galina Churkina, 2020). Several examinations regarding the amount of harvesting of wood needed for the construction of timber-based buildings highlighted the importance of merging the harvesting from all the obtainable tree varieties in order for the high percentage demanded to be contained (Galina Churkina, 2020). Furthermore, for the fabrication of wood-based products, it has resulted in less energy required in contrast to the conventional products from concrete and steel, and along with the positive impact of the forest, concluded to a high quota of reduction of GHG emissions (James Salazar, 2009). Thus, the proposal and already examined from a few countries management of timber on long-live products and replacing the use for fuels, associated with the storage of carbon after building's demolition, absorbed from the land and avoid its spread to the atmosphere. In general, after observing a variety of examinations regarding the diversity on using timber as an alternative to concrete and steel on the construction phase of a building, it has resulted in a significant reduction of GHG emissions of 69% and more importantly to a 9% mitigation of the emissions worldwide, considering the reduction of Global Warming (Austin Himes, 2020).

On the other hand, another key parameter to the equation on efficiently reducing the GHG emissions in the building sector, correlated with energy efficiency measurements. Such interventions are made accordingly to the climatic zone, the surrounding environment, the architectural design, and the position of the building, aiming not only to the reduction of the carbon emissions but to the saving of money over time. The majority of interpolations, related to the windows by changing the panes, the appropriate insulation on the walls, the accurate measurement of the heating and cooling loads for the implementation of the efficient HVAC system, and the placement of the appropriate amount of photovoltaic(PV) system, for the energy, demands to be covered and most importantly the beneficial collaboration of saving energy along with money during a future period of time (Kneifel, 2009). In addition, the manufacturing phase of PV systems and the inverters corresponds to a significant amount of impact considering the phenomenon of Global Warming along with the human health, by the emissions emanated to the atmosphere, almost identical to concrete and steel construction, related with the usage of crystalline silicon, gravel-based materials, and a variety of electric apparatuses respectively (Cassandra L.Thiel, 2013). Overall, the application of that kind of energy measurements in the building's envelope, concludes with a lessening of around 30% of the carbon emissions, which quota vary depending on the energy use of countries across the world (Kneifel, 2009).

3.3. LCA approaches in the building sector

For the accomplishment of the precise quantity of carbon footprint consequential from the construction materials of a commercial or residential building, diverse LCA methodologies were applied either in the construction materials or in energy interventions, concluding to the influence on Global Warming concerning carbon emissions released in the atmosphere. Overall, Life Cycle Assessment(LCA) refers to the environmental impact that a product or a material will have during its entire life cycle (Iyyanki V. Muralikrishna, 2017). The life cycle of a product mainly consists of materials extraction, manufacturing, distribution, usage, and end-of-life management (EPA, 2021). Additionally, the execution of an LCA predominantly analyzes either the environmental impact of a product through the entire life cycle, by assessing interventions on several stages, or the analytical analysis among numerous products, considering the impact on the environment (Iyyanki V. Muralikrishna, 2017). The key ingredients of an LCA are the Goal and Scope definition, the inventory analysis, the impact assessment, and the interpretation (Iyyanki V. Muralikrishna, 2017). In general, all these processes throughout an LCA intend to stipulate individuals and companies with the suitable acquaintance, by using the outcomes of the analysis as a knowledgeable database, considering the vigorous categories of today's world such as the impact of a variety of products on the environment, highlighting the percentage of CO_2 emissions, and on human health (Iyyanki V. Muralikrishna, 2017). On the other hand, the majority of the LCA researches on the building sector for detection of GHG emissions focused mainly on the building envelope, comparing conventional materials with the alternative low-carbon materials consisting predominantly of wood, pointing at the consolidation of low-carbon materials in the construction phase, with a highly promising outcome on the Global Warming and GHG emissions correspondingly.

4. Methodology

4.1. LCA methodology for the construction materials of a building

To analyze extensively the overall impact on the environment, that a product or a material will have during the four key phases of a Life Cycle Assessment(LCA), the importance of exploiting an appropriate LCA methodology among a variety of systems, such as SimaPro, OpenLCA, GaBi, and Umberto, is denoted by the majority of the researchers (A P Iswara, 2020). Hence, inspired by the analysis of (Su-Hyun Cho, A Study on Life Cycle CO2 Emissions of Low-Carbon Building in South Korea, 2016), which examined the impact on the environment concerning the CO_2 emissions of the construction materials of a conventional building compare to a modified one, by applying low-carbon concrete, along with energy-saving materials in Korea using an LCA model, the current thesis adopts a part of the mentioned above methodology for the estimation of carbon emissions of the main materials from a typical house, considering principally the impact on the most impactful environmental categories by the usage of OpenLCA software.

More explicitly, all started from the preliminary idea of Andreas Ciroth, Michael Srocka, and Jutta Hildenbrand, which involved the formation of an innovative, reliable, and at the same time free of charge software, consisting of a variety of procedures correlated to the life cycle demonstrating and sustainability assessment, in parallel with the establishment of suppleness by allowing users to enhance their own processes, on the already existed database, concluded to the application of OpenLCA in 2006 (openlca.org, n.d.). After the institution of the software, GreenDelta with headquarters in Berlin, in collaboration with an experienced development group undertook the full expansion and administration of the program (openlca.org, n.d.). Further, one of the ingredients that made it a globally well-known software is the availability of a beneficial database called openLCA Nexus, where any individual can find a variety of free LCA databases depending on the subject, multiple case studies to explore, informative free documents related to LCA databases for downloading, a map highlighting the source of the databases worldwide, and the possibility to deepen and better comprehend the software and the LCA in general, through a training group from GreenDelta with the cost varying according to the property of each participant, following the above by an easy registration to the platform (openlca.org, n.d.). Also, the user after downloading the preferable database has the capability of implementing his own processes and flows, creating new product systems with the preferred measurement type, and calculating the impact on the environment by importing a downloaded openLCA LCIA method database from the Nexus OpenLCA, with the results displayed either on the software with graphs or exported to an Excel file. Following the manufacturing of a new product system, there is a variety of calculation processes regarding the appropriate impact assessment method, containing quick results, an extensive analysis, regionalized Life Cycle Impact Assessment(LCIA), and Monte Carlo simulation, resulting in the influence on the environment via the numerous impact categories of the software for comprehensive study. Last but not least, in the OpenLCA software can easily be imported a second database, offering to the user the ability to make a thorough evaluation of the selected processes considering their final outcome. In the current dissertation, for the calculations on the impact on the environment considering the CO_2 emissions, the latest version of OpenLCA, the 1.10.3 edition is preferred.

Initially for this diploma thesis, in order for the identification of the specific amount of carbon footprint concerning the construction materials' impact on the environment, a typical residential building was selected from personalized data from previous work space. Following the building's selection, and after deciding OpenLCA as the software for the examination, investigation for tracing the appropriate database along with the preferred processes and flows from the Nexus OpenLCA followed before selecting agribalyse_v301_27052021 database and ingress it on the software. The next step was the creation of a new process in the database, which was named building construction, and the placement of the inputs and outputs described as the main construction materials needed for the construction of the building. Then, the creation of a new product system with the ideal type of measurement, maintaining the name of the process and observing the delineation of the model graph along with the statistics considering the inputs and outputs affect. The last stage of the software is the calculation of the product system, by downloading an openLCA LCIA method database named openLCA LCIA method 2_1_1 from the Nexus OpenLCA before importing into the software, and examining the results regarding the impact categories from quick results, analysis, and regionalized LCIA.

4.2. Overview of the selected building

The selected building refers to old construction, in the area of Toumpa in Thessaloniki, providing an extremely low energy category Z. Hence, for the calculations in the OpenLCA software, the area, the electricity price, the HVAC system, and the volume of the building will be maintained, in contrast to the materials sector, where the current construction materials will be added, with their values obtained from the internet, as presented in Table 1 and 2 respectively from (www.dailycivil.com, n.d.), and (Kluziak, 2021). Since a significant percentage of the Greenhouse Gas(GHG) emissions globally is related to the building sector, this paper aims to evaluate approximately the carbon footprint of each conventional material along with wood-based material such as timber, considering their environmental impact (Cassandra L.Thiel, 2013).

No.	Material	Unit Weight
1	Aluminum	2700 kg/m^3
2	Cement	1440 kg/m^3
3	Brick	1600 kg/m^3
4	Reinforced Concrete	2500 kg/m^3
5	Timber	650 kg/m^3
6	Lime Plaster	1700 kg/m^3

7	Plastic	1250 kg/m^3
8	Stones	1750 kg/m^3
9	Steel	7850 kg/m^3
10	Water	1000 kg/m^3
11	Asbestos	1600 kg/m^3
12	Coal	600 kg/m^3
13	Sand	1600 kg/m^3

Table 1. *Building materials unit*

`Division	Description
Building	Conventional material building
Area	90,00 m^2
Volume	126,00 m^3
Site	Toumpa, Thessaloniki, Greece
HVAC system(Gas)	160,60 kWh/m^2
Electricity use	12,00 kWh/m^2

Table 2. *Overview of the building*

4.3. Material Production Phase

The GHG emissions emanated in the atmosphere in the building sector are divided into four main phases of emittance. One of the key stages considering the life cycle of a material acquired by the equally productive of carbon emissions production phase, where every construction material before its manufacture consisted of a variety of combination of raw materials, which will be examined in this phase (Su-Hyun Cho, A Study on Life Cycle CO2 Emissions of Low-Carbon Building in South Korea, 2016). The majority of the inputs imported into the OpenLCA software were associated with the production of construction materials needed for the building's construction, with the reinforced concrete obtaining approximately 41,72%, concerning the contribution rate of Global Warming, in contrast to timber with a 12,25%, as observed in Table 3.

Collectively, over 2 tones of raw materials were needed for the construction of the selected building.

No.	Material	Input	Contribution Rate
1	Reinforced Concrete	315000 m^3	41,72%
2	Cement	181440 kg	0,11%
3	Brick	201600 kg	0,09%
4	Timber	81900 m^3	12,25%
5	Lime Plaster	241200 kg	0%
6	Steel	989100 kg	3,92%
7	Stones	220500 kg	0%
8	Asbestos	201600 kg	0%
9	Coal	75600 kg	0%
10	Sand	14454 kg	0%
11	Water	126000 m^3	0%
12	Aluminum	340200 kg	5,01%
13	Concrete	315000 m^3	36,90%

Table 3*. Inputs relating to the production phase of the building*

4.4. Construction Phase

During the construction of a building, there is a combination of several mandatory events and working teams, that take part in the applicable placement and operation of the materials considered necessary. More precisely, carbon emissions are mainly detected in the transportation and operation of several materials, such as the use of tracks for the transport of materials or even concrete mix tracks for the creation for example concrete prior to placing it in the construction (Zahra S.Moussavi Nadoushani, 2015). For this phase, the primary focus, relating to carbon emissions is on means of transport along with distance covered, and their fuels. Thus, before inputs are imported into the software, it is assumed the usage of two trucks for a preferred distance, and diesel as a fuel, with the value in kg for the diesel, was calculated by using the (company, 2020), as presented in Table 4.

Material	Input
Truck	2 Item(s)
Diesel	750 kg

Table 4. *Inputs relating to the construction phase of the building*

4.5. Operation and Maintenance Phase

After the completion of the construction of the building, a significant percentage of emittance CO_2 occupied from the Heating, Ventilation, and Air conditioning(HVAC) system along with the electricity used, such as for lamps. In the operation and maintenance phase, the majority of carbon emissions that were detected in the building sector were associated with energy consumption, considering the HVAC system and the general electricity needed. Hence, for the determination of the carbon footprint in this area of the building, the gas boiler as the system for Cooling and Heating, and the electricity in kWh are maintained as inputs in the OpenLCA software and presented below in Table 5. The processes interrelated to those inputs were imported from the SimaPro database.

Flow	Input
Gas	14454 kWh
Electricity	1080 kWh

Table 5. *Inputs for the operation and maintenance phase*

4.6. End-of-life Phase

In recent years, a lot of discussions have been retained about the GHG emissions in the building sector and their course after demolishing. Additionally, in case that a building due to age and non-compliance with static boundaries, aiming to prevent an unexpected accident, the demolition is decided by the assistance of several machines, concluded to a percentage of emitted carbon emissions during the process until the placement in landfill (Zahra S.Moussavi Nadoushani, 2015). A significant part in the quota of carbon emissions plays the extraction of the foundation, which is mainly structured by reinforced concrete for the durability of the building, making it extremely complicated to separate it from the land. Overall, the end-of-life phase is associated with processes required for the demolition of the building, including transportation, energy use, landfill, and recycling of the products, concerning the type of material (Zahra S.Moussavi Nadoushani, 2015). For this phase, due to the complexity of the software, in combination with the almost identical area of the reference house in the study of (Su-Hyun Cho, A Study on Life Cycle CO2 Emissions of Low-Carbon Building in South Korea, 2016), decided to preserve the disposal values for the waste sector converting them for $90m^2$, for a comprehensive examination of CO_2 emissions, as it can be seen in Table 6.

Flow	Input
Wood waste	139,76 kg
Concrete waste	271535,29 kg
Glass waste	4221,53 kg

Table 6. *Disposal values for the end-of-life phase*

5. Results

5.1. Impact on Global Warming

Following the current heightened concern about the increasing amount of carbon emissions in the building sector, the majority of the scientists discussed the overall impact regarding the phenomenon of Global Warming and stated the importance of diminishing carbon emissions. Overall, Global Warming considering the building area refers to the emitted CO_2 emissions from all the surrounding phases of the building. In this stage of the dissertation, after running the imported inputs to the OpenLCA software, resulting in the materials of each phase of the LCA with the biggest impact on Global Warming. Thus, in the following sectors, the concluded graphs will be presented in % for the values with the largest impact and in kg the ones with the smallest quota, concerning the CO_2 emissions.

5.1.1. Production Phase

In this phase, the findings for the production of the construction materials, considering the CO_2 emissions, are represented in the following Figure 1. Pondering the below graph, as expected the reinforced concrete production obtained the greatest value of carbon emissions, mainly due to the involvement of steel in the procedure, concluded to a 41,72% approximately. Then, followed by the concrete production by a small margin of difference contributing to 36,90%, and the production of timber with 12,25% regarding the harvesting of the forests. The materials with the smallest impact were aluminum and steel with an almost identical percentage below 10%, and the cement, and brick followed with a percentage lower than 1%.

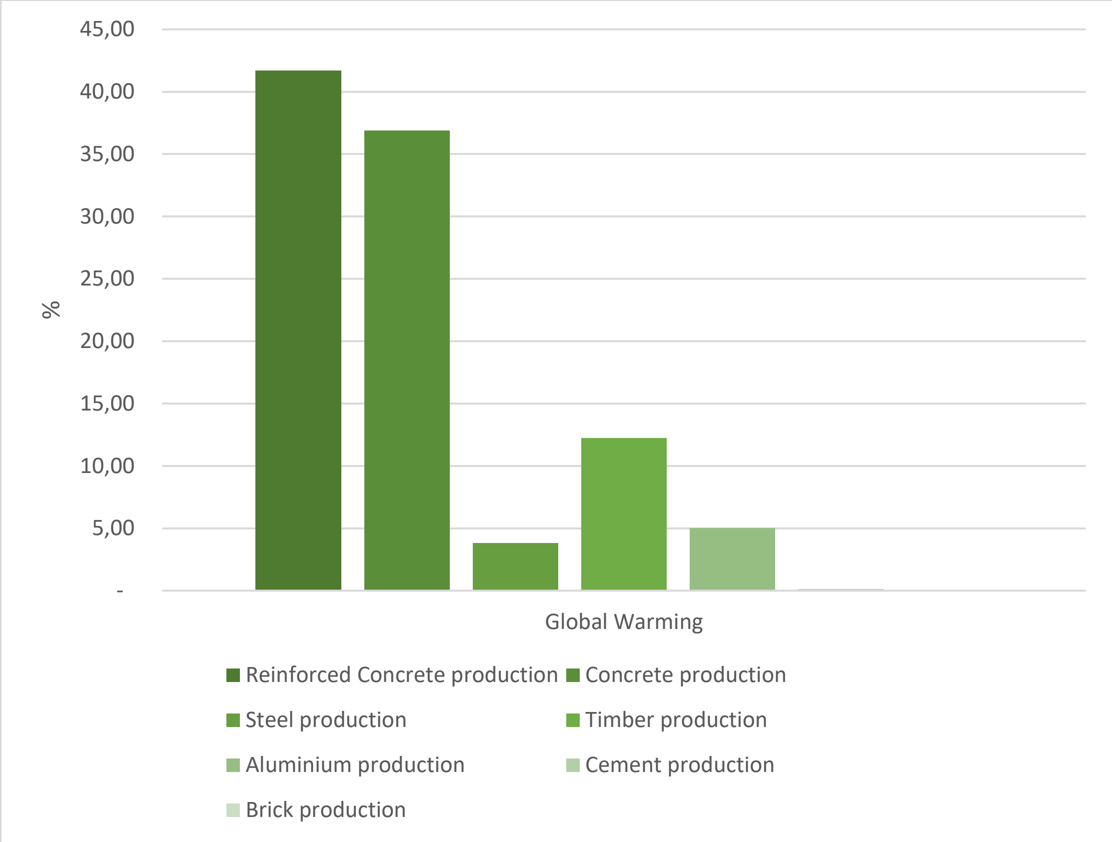

Figure 1. *% of kg CO_2 emissions percentage on the production phase*

5.1.2. Construction phase

In this part, the outcomes of carbon emissions contemplating the construction phase, are shown in the below Figure 2. Considering the available inputs from the database of OpenLCA software, the inputs for transportation of the materials were used, providing the highest value, principally owing to the distance needed to be covered for the transportation in general with 3381,87 kgCO_2. In the software, considering the calculations, for the trucks were used two items, with the distance presumed to be 50 km, including a carbon mixer truck and the truck for the transportation of the materials, using diesel as a fuel, contributing to 2370,11 kgCO_2 largely.

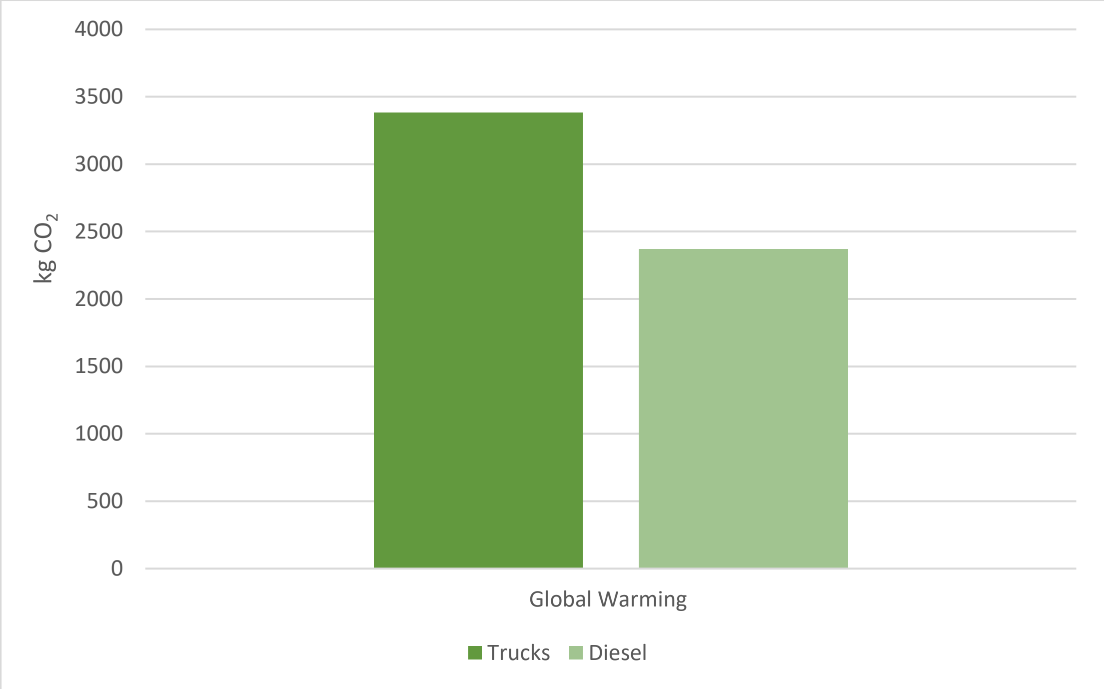

***Figure 2**. kg CO_2 emissions values on the construction phase*

5.1.3. Operation and Maintenance phase

In the graph of Operation and Maintenance phase, gas and electricity are displayed. More precisely, their contribution to Global Warming is measured in kgCO_2. Comparing the two, Gas has significantly higher pollution than electricity. More explicitly, the gas emits nearly 4000 kgCO_2, in contrast to electricity that produces only 1334,19 kgCO_2, as is presented in Figure 3. The general diversity observed is mainly due to the value in kWh of the two inputs, considering the usage of gas for the HVAC system, and more accurately the majority of the percentage applied for Heating, and thus concluding to a higher value.

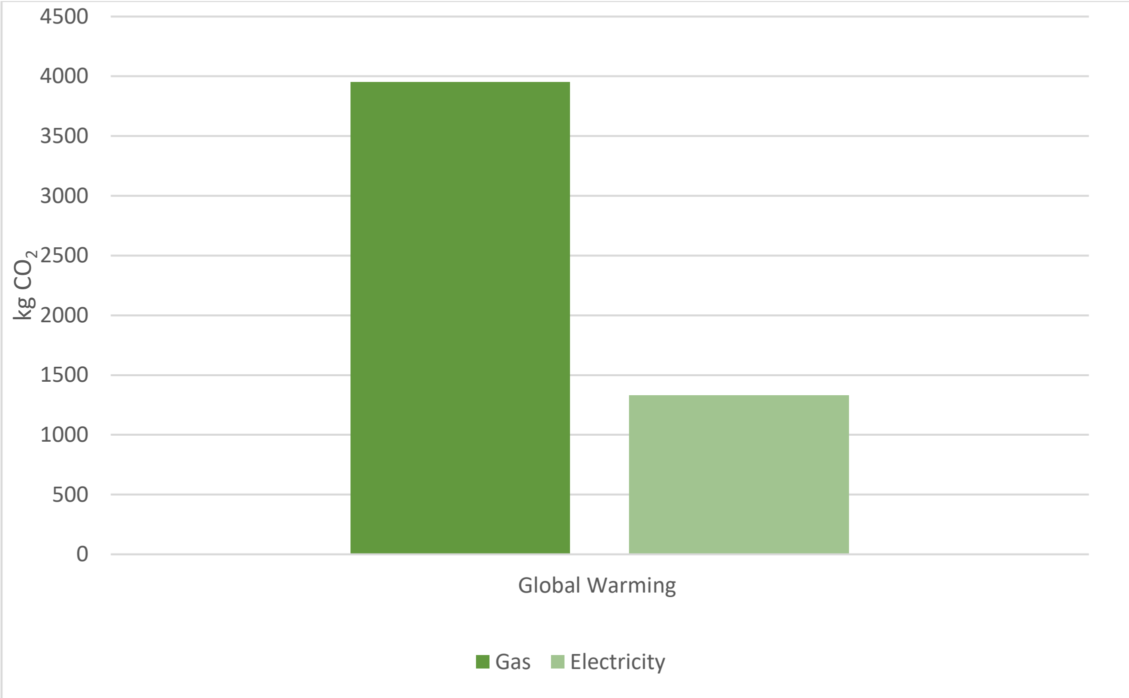

Figure 3. *kg CO_2 emissions on the operation & maintenance phase*

5.1.4. End-Of-Life phase

Pertain to the graph of the End-Of-Life phase, glass, concrete, and wood waste are exhibited in Figure 4. Additionally, the deficiency of waste steel is related to the OpenLCA database, where there was only steel waste as a flow and not as a process, and after running the software, the item of steel was not captured in the Life Cycle Impact Assessment(LCIA) method, and therefore it was decided to remove it from the calculations. For this phase, the waste materials that were imported on the software, referring to the treatment for the final disposal, including the transportation of the materials, and a variety of methods such as recycling and exported to landfill. Observing the results, the concrete waste obtains a significant value of 3195,14 kgCO_2, in comparison to glass and wood with values below 50 kgCO_2, considering the overall amount of concrete in the building envelope.

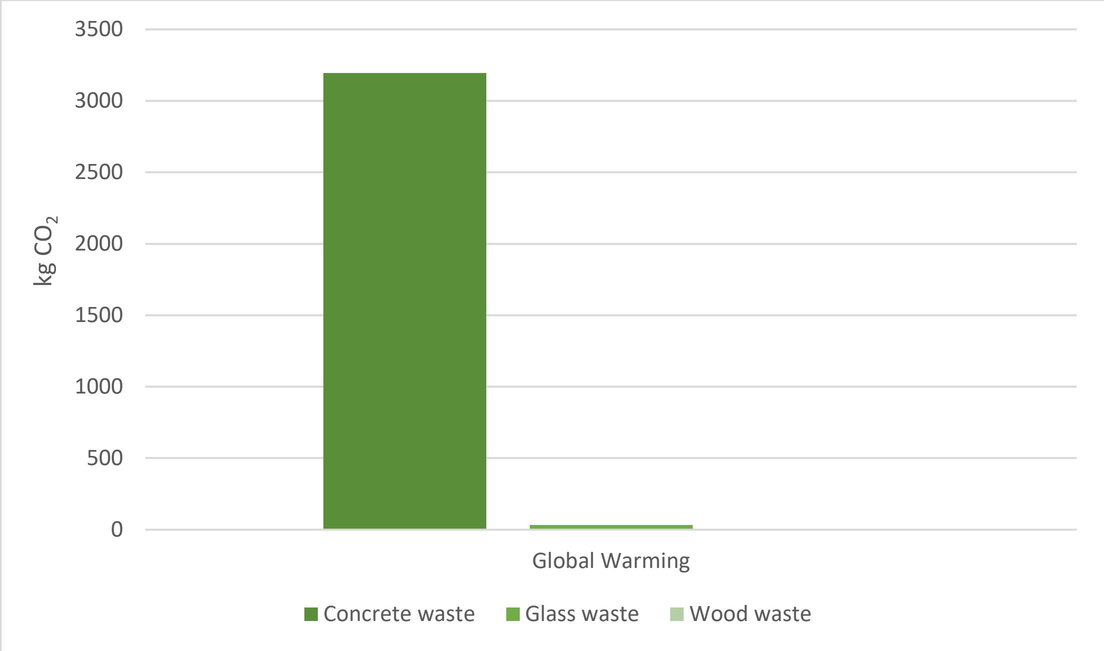

Figure 4. *kg CO_2 emissions on the End-Of-Life phase*

5.2. Impact on Terrestrial Acidification

Moving on, the next impact category selected for examination, from the OpenLCA software is Terrestrial Acidification. Terrestrial Acidification is mainly related to the land and the impact on the plants, considering their development by absorbing the necessary components from the soil (Ligia B.Azevedo, 2013). Overall, a key role in their growth obtain the level of acidity in the ground, which after surpassing the boundaries of ph. affects the life of plants significantly, along with the high values of sulfur and nitrogen (Ligia B.Azevedo, 2013). The high value of acidity on the soil will determine to be the anchor of smooth plant growth and in general on soil growing species (Ligia B.Azevedo, 2013). In this impact category, the values of the construction materials from all the phases of the LCA will be analyzed, measured in kg of sulfur dioxide(SO_2).

5.2.1. Production phase

Observing the production graph, the percentages of Terrestrial acidification from steel, timber, aluminum, brick, cement, concrete, and reinforced concrete production are positioned in the below Figure 5. Further, the involvement of the designated materials referring to the environmental effect will be quantified in kg SO_2. According to the comparison of the outcomes, the highest value of 107839 kg SO_2 was obtained by the production of reinforced concrete compared to the other materials, with a contribution quota of 33,39%. Then, follows the percentage of simple concrete and timber production with a small discrepancy of approximately 7-8%, and 20000 below in kg SO_2 correspondingly. The lowest ratios were noticed in steel and aluminum production with less than 10% impact, in contrast to cement and brick which represented rates below 0,10%.

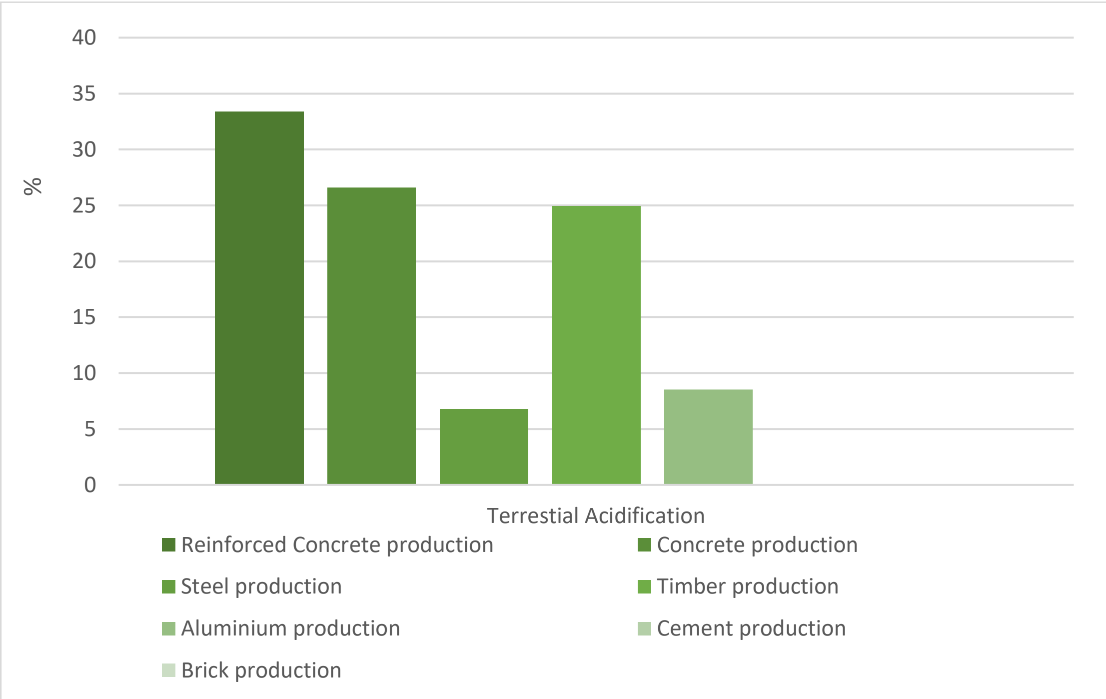

Figure 5. *% of kg SO_2 emission on the production phase*

5.2.2. Construction phase

In the graph of the construction phase, trucks and diesel standards are demonstrated. Corresponding to the findings illustrated in Figure 6, the environmental impact from the trucks and diesel considering the LCIA is relatively low in comparison to the other phases, mainly owing to their abstention in everything that has to do with soil and thus receiving 0% contribution. Nevertheless, evaluating the two inputs, the trucks due to the number of items have the highest price, corresponding to 14,44 kg SO_2. In contrast to trucks, diesel fuel emits practically 3 kg less SO_2.

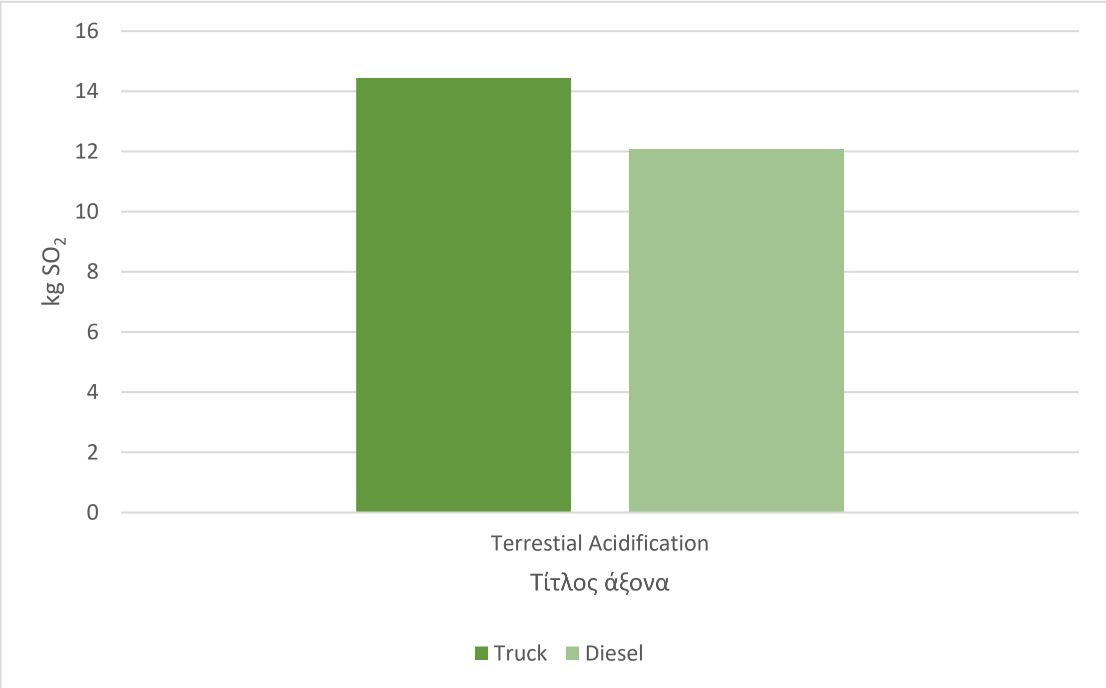

Figure 6. *kg SO_2 emission on the construction phase*

5.2.3. Operation and Maintenance phase

Furthermore, another phase that has a less significant influence on the specific impact category, described in the operation and maintenance phase. Bearing in mind that the majority of the emissions from the displayed inputs affect the atmosphere, such modest consequences are frequently anticipated. In addition, comparing those two inputs, electricity has substantially elevated contamination than gas, as presented in Figure 7. Electricity can affect the development of the plants on soil mainly by absorbency, due to water existence and moisture (Fourie). Mastering the graph, the contribution concerning both inputs is 0% for this impact category, with 14,44 kg SO_2 and just above 12 for electricity and gas respectively.

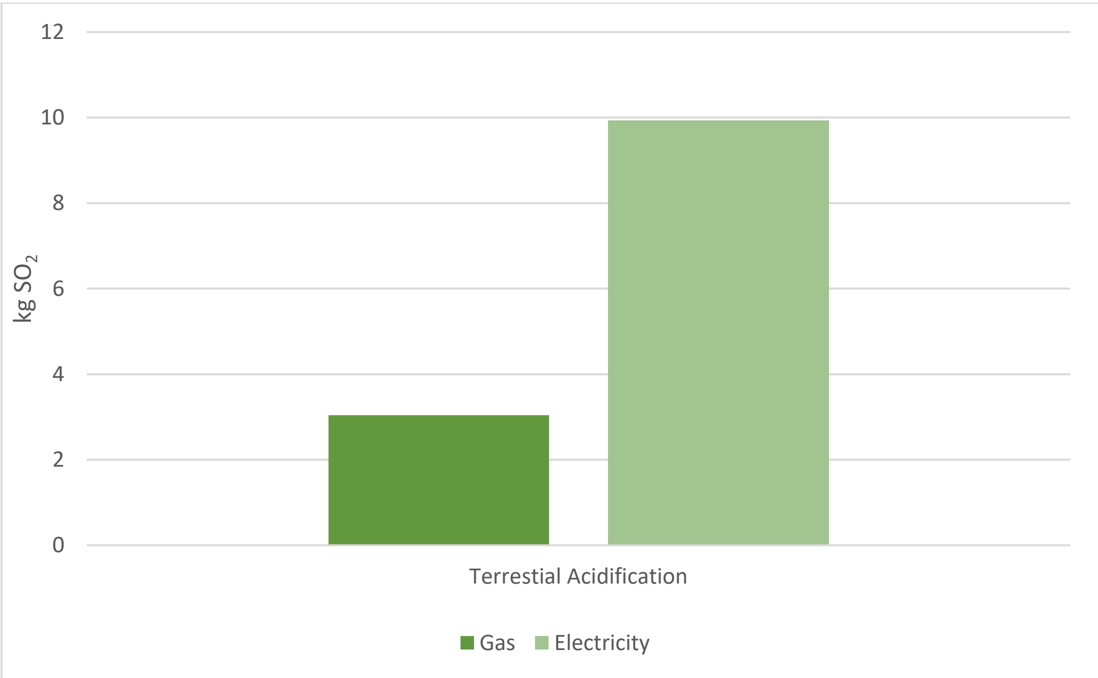

Figure 7. *kg SO_2 on the operation and maintenance phase*

5.2.4. End-Of-Life phase

Another crucial factor in the impact category of Terrestrial Acidification obtained by the demolition phase, which demonstrates the values of pollutants in the graph below. After the computations, it is observed a considerable disparity between the exhibited inputs, as regards the prices of kg SO_2. Essentially, concrete waste has a sizable distinction from glass and wood waste, with the value calculated from the OpenLCA software achieving almost 16 kg of SO_2, in contrast to the nearly zero estimates of the alternative inputs, putting in an appearance in Figure 8. Predominantly, during the process of extraction of the building construction materials from the ground, a significant amount of dust is emitted, affecting the soil and the plants separately (R.Eugene Lamare, 2019).

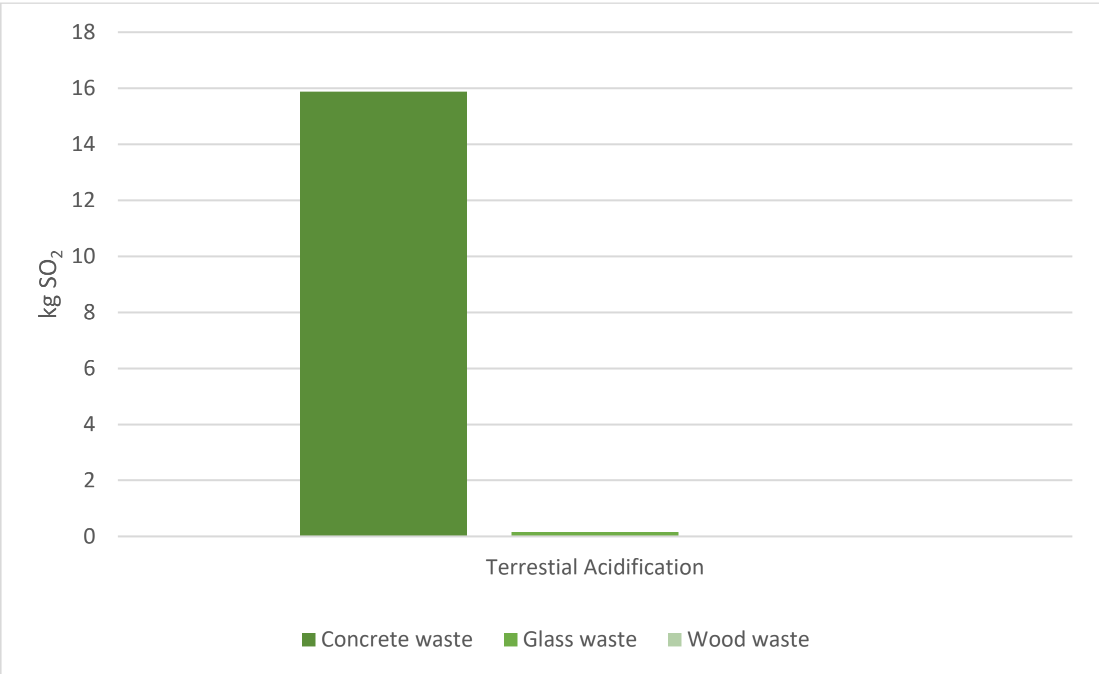

Figure 8. *kg SO_2 on the end-of-life phase*

5.3. Impact on Ozone formation-human health

Simultaneously, a key impact category on the subject of environmental pollution, obtained by Ozone formation on human health. Ozone formation was initially started by the conversion of the emanated emissions of Non-Methane Volatile Organic Compounds(NMVOC) and Nitrogen Oxides(NO_x) in the atmosphere, along with chemical and atmospheric interactions in the air (Rosalie van Zelm, 2016). More profoundly, the majority of the emissions associated with Ozone formation are radiated from a variety of phases, such as construction, production, energy consumption, demolition, and transportation (Ganlin Huang, 2017). Additionally, the next destination of the cited directly above emissions is the damage to human health and in general, the influence on the atmosphere and the soil, taking into consideration the emitted quantity of pollutants (Rosalie van Zelm, 2016). Predominately, concerning the specific impact category, the impact of the smuggled construction materials will be investigated from the software, through all the phases, measured by kg NO_x.

5.3.1. Production phase

In the graph of the production phase, the percentages of reinforced concrete, concrete, steel, timber, aluminum, cement, and brick production are provided, regarding their contribution of kg NO_x. Taking all things into thorough consideration, resulted in a quota of around 35% for reinforced concrete, and was identified as the one with the highest value of pollutant with 107307 kg NO_x. Moreover, the nearly indistinguishable values of timber and concrete production were within an insignificant diversity to reinforced concrete, with a percentage in close proximity to 30%, as appeared in Figure 9. Then, the production of steel and aluminum followed, with a major difference contrasted to the above inputs, with a contribution of around 5% for both individually, and values of below 17000 kg NO_x. Lastly, the inputs of brick and cement production resulted in the lowest values of below 200 kg NO_x, and to not measurable quota of less than 0,1% respectively.

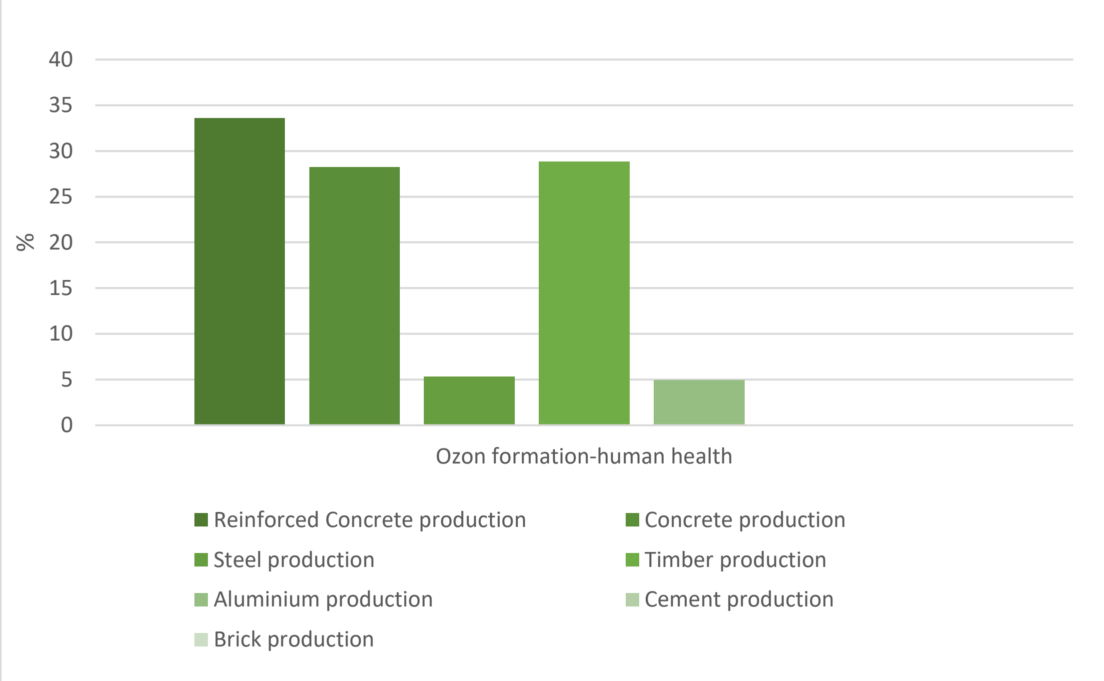

Figure 9. *% of kg NO_X on the production phase*

5.3.2. Construction phase

As well, Figure 10 provides a summary of NO_x emissions associated with the imported inputs, consisting of gas and electricity for the construction phase. Further, their involvement in ozone formation-human health is quantified in kg NO_x. As expected, predominantly due to the burning fuel, the inputs of diesel obtain the highest value of 31,71 kg NO_x equated to a relatively small number of 9,69 kg NO_x for the trucks. Overall, their contribution in percentage is 0 for the trucks and 0,01 for the diesel, considering the low distance of 10 km, which was understood.

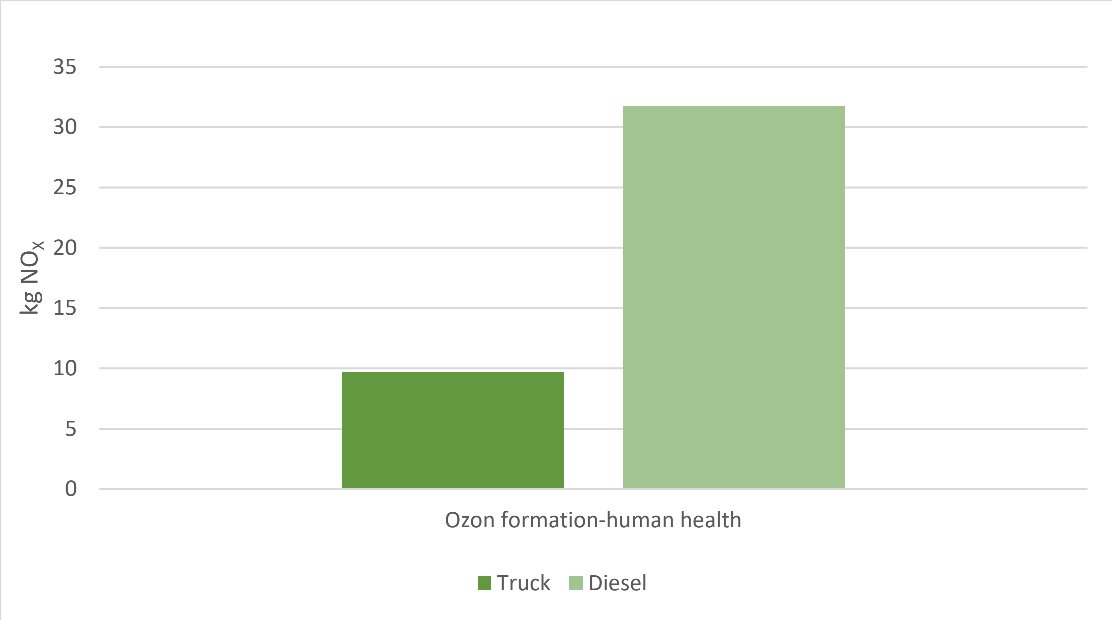

***Figure 10**. kg NO_X on the construction phase*

5.3.3. Operation and Maintenance phase

Moving on to the next phase of the LCA concerning the Ozon formation on human health, the resulting values from OpenLCA software involving the inputs of gas and electricity are revealed below in Figure 11. Examining the final outcomes on the graph, the resemblance in the values between the two inputs is highlighted, with electricity emitting 3,87 kg NO_X compared to 2,21 kg NO_X from gas. Subsequently, the resulted in zero percentage of contribution for both inputs, and particularly gas is related to the low amount of carbon emissions discharged in the atmosphere, contemplating the usage of gas for the HVAC system. On the other hand, the value of electricity is slightly higher, mainly due to the overall worth mentioning amount of impact that electricity has on ozone formation, however, in the particular dissertation case, the electricity use is very low in kWh, and thus concluding to the calculated mineral damages on the atmosphere (PowerScorecard, 2004).

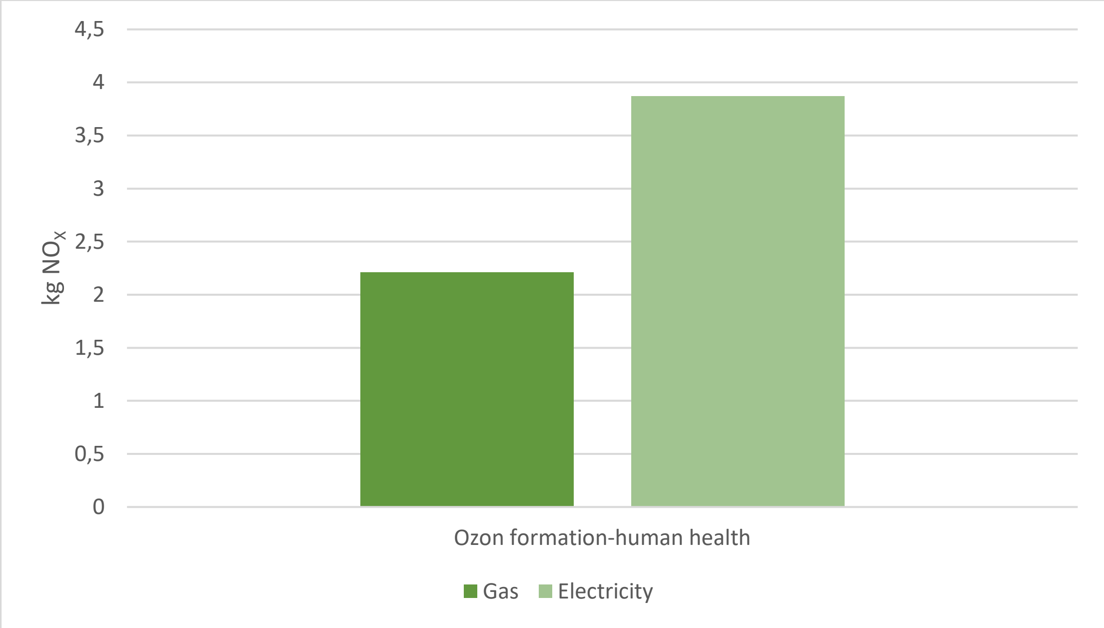

***Figure 11**. kg NO_X on the operation and maintenance phase*

5.3.4. End-Of-Life phase

Regarding the graph of the end-of-life phase, the preferred values of concrete, wood, and glass waste are illustrated below in Figure 12. Evaluating the three materials in the demolition phase, a sizable amount of 29,31 kg NO_X is captured in concrete waste, followed by the nearly zero values of glass and wood waste. Thus, in terms of contribution to the impact category of Ozon formation on human health, the percentage of concrete attained 0,01%, in contrast to the zero quota for the alternate materials. A key ingredient to the pollutant of the atmosphere from the concrete extraction is the already revealed above dust throughout the process of devastation, and the effect on the upper soil, considering also the influence of water (R.Eugene Lamare, 2019).

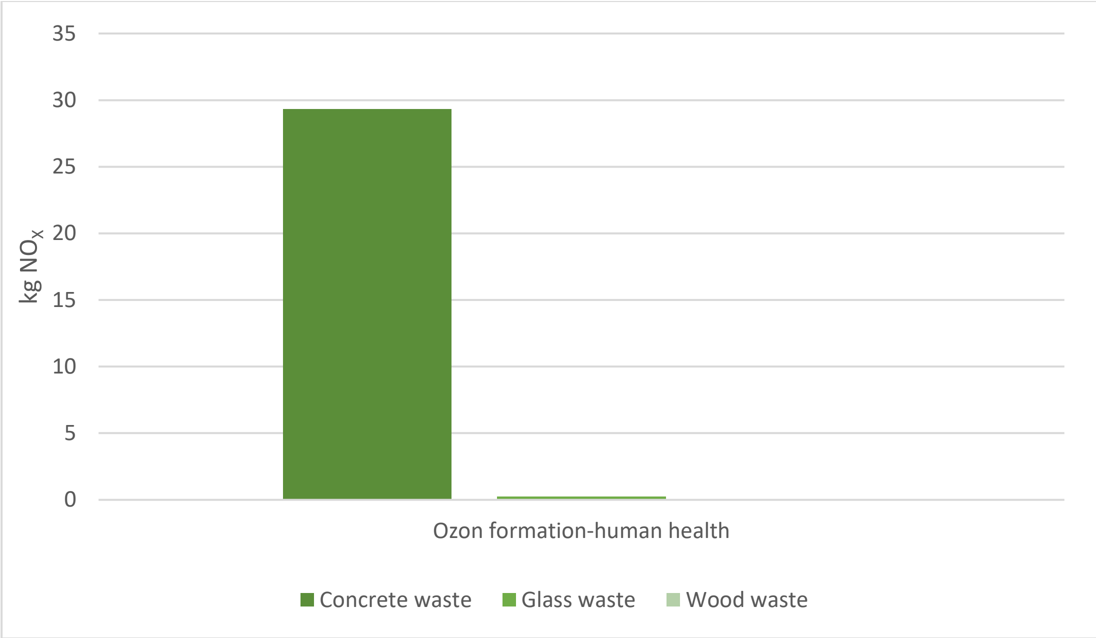

Figure 12. *kg NO_X on the end-of-life phase*

5.4. Human carcinogenic toxicity

Consequently, a further drawback from the pollutants of the atmosphere, considering the human health, and an important impact category, which will be analyzed profoundly, is human carcinogenic toxicity. Originally, Human carcinogenic toxicity is related to the various circumstances in which an individual can be exposed to a highly toxic chemical that roam the atmosphere, triggering thoughtful health problems such as cancer, in numerous parts of the body (Mark A.J. Huijbregts, 2005). More precisely, the majority of chemicals extracted from the building materials are wood dust by inhalation, asbestos, and coal-tar products by inhalation and contact (Center, 2017). The measurement for this kind of impact category is kg 1,4-Dichlorobenzene(DCB). Taking into a thorough examination, the results attained by the software, pertaining to the construction materials in each LCA phase will be presented in the following graphs.

5.4.1. Production phase

Scrutinizing thoroughly the following graph, it can be seen the sizeable discrepancy in the amount of quota of contribution to the Human carcinogenic toxicity for the reinforced concrete and steel production, in comparison to timber, concrete, cement, brick, and aluminum production. Additionally, evaluating the two greatest proportions, reinforced concrete has the highest with 54,64% and 46,38% for steel separately. On the other hand, the ideals of concrete, timber, and aluminum production are virtually nearly equal, and in parallel with a relatively low contribution regarding the impact, with a value of below 10% on the specific impact category. Also, the ratios of cement and brick production are not noticeable in the underneath Figure 13 due to the nearly zero amount of contribution, with 1245,46 and 1517,81 kg 1,4-DCB individually.

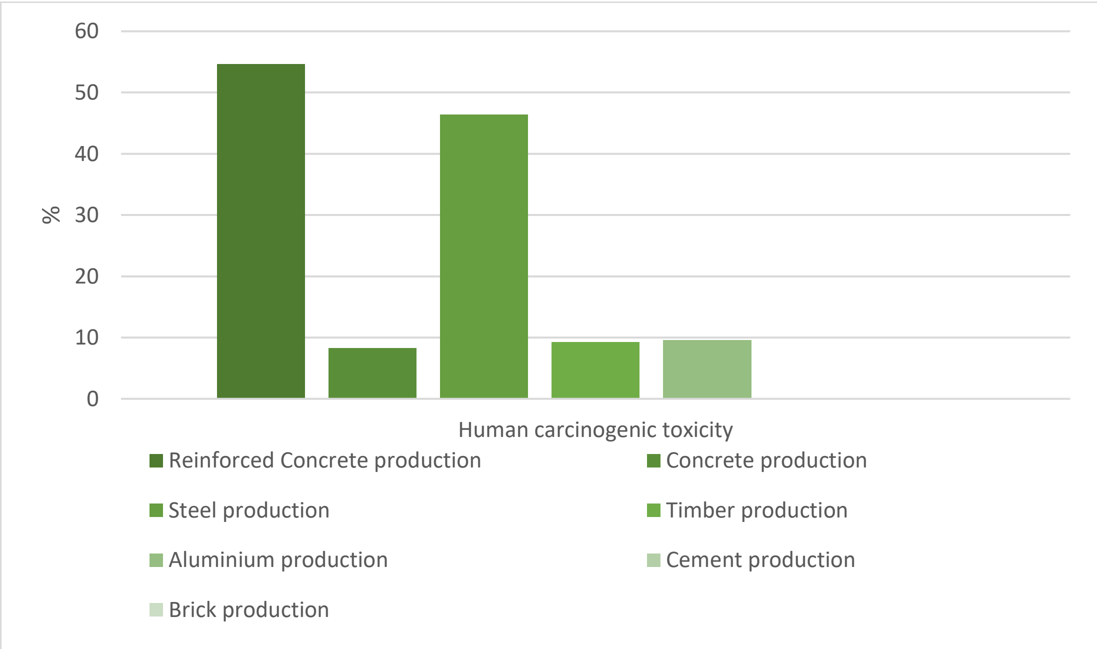

***Figure 13**. % of kg 1,4-DCB on the production phase*

5.4.2. Construction phase

Continuing with the next graph, the inputs of trucks and diesel are displayed in the below Figure 14. Fundamentally, the only visible value on the graph is the one referring to the trucks, with a slight contribution to the overall impact category of 0,01% and 915,67 kg 1,4-DCB. In contrast to the truck input, the ratio of diesel is zero regarding the contribution to Human carcinogenic toxicity, along with the emitted 0,031 kg 1,4-DCB. Generally, the observed major diversity among the two inputs is basically due to the smoke extracted from the exhaust during the operation of the truck, collaborating with the specific covered distance.

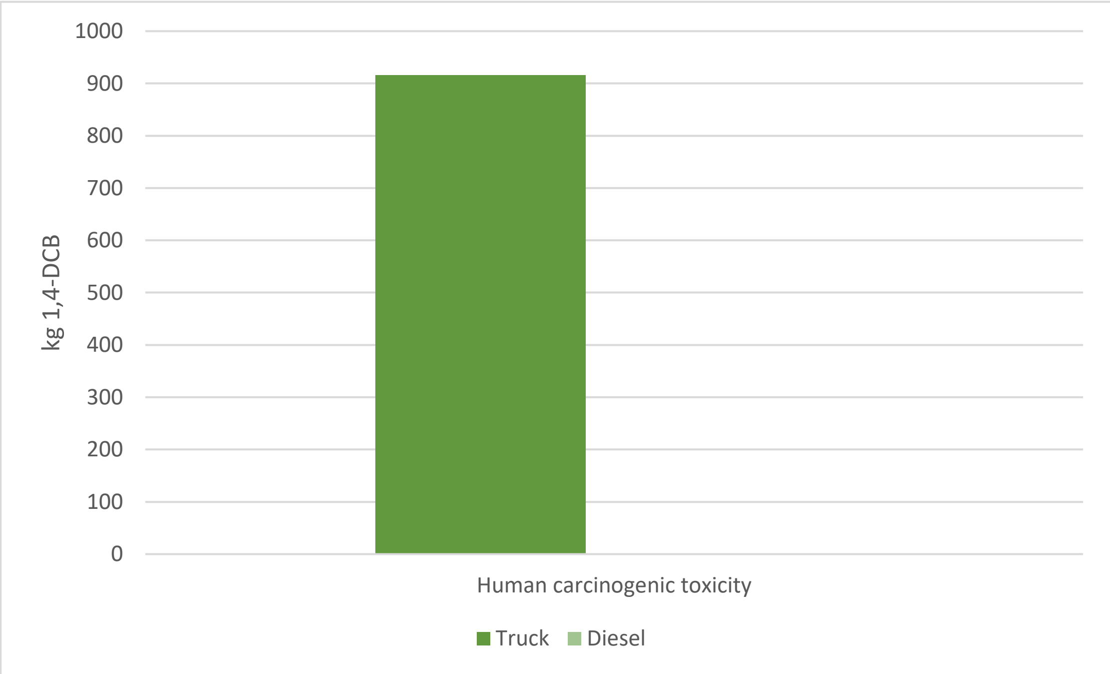

***Figure 14**. kg 1,4-DCB on the construction phase*

5.4.3. Operation and maintenance phase

In the following Figure 15, the inputs gas and electricity are placed in the OpenLCA software and described regarding their kg of pollutant below. According to the results from the software, mutually have zero contribution on the specific impact category, along with prices below 30 kg 1,4-DCB. Comparing the below-illustrated graph, the highest value is having the gas, reflecting in just over 25 kg 1,4-DCB, in contrast to electricity with a value above 15 kg 1,4-DCB. Overall, the low amount of gas needed for the HVAC system to operate along with the low amount of electricity applied concluded to the following unharmful for the human health findings.

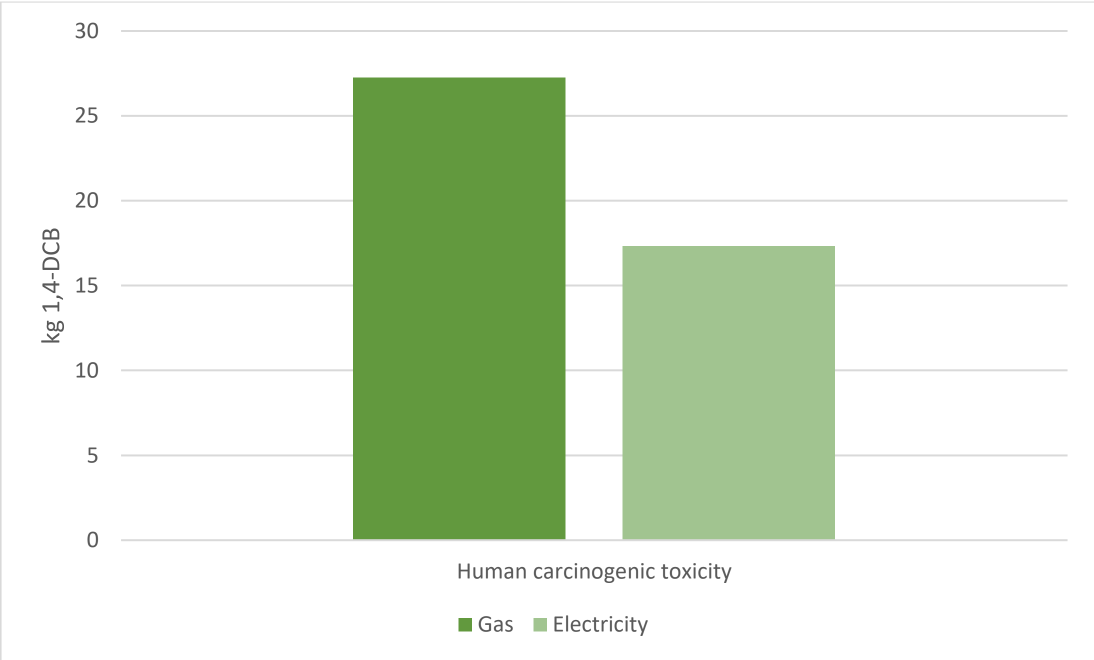

Figure 15. *kg 1,4-DCB on the operation and maintenance phase*

5.4.4. End-Of-Life phase

Corresponding to the upcoming graph, the values of concrete, glass, and wood waste are exemplified for assessment. As anticipated, the pollutant of concrete waste is considerably higher than glass and wood. More deeply, in terms of kg 1,4-DCB concrete emits precisely 72,93 kg, in contrast to glass and wood which values are less than 1kg. Nonetheless, their overall percentage concerning the impact on Human carcinogenic toxicity is zero, in comparison to the LCA phases. Overall, concrete waste affects human health in a large percentage, but not like the chemicals emitted from the other materials in different phases of the LCA, causing vital health problems such as cancer, and thus the percentage is low, as shown in Figure 16 (Beech, 2019).

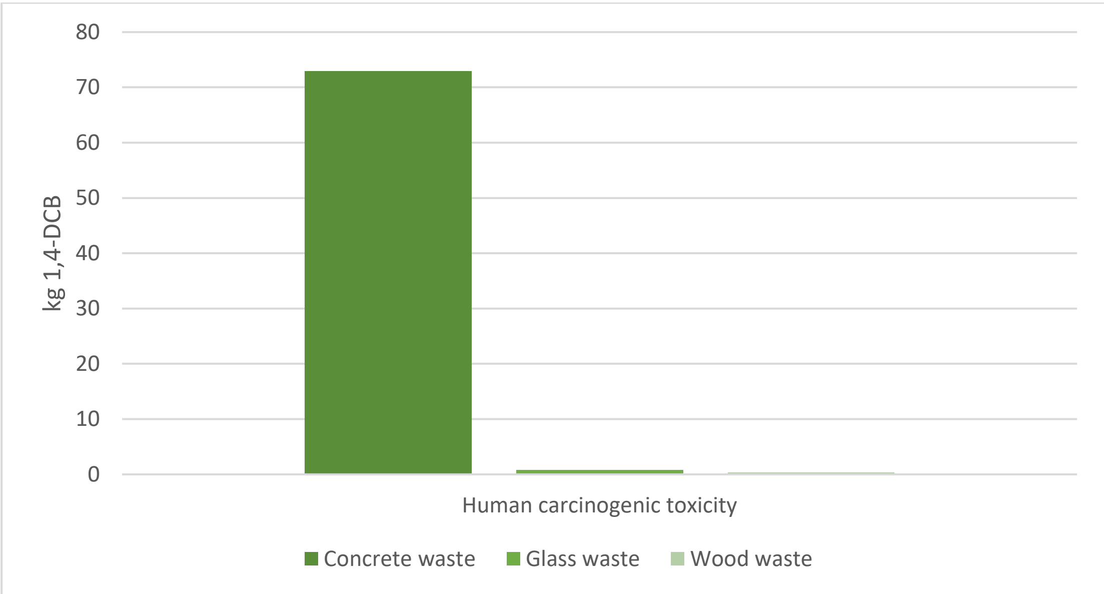

***Figure 16**. kg 1,4-DCB on end-of-life phase*

5.5. Human non-carcinogenic toxicity

On the other hand, another worth mentioning impact category is Human non-carcinogenic toxicity. Having formerly discussed and examined the results on Human carcinogenic toxicity, there are some similarities with non-carcinogenic and alterations, which will be explored intensely in the following sentences. More specifically, one of the major differences in the mode of absorption of the toxic pollutants from the atmosphere, which is mainly from inhalation and ingesting, compared to a variety of exposures ways to carcinogenic chemicals (Mark A.J. Huijbregts, 2005). Overall, Human non-carcinogenic toxicity refers to a general impact on human healthiness, considering the breathing sector, along with the inflections in an individual body, that can be caused by exclusively non-carcinogen ingredients, either in the atmosphere or through contact, or even by incorporation of polluted consumers goods (commission, 2018). Hence, in this impact category, the results extracted from the OpenLCA will be discussed, measured like the Human carcinogenic toxicity in kg 1,4-DCB.

5.5.1. Production phase

In this phase, an illustration of the most impactful materials on Human non-carcinogenic toxicity during the production phase took place in the following Figure 17. Furthermore, the sovereignty of reinforced concrete compared to the other materials is easily distinguished and in this impact category. Fundamentally, emits 53428200 kg 1,4-DCB, reflecting a percentage of contribution to over 45%. Following the reinforced concrete values, is the steel production, obtaining a ratio over 25%, in comparison to the almost identical concrete and timber production values of just over 20% for both materials. Also, in aluminum production, a percentage of around 5% is observed, along with the nearly visible quota of brick and cement production, contributing to 0,02% and 0,03% correspondingly.

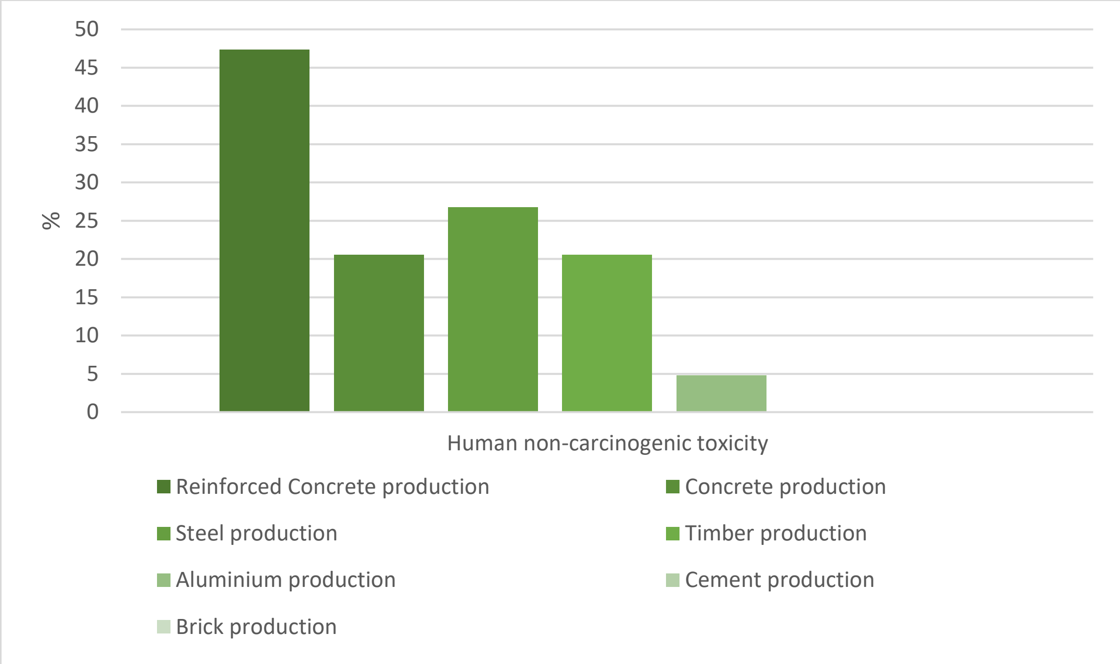

Figure 17. *% of kg 1,4-DCB on the production phase*

5.5.2. Construction phase

Moving on, an additional phase of an LCA is attained by the construction phase, which findings corresponding to the inputs of truck and diesel, after operating the software are illuminated in the below graph, determined in kg 1,4-DCB. Viewing Figure 18, the input of trucks resulted in a significantly higher number of emissions, with approximately 30000 kg 1,4-DCB, in contrast to the 9,28 kg of diesel fuel. Overall, their main contribution to Human non-carcinogenic toxicity acquires one of the lowest possible ratios in the particular impact category. The highest value of the truck, referring not only to the emissions from the burning fuel during transportation, but also considering the dust extracted from the truck mixer, and thus affecting human health (Jin-Young Choi, 2021).

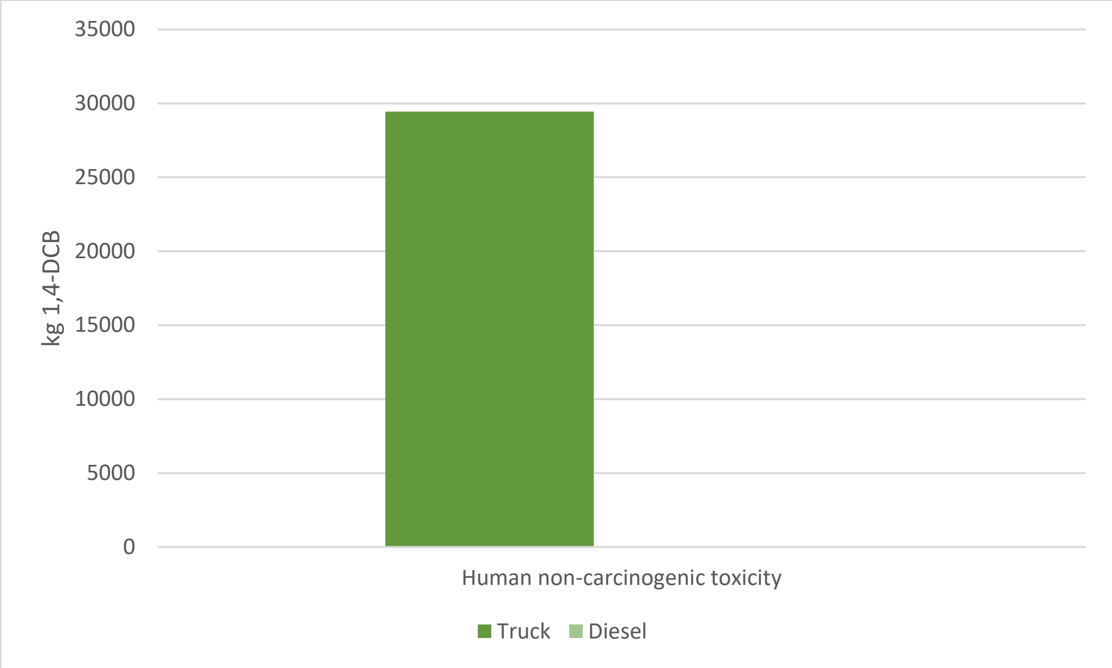

Figure 18. *kg 1,4-DCB on the construction phase*

5.5.3. Operation and maintenance phase

Entrusting the stemmed values from the OpenLCA software, among the imported inputs gas and electricity are in the category of less impacting processes on the subject of Human non-carcinogenic toxicity, as shown in Figure 19. Obviously, observing the lower diagram, the radiated emissions from gas are slightly higher than electricity, with a diversity of approximately 150 kg 1,4-DCB. In addition, their percentages contemplating the impact on human health are zero mutually. Overall, gas when used as an HVAC system, in parallel with regular inspection for any leaks, was concluded to have almost zero effect on human health, and hence in the selected building for the dissertation, the values are very low (Ginta, 2017).

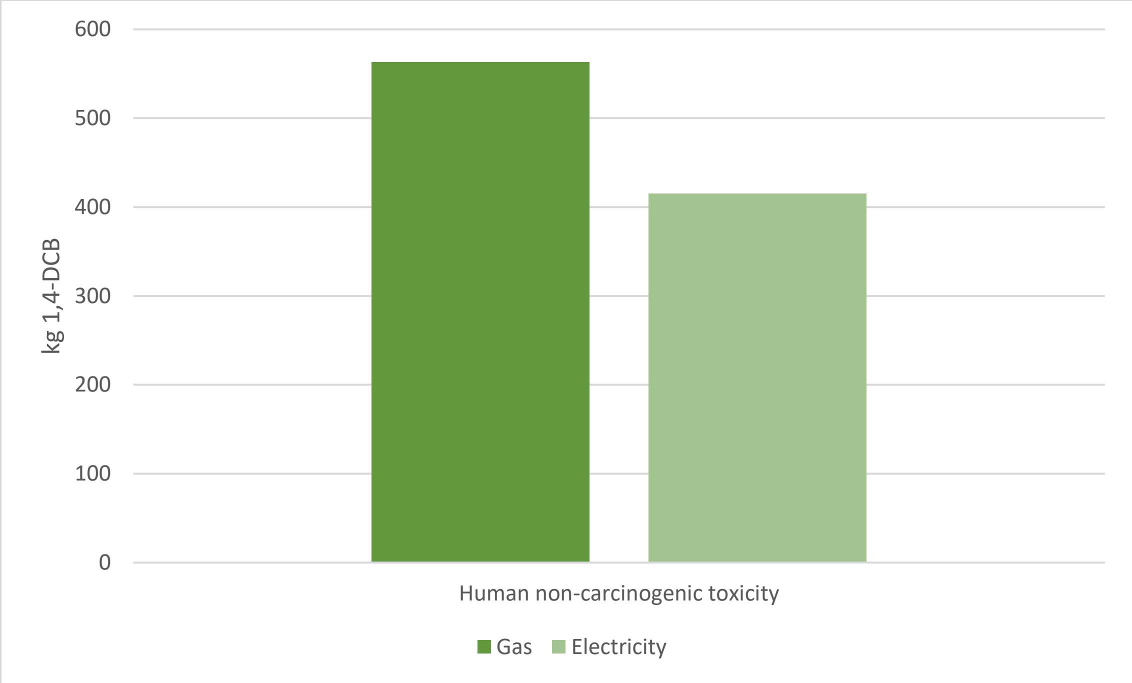

Figure 19. *kg 1,4-DCB on the operation and maintenance phase*

5.5.4. End-Of-Life phase

In the subsequent chart of the End-Of-Life phase, wood, glass, and concrete waste are demonstrated. As usual, the same outcome, with concrete waste providing a substantially elevated value examining the pollutant, with over 1200 kg 1,4-DCB, contrasted to the residual materials. More prissily, the amount of emanated emissions from glass and wood in the demolition phase, considering the Human non-carcinogenic toxicity, are less than 18 kg 1,4-DCB, as presented in Figure 20. However, the overall contribution remained the same for all three materials in the end-of-life phase, representing zero percentage. As mentioned above, the high value of concrete waste owing to dust emanated to the atmosphere, and mainly non-cancer health problems, related to the respiratory system (Beech, 2019).

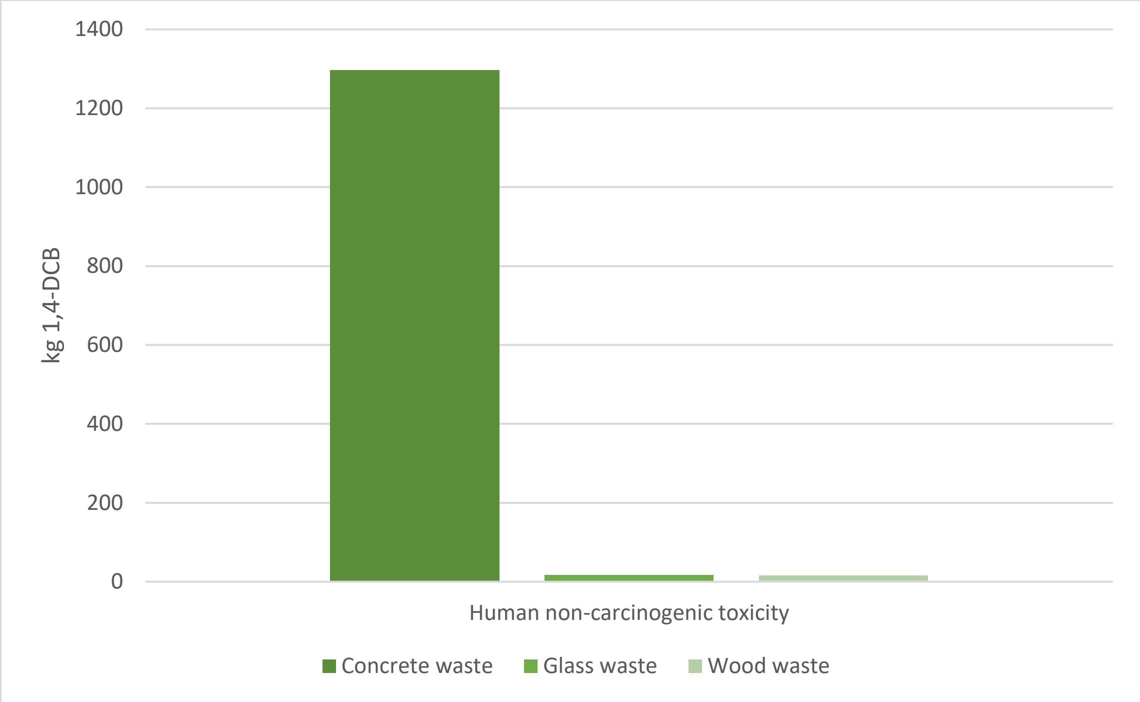

Figure 20*. kg 1,4-DCB on the end-of-life phase*

5.6. Terrestrial ecotoxicity

Likewise, continuing the calculations on the selected construction building materials from the OpenLCA software, the essential impact category of Terrestrial ecotoxicity is described below. The word ecotoxicity refers to chemicals and high toxicity pollutants covering the majority of the impact categories, such as atmosphere and soil, concluding to a significant impact on the ecosystem in general (LC-IMPACT.eu, n.d.). Essentially, Terrestrial ecotoxicity indicates the outcome to the soil for pollutants either from the atmosphere or by an individual, concluding to the significance of frequent inspection of the carefully chosen growth medications for plants by agronomists, inhibiting damages on the ecosystem (ChemSafetyPRO, 2016). For this sector, the findings of the software, concerning the LCIA will be illustrated in the following chapters, computed in kg 1,4-DCB.

5.6.1. Production phase

Taking into a thorough observation the following graph, the values of the production of the selected construction materials, with the reinforced concrete production achieving the greatest ratio concerning the Terrestrial ecotoxicity emissions, as shown in Figure 21. In fact, reinforced concrete emits a significantly high number of 142488000 kg 1,4-DCB, concluded to 30,60% of contribution in the overall impact category. Then, the steel and concrete production followed by contributing to almost 20% mutually. Furthermore, comparing the remaining materials, steel has an appreciably higher ratio of over 10%, compared to aluminum, brick, and cement production, which contribution rates are nearly zero.

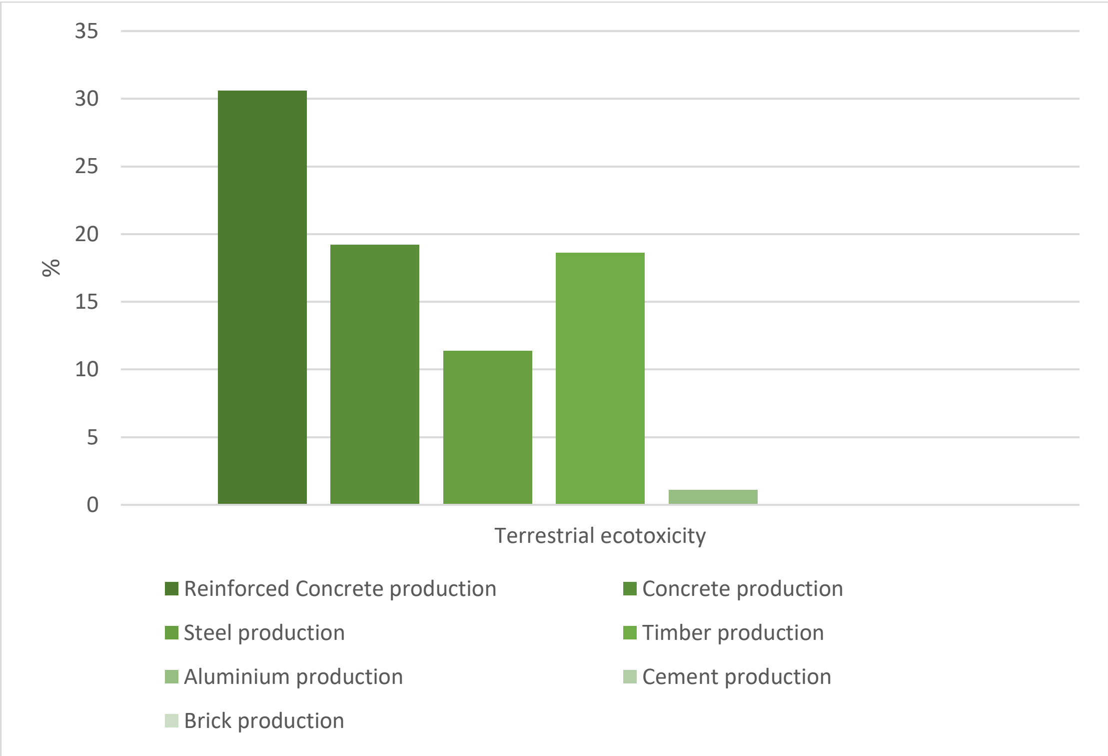

***Figure 21**. % of kg 1,4-DCB on the production phase*

5.6.2. Construction phase

In this phase, the inputs of truck and diesel were imported to the software, resulting in the following presented values in Figure 22. More surely, after evaluating the two inputs, the trucks emit over 25000 kg 1,4-DCB, in comparison to diesel fuel with approximately 2500 kg, regarding the Terrestrial ecotoxicity pollutant. Considering the contribution ratio for the specific impact category, the values are calculated nearly zero. As expected, during the transportation and the production of cement for example with the mixer, the pollutants from trucks are going to be significantly higher to the soil than the diesel input (Pushkar, 2019).

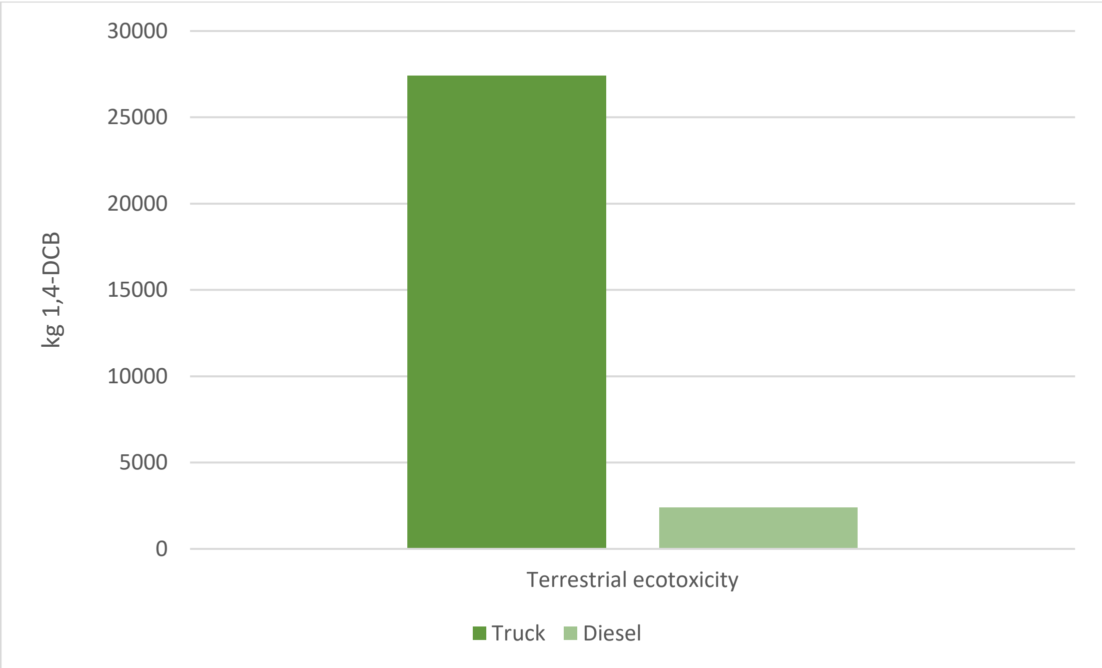

Figure 22. *kg 1,4-DCB on the construction phase*

5.6.3. Operation and maintenance phase

Additionally, after thoroughly observing Figure 23 below, the preferred inputs for the calculations to the software concluded to an expectedly low value of pollutant considering the complete Terrestrial ecotoxicity, respectively. Predominately, the noticed higher value is for the gas fuel, with the kg of 1,4-DCB just over 1050, in contrast to electricity, which emits approximately 1000 kg 1,4-DCB. Taking into consideration the usage of gas as a fuel, which after burning emits emissions to the atmosphere, resulting in the pollutant of the rain and soil at the same time, and thus the value of gas in the dissertation case is slightly higher than electricity (evergreenhomeheatingandenergy.com, 2017). Therefore, the overall contribution to the impact category is considered negligible with nearly zero percent.

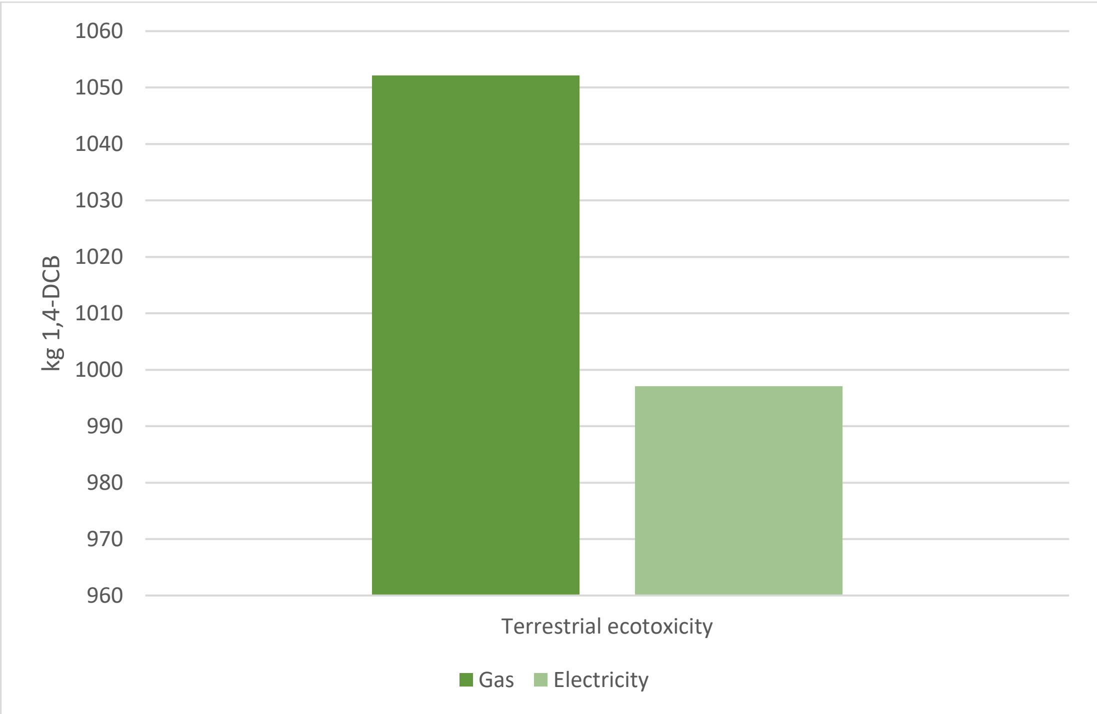

Figure 23. *kg 1,4-DCB on the operation and maintenance phase*

5.6.4. End-Of-Life phase

Studying the subsequent graph, where glass, concrete, and wood waste are represented, the final outcome of the software calculations concerning Terrestrial ecotoxicity is extremely discernible in Figure 24. More overtly, their influence on Terrestrial ecotoxicity is presented in kg 1,4-DCB. Assessing the three inputs, concrete waste has a projected drastically higher pollution than glass and wood waste. Broadly, in kg of 1,4-DCB, the concrete emits over 20000, in contrast to glass and wood, which generates only down 350. On the other hand, their contribution ratio among all the phases of the LCA is zero, and thus judged insignificant.

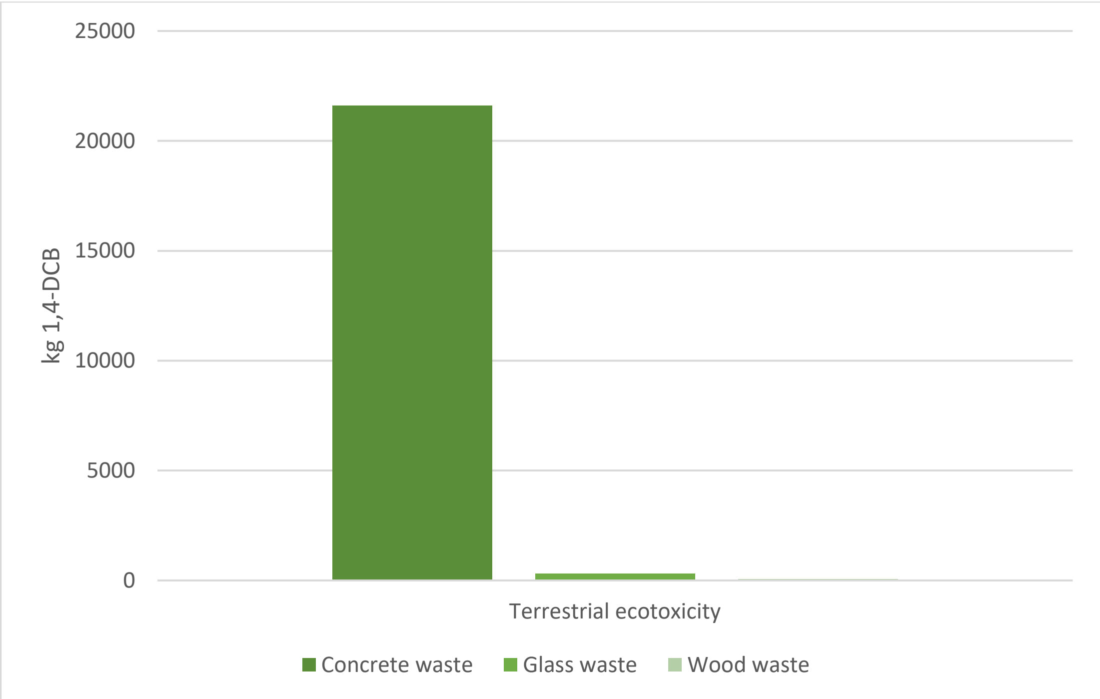

Figure 24. *kg 1,4-DCB on the end-of-life phase*

5.7. Ozone formation – Terrestrial ecosystems

Further, one of the key impact categories associated with OpenLCA software is the Ozone formation – Terrestrial ecosystems, and hence included and thoroughly analyzed in the upcoming sentences of the current dissertation. Originally, Terrestrial ecosystems referred mainly to soil constituted territories, such as forests and in general a variety of lands developing plants, which sequence highlights the ecosystem (nationalgeographic.org, n.d.). As mentioned in the chapter on Ozone formation-Human health, Ozone is produced in the atmosphere from the discharged variety of emissions by chemical reactions, concluding to major impact on land regarding the increasing ph. Ratios and toxicity levels (Rosalie van Zelm, 2016). Thus, the formation of Ozone influences immediately the Terrestrial ecosystems, considering the amount of toxicity (Rosalie van Zelm, 2016). For the specific impact category, the critical phases of LCA from the software computations will be examined deeply, and quantified in kg NO_X.

5.7.1. Production phase

Regarding the following graph, the involvement ratios of the most impactful materials for the duration of the production phase, are exemplified in Figure 25. Simultaneously, the highest value of over 1050000 kg NO_X and exactly 33,58% was captured by reinforced concrete, compared to the following construction materials. In addition, the ratios of timber and concrete cumulatively correspond to the half impact category, in terms of contribution. Then, the ratios of aluminum and steel are expectedly low due to the avoidance of impacting soil during the production, with a value of around 5%. Lastly, the numbers of brick and cement production play an insignificant role in the contribution, with 105,78 and 189,69 kg NO_X respectively.

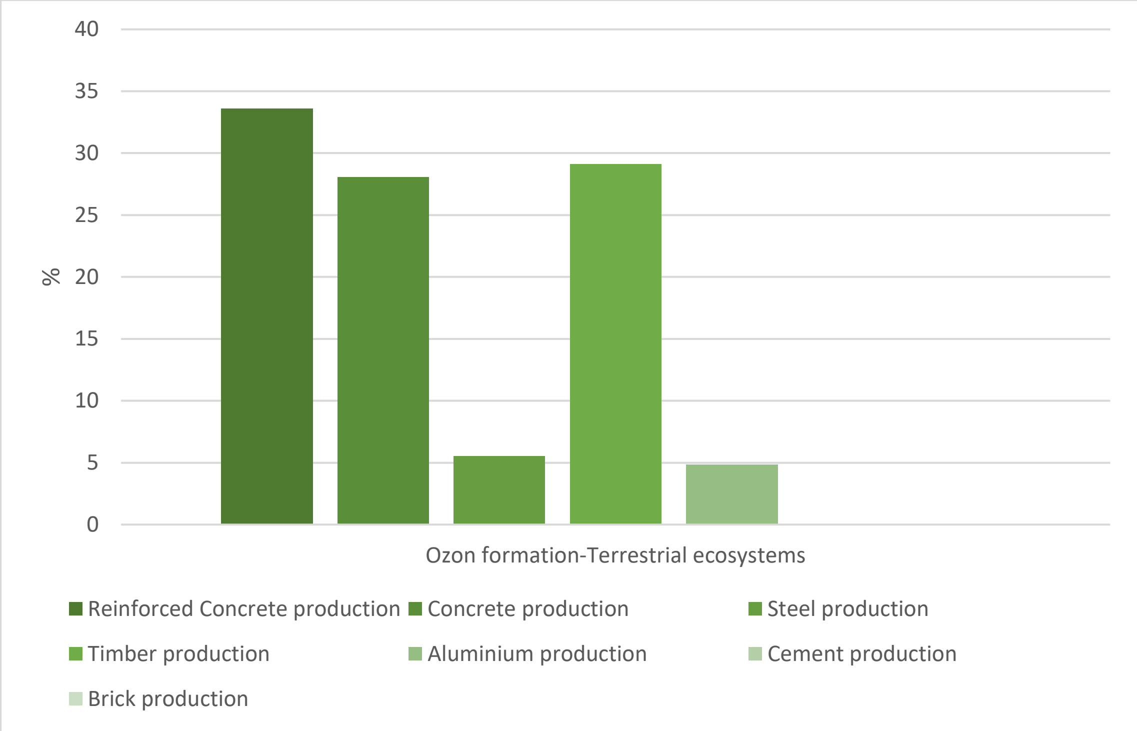

***Figure 25**. % of kg NO_X on the production phase*

5.7.2. Construction phase

Moving on, the contrast of truck and diesel inputs is taking place in the following display. Observing deeply Figure 26, the truck input has a significantly lower value matched to diesel. Specifically, the diesel fuel resulted in a number above 30 kg NO_X and an overall nearly zero percentage contribution to the Ozon formation-Terrestrial ecosystems category. Furthermore, diesel fuel contributed to the insignificant ratio of 0,01%, but expectedly acquired the highest amount of emissions, mainly owing to the increasing percentage of the impact that diesel fuel has worldwide (eea.europa.eu, 2021). On the other hand, the two trucks resulted in just over 10 kg NO_X, and zero effect on the whole impact category.

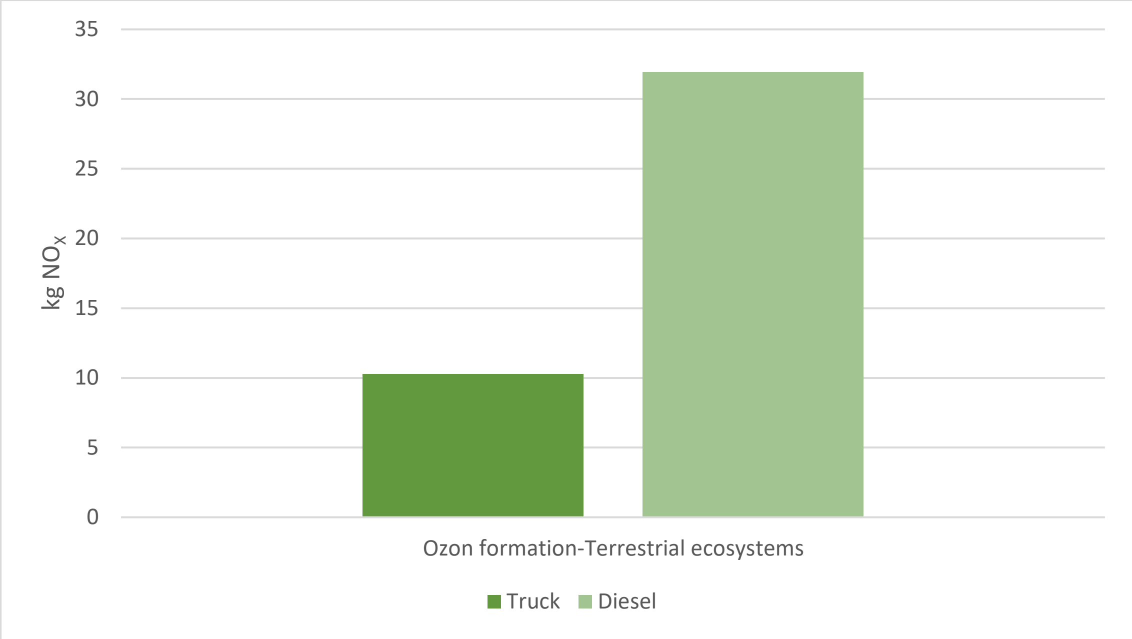

***Figure 26**. kg NO_X on the construction phase*

5.7.3. Operation and maintenance phase

Additionally, in the graph of the operation and maintenance phase, the lowest values in the Ozon formation-Terrestrial ecosystems category of gas and electricity are illustrated in the following Figure 27. The demonstration of the outcomes considering the certain impact category from the OpenLCA software is going to be evaluated in kg NO_X. Also, likening the two, electricity has slightly higher pollution than gas. More genuinely, with a value of around 4 kg NO_X gas as an HVAC system dominates in the pollution sector of this diagram, equated to approximately 2,5 kg NO_X for the eco-friendlier natural gas. Overall, both imported inputs had an inconsequential contribution to the impact category.

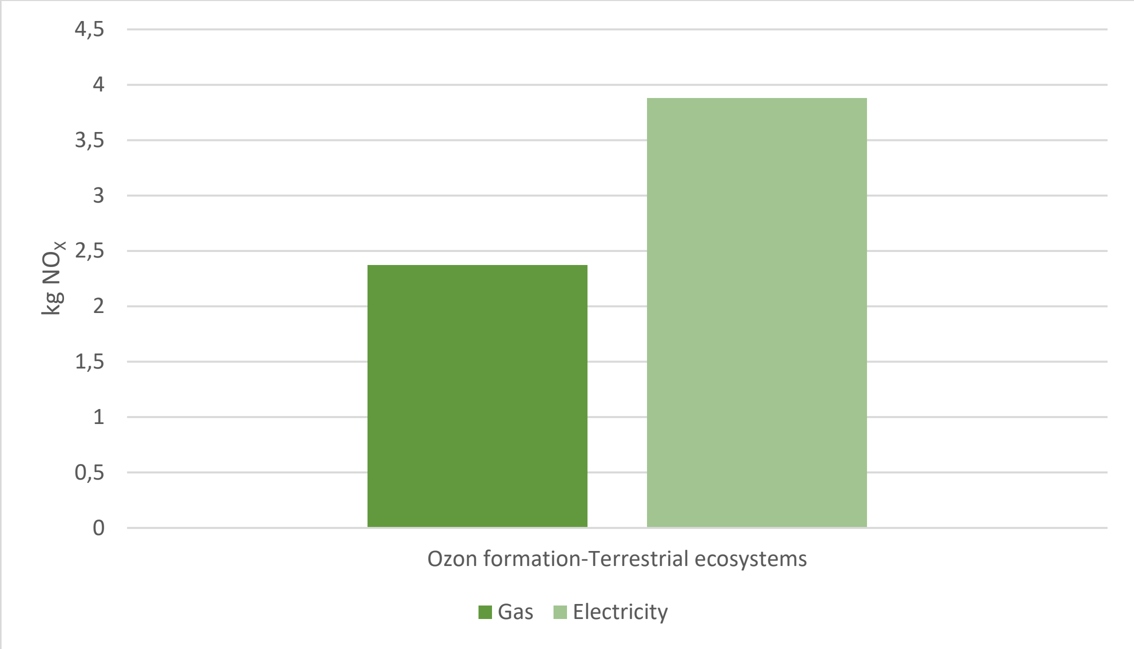

***Figure 27**. kg NO_X on the operation and maintenance phase*

5.7.4. End-Of-Life phase

Analyzing the following illustration, concrete waste corresponds to a significantly higher pollutant number relating to Ozon Formation-Terrestrial ecosystems on this phase of LCA, compared to the alternate construction materials of glass and wood. Specifically, in Figure 28 the introduced inputs to the software for the individual environmental impact category, are measured in kg NO_X. Bearing in mind the emanated dust to the atmosphere and especially to the upper soil during the demolition phase of the building, concrete secretes around 30 kg NO_X to the environment, in contrast to the illegible glass and wood waste number due to their negligible contribution to the impact category (R.Eugene Lamare, 2019).

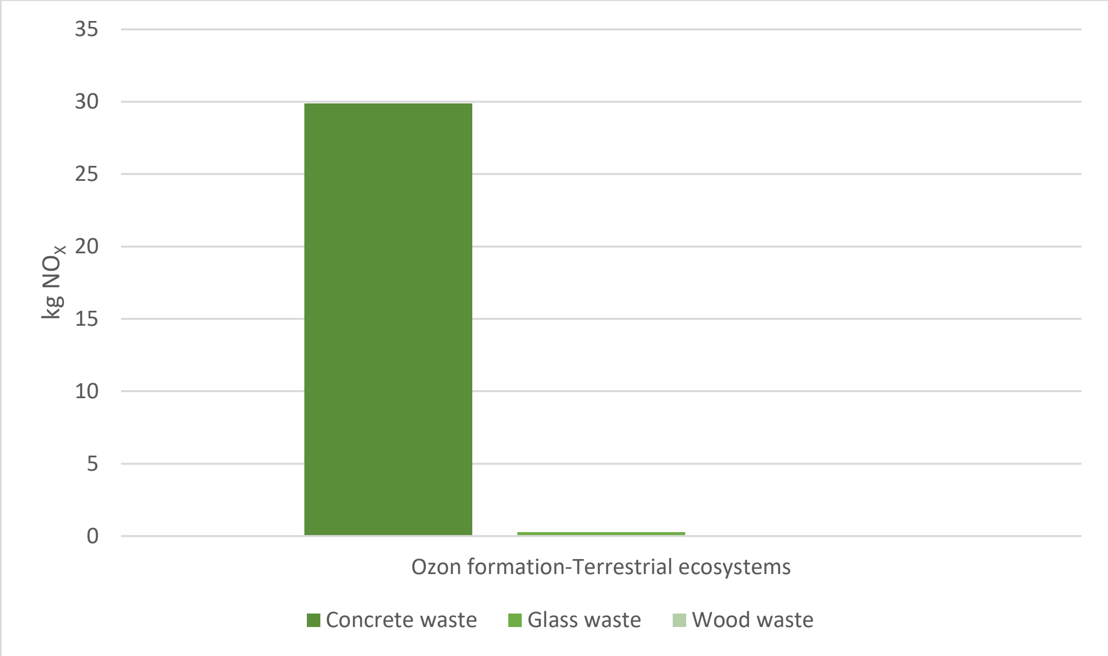

***Figure 28**. kg NO_X on the end-of-life phase*

6. Conclusions

The current dissertation aimed to denote the existence of a variety of emissions concerning the overall environmental impact, emanated from the building sector throughout the entire life cycle of the building. Leaving in a rapidly changing and hard persuaded world, the innovative scheme of carbon offset is urging to the top as an environmental trend worldwide. The idea is to influence the majority of individuals and companies to be part of the aggregate effort made to mitigate pollutants to the environment, and consequently participate in carbon offset-related programs related to building interventions, concluding to the reduction in the ratio of Global Warming globally. The specific target could be achieved with the appropriate information from governments or private organizations to the people regarding the current carbon offset systems and the possible intercessions in the building, along with the willingness to essentially subsidize to prevent any further environmental damage.

Fundamentally, in the initial part of the diploma thesis, the main parts equivalent to carbon offset were extensively analyzed, in order for anyone to be familiar with the specific study. Also, the meaning of carbon offset and the associated markets were followed, in parallel with the illustration of the alternative low-carbon materials and energy efficiency interventions, concluding with a variation of proposals regarding the usage of timber as a substitute to concrete construction material, for the ultimate lessening of the Greenhouse Gas(GHG) emissions. On the other hand, to appropriately detect the destination of carbon emissions and evaluate the materials of the building, the importance of the Life Cycle Assessment(LCA) and the Standards databases was highlighted.

Predominately, the subsequent sector of the dissertation was attentive to the examination of a selected conventional building, considering the construction material's impact on numerous impact categories, utilizing the OpenLCA software. Overall, the intention of the report was the placement of the preferred construction materials into the software, and the analysis of the findings in the whole life cycle of the building after the operation of the program, in order for the recognition of the greatest pollutant materials and the particular phase. More explicitly, the essential impact categories related to Ozone formation, Terrestrial sector, Human toxicity, and Global Warming, measured in percentages for the most impactful and in units the lowest quota depending on the impact category, were demonstrated in diagrams and discussed.

Furthermore, concerning the results from the software in the impact category of Global Warming measured in kg CO_2, concrete and reinforced concrete assembled as anticipated the highest amount of carbon emissions, by contributing mainly to the production and end-of-life phase for almost 50% to the whole inputs in the specific category. The findings of the supplementary construction materials during the production phase, such as timber and aluminum followed, with an overall contribution below 15% respectively. On the other hand, the ratios of the inputs from the additional life cycle phases were insignificant.

In addition, the impact on the Terrestrial sector consisted of, Terrestrial ecotoxicity, and Terrestrial acidification. Also, due to the differentiation in the measurement unit of the two impact categories, the contribution rates were also presented referring to the whole life cycle of the building. Combining both outcomes, the contribution rate of reinforced concrete produced a significantly higher number over 30% compared to the alternative inputs. Further, slight mitigation was observed in the ratios of concrete, timber, and steel production in the impact category of Terrestrial ecotoxicity, with a 20% contribution give or take. In terms of contribution in units, the outcome for the end-of-life phase of the concrete waste dominated in both impact categories, compared to glass and wood. On the other hand, in the construction phase for the acidification category, the numbers were virtually equal for the two inputs, in contrast to the ecotoxicity impact category, where the substantial dominion of the truck input was observed, mainly owing to the pollutant of the ecosystem. Generally, the findings for both impact categories were nearly equivalent, considering the inputs with the highest values in each phase.

Moreover, regarding the impact on human toxicity, Human carcinogenic toxicity, and human non-carcinogenic toxicity were included. As expected, the value of reinforced concrete in the production phase resulted in the highest contribution ratio, with 54,64% and 47,33% for both impact categories correspondingly. Nonetheless, in the production phase of the concrete, timber, and steel the ratios were almost identical around 20% for the non-carcinogenic toxicity, in contrast to carcinogenic toxicity with the value of steel almost identical to reinforced concrete, and the contribution of timber and concrete to a percentage of approximately 9%. In addition, the discrepancy between the highest and the lowest input was nearly the same for both impact categories, concerning their involvement in pollutants measured in kg 1,4-DCB, with the findings in non-carcinogenic toxicity capturing the highest values.

Lastly, the sector of Ozone formation involved, Ozone formation-Terrestrial ecosystems, and Ozone formation-Human health. After combining the results from both impact categories, the almost identical contribution rates to all the life cycle phases were denoted. More precisely, the ratio of reinforced concrete contributes to over 30% in each category, followed by a tiny difference in the values of concrete and timber with about 28%, and steel production with around 5% respectively. Moreover, the ratios of the remaining inputs were considered inconsequential for the specific impact categories, with percentages nearly zero. Essentially, the overall outcome was identical in all the life cycle phases of the building, with slightly increased numbers observed in the Terrestrial ecosystems impact category.

7. Limitations

Through the development of the current dissertation, the imported inputs to the OpenLCA software were thoroughly examined and positioned manually. The source of extraction of an appropriate database is the Nexus OpenLCA database, where the basic database was selected, before importing the applicable inputs and LCIA methodology for the software to operate. Nevertheless, during the research of a residential building database, it was discovered that only by purchase any database referring to a building would be available. Hence, after comprehensive research on the available free databases, a common irrelevant to building database was selected to create a new process referring to the construction of a building with the available building material-based inputs on the software. Additionally, the values of the imported construction materials were manufactured based on the internet values, along with personalized data from my previous work space involving the designated building's characteristics. Bearing in mind the mentioned above justification, along with limited input data from the software, some minor deviations considering the values on the diagrams are visible in the methodology chapter, and therefore the specific dissertation is not a precise analysis of the building construction materials.

8. Discussions

In this diploma thesis, only the crucial impact categories of the selected building considering the construction materials were examined. Predominantly, based on the variety of researches and studies, along with the data of the dissertation, reinforced concrete dominated all the impact categories throughout the entire life cycle of the building. Hence, the usage of timber or low-carbon concrete would be extremely beneficial considering the reduction of carbon emissions. Further research, in combination with time and available resources, could be conducted examining the whole construction materials of a reference building, compared to a building with low-carbon materials, and hence concluding to extensive and more accurate findings.

9. Acknowledgments

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