Estimation of Carbon Emissions from a Plastic Road Using LCA: A case study of a road in Islamabad.

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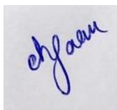
Student/Author Signature:  ____________________

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ABSTRACT

Carbon dioxide emissions mitigation from road construction activities is one of potential pathways to deal with climate change. Aiming to estimate the magnitude of carbon dioxide emissions from construction phase of real entire road project. This thesis focuses on calculation of carbon emissions from a road project made from recycle plastic at Ataturk Avenue, Islamabad. The plastic waste quantity in municipal solid waste is increasing due to increase in population and changes in lifestyle. Plastic roads are found to perform better than ordinary roads and therefore use of plastic road construction has gained importance these days. Utilization of waste plastic bituminous mixes has proved that these enhance the properties of mix in addition to solving disposal problems. The emissions from road materials extraction and production, to-site transportation, on-site construction machinery and other phases during road life cycle including road construction, maintenance, recycling of road even make up 5% to 25% of total CO_2 emissions from transport and among stages, construction phase was the biggest contributor to road project emissions.(Y. Liu, Wang, & Li, 2017) This research aims at identifying critical factors in calculating carbon emissions from a road construction project. This research uses Life Cycle Assessment as its methodology to calculate the emissions from material, equipment and transport which makes up for the total carbon emission. This study undertakes a comparison between a conventional and plastic mix asphalt road based on carbon emission amount. Inventory analysis is done which shows that the materials used are the major source of carbon emissions. This study helps identify major factors important for calculating carbon emission which are emissions from material, emissions from transport and emissions from equipment. Also, this study shows that plastic road emits 5 ton lesser CO_2 emissions than from a conventional road. It suggests this as well that difference between the emissions is from the difference between the quantity of materials due to the addition of waste plastic in plastic mix asphalt.

Keywords: Carbon Emission, Climate Change, Plastic Road, Plastic waste management, Plastic waste recycling, Circular Economy.

CHAPTER 1: INTRODUCTION

1.1 Background Study

Plastic is a substance that does not degrade naturally and can persist for a very long time. The recycling of plastic garbage is becoming more and more important in industrialized nations. The great majority of plastic garbage generated worldwide is either disposed of in nature, landfilled, or burned instead of being recycled. Reuse alternatives that turn waste into resources are badly needed to control the waste stream given the continually expanding volume of plastic garbage. However, limiting the usage of plastic is a significant problem for developing nations. Numerous studies on the usage of plastic waste and the widespread use of polymers as asphalt modifiers both point to the potential benefits of plastics for enhancing pavement performance.

Achieving net-zero carbon dioxide emissions, also known as a balance between carbon outputs and carbon sinks, is referred to as carbon neutrality. Carbon neutrality can be achieved in large part through reducing carbon emissions. Many nations have made commitments to date to achieve carbon neutrality. One possible method of combating climate change is the reduction of carbon dioxide emissions from road construction activities. Trying to gauge amount of carbon dioxide emissions embodied with the conventional ways of paving roads. There is an increasing trend in studying the use of waste plastic in paving roads to help with better waste management and reducing the carbon emissions as compared to conventional asphalt pavements.

1.2 Problem

With increasing population, waste production, especially plastic waste production is increasing exponentially. Plastic being a waste that is non-biodegradable, and it stays in the environment forever. This waste generally is treated by dumping in landfills and by incineration which in turn pollutes the environment and our land even more. Also, as the world is moving towards reducing carbon emissions and striving for carbon neutrality there is a need for identifying and finding creative ways to deal with this issue.

1.3 Previous Studies

1.3.1 Plastic Waste Production

Plastic products are widely used in everyday life. There is rapid urbanization, population growth, and technological advancement in many places throughout the world, which creates a significant problem with managing waste. The worldwide plastic production in 1950 was estimated to be 1.5 million tons, and increase nearly 200-fold to reach 359 million tons in 2018 (Miandad et al., 2019; Ritchie & Roser, 2018). Large amounts of plastic garbage have been produced worldwide because of the continual production of plastic over many years. The generation of plastic waste worldwide has been estimated at more than 300 million tonnes, with a development.(Ritchie & Roser, 2018)

Plastic is everywhere in modern life. It is mostly used for packaging, protecting, serving, and even getting rid of various kinds of consumer goods. Both urban and rural areas of the world are used to gather plastic. Plastic, which comes in a variety of forms, is harmful by nature. The issue of plastic waste can be resolved in two ways. Either substitute the plastic with other materials to reduce its usage consumption or collect the plastic waste and recycle it to reduce the already present plastic waste (Bharti & Sharma, 2021). A little over 27 million Mg of plastic garbage was collected in Europe in 2016; 31% of it was recycled, 42% was burned, and 27% was dumped, separate assortment of In-house bin systems, curbside collection, drop-off containers, and recycling facilities all accept plastic garbage for recycling.(Jacobsen, Willeghems, Gellynck, & Buysse, 2018)

Waste plastic, which includes industrial plastics, plastic bags, and plastic bottles, is a serious and escalating environmental problem. For instance, according to (Taylor, 2017) , the globe produces a million plastic bottles every minute, with fewer than half of them being recycled. Those that were collected for recycling were used to make plastic bottles to a lesser extent (less than 7%). The remainder end up in landfills or make their way into the environment, where they cause a plastic island to form in the Atlantic Ocean, wash up on Antarctic beaches, pollute UK beaches, or are eaten by fish.(Van Cauwenberghe & Janssen, 2014) By the year 2050, it is predicted that oceans will contain more plastic (by mass) than fish.(White & Reid, 2018)

Every person uses about 45 kg of plastic each year, which means that the world's total plastic production is currently at 360 million tons. Multiple plastics are discarded after a brief lifespan (like single use), which has serious environmental implications. However, despite its innumerable advantages, plastic also has disadvantages. Since plastic is inherent to nature, it cannot be disposed of as readily. It will remain there for a few decades or longer without decomposing.(Rahi, Chandak, & Vishwakarma, 2019; Shamim & Vikram, 2023)

1.3.2 Environmental Impacts of Plastic Waste

It is now commonly accepted that plastic trash pollution poses a serious threat to the environment, especially in aquatic environments where plastics degrade slowly through biophysical processes, harm species, and have limited cleanup alternatives. Plastics made of polymers derived from petroleum are commonly utilized in homes and workplaces. When these polymers' useful lives are over, they are frequently landfilled alongside regular municipal solid waste. Phthalates, polyfluorinated compounds, antimony trioxide, bisphenol A (BPA), brominated flame retardants, and other toxic materials included in plastics that might seep out and have a negative impact on the environment and public health.(Alabi, Ologbonjaye, Awosolu, & Alalade, 2019)

Plastic production accounts for 8% to 10% of global crude oil production. By 2050, it is predicted that the global plastics industry will consume 20% of all the oil used.(UNEP, 2018) Over 5 billion tons of plastic waste have already been dumped in landfills. Urbanization has reduced the amount of land suitable for landfills, particularly in cities. Currently, 31% of waste plastic in the European Union (EU) and 40% of waste plastic in the United States are disposed of in landfills.(EUROPEAN & COMMISSION, 2018) On the other hand, more than 80% of marine litter is made of plastic. Globally, plastic pollution causes at least USD 8 billion (United States Dollar) in damage to marine environments every year. By 2050, it is predicted that there will be more plastic in the water than fish in the world. (Forum, 2016)

Secure disposal of plastic waste is a major environmental concern because, if it is dumped in landfills, it will eventually find its way back into the environment via air and water, can clog drains, may be consumed by grazing animals and result in illness or death, and may also pollute construction fill.(Shamim & Vikram, 2023)

This plastic gets up in the environment (particularly the maritime environment), where it keeps breaking down into smaller and smaller pieces, endangering plants and other non-human species and making cleanup difficult. Plastic is persistent in the environment, which means that it bioaccumulates in living things and may eventually damage fragile marine ecosystems and food chains while posing unknown risks to human health. Several studies proven that the disposal of plastic causes many health problems and also reduces the fertility of soil.(Smith & Brisman, 2021)

The management of discarded plastics is currently a significant environmental problem. For the disposal of plastic trash, a few methods have been used, including recycling, disposal in landfills, incineration, microbiological decomposition, and conversion into valuable materials. The collection, sorting, and processing of waste plastics makes recycling expensive and time-consuming, and the low quality of the recovered products restricts their widespread usage (Hopewell, Dvorak, & Kosior, 2009). Filling up with waste causes productive land to become unusable for other purposes. Hazardous air pollutants are released during the incineration and pyrolysis of waste plastic.

According to reports, human activities are the main source of carbon emissions, accounting for over 90% of all carbon emissions worldwide.(Change, 2007) Of these activities, transportation is a significant source of CO_2 emissions. Statistics show that the transport sector accounts for around 27% of all global emissions connected to energy.(I. E. Agency, 2012)

The release of chemicals from plastic waste or the decomposition of plastic into secondary microplastics may be impacted by changes in temperature and the environment, secondary microplastics are those that are created when bigger plastic components break down.(Arthur, Baker, & Bamford, 2009) Regional variations exist in the global problem of plastic waste. Burning plastic debris outside and warming the air in the area are two sources of air pollution. In terms of water contamination and chemical release, the same is true for plastic garbage in the marine environment.(Verma* & 2015)

1.3.3 Carbon Emission and Climate Change

According to the EPA (U. S. E. P. Agency, 2016), carbon dioxide is the main greenhouse gas causing the most recent climate change. The majority of nations have agreed to reduce

CO_2 emissions, and some wealthy nations even set a goal in their low-carbon development plans to cut their domestic carbon emissions by more than 60% by the year 2050.

The issue of excessive GHG emissions-related global warming has gained significant international attention. One of the main interconnected issues facing human society is climate change, along with its social, environmental, economic, and ethical ramifications. According to (Huisingh, Zhang, Moore, Qiao, & Li, 2015), the effects and costs will be significant, profound, and unevenly distributed throughout the world for decades. The majority of governments have taken explicit steps to reduce GHG emissions and global warming since the Copenhagen Conference in 2009.

China stated its intention to become carbon neutral by the year 2060 in September 2020.(Dong, Miao, & Wen, 2021) The Intergovernmental Panel on Climate Change and this goal are very similar. According to the IPCC's Special Report on 1.5°C (SR15), global CO_2 emissions must start to drop well before 2050 in order to prevent the expected 1.5°C global warming. Asia's average temperature has risen faster than natural variation, and extreme warming episodes are happening more frequently. (Masson-Delmotte et al., 2021) To achieve carbon neutrality, it is vital to take air temperature change into account while limiting carbon emissions.

According to numerous studies carbon neutrality lowers air pollutant emissions, lessens haze pollution, and expedites mitigation of the adverse effects of climate change.(Chen, Cui, Xu, & Ge, 2021) The disruption of the Asian monsoon cycle and other climatic elements caused by global climate change make it difficult to predict changes.(Fiore, Naik, Leibensperger, & Association, 2015) Due to the close relationship between regional air quality systems and global climate change systems, simultaneous consideration of both must be made in order to handle complicated future scenarios involving regional emission reduction and worldwide climate change.(Xu et al., 2022)

The world is in thermal disequilibrium at the current levels of greenhouse gas (GHG) concentrations, but emissions at these intensities cause a 2°C rise in temperature.(Hansen et al., 2008) It is clear that climate change poses serious risks to human well-being, ecosystems, and the stable climate necessary for life on Earth. SDG 12 of the UN 2030 Agenda for Sustainable Development must be achieved immediately in order to combat climate change through reducing carbon emissions and avert detrimental effects on human society from additional disruption of the earth's thermal balance.(L. J. C. E. Li & Technology, 2021; Tal, 2009)

1.4 Problem Statement

Conventional methods to pave roads are not environment friendly as per new trends and targets to reduce carbon emissions. There is a way to deal with the problems by analyzing the amount of carbon emissions emitted from a plastic road.

1.5 Research Objectives

- To enlist factors critical for the calculation of carbon emissions of a road project.
- To do inventory analysis and carbon emission calculation of a case study plastic road using LCA.

1.6 Significance of this research

The environment and natural resources must be protected, and this can only be done by taking sustainable action. The take-make-dispose formula is no longer viable, and the repercussions of industrial activities are gravely impacting human health and the ecology. Therefore, a shift based on the circularity of material flows is important in order to minimize intense supply and waste output. The handling of waste is one of the circular economy's first major advantages. Many academics are working to understand the advantages of replacing the raw materials in the grading curve for generating asphalt mixes with waste in order to advance the circular economy goal and also to tackle the issue of climate change in the domain of road pavement construction.(Russo, Oreto, Veropalumbo, & Recycling, 2022)

With 55 billion plastic bags created each year and 48.5 million tonnes of solid garbage produced annually, Pakistan has the highest percentage of improperly managed plastic waste in South Asia. The amount of solid trash produced per day in Pakistan, according to the government, is estimated to be 87,000 tonnes, largely in the country's largest cities. In most of Pakistan's main cities, local and municipal governments are in charge of rubbish collection, and 60–70% of solid waste is collected. Some communities supplement other collecting methods by employing sanitation staff and street sweepers. Before any waste ever reaches disposal facilities, a large portion of it is recovered for recycling, primarily by scavengers. Despite neighboring nations using PET to build low-maintenance roads, no organization in Pakistan has yet to take such a step.(Center, 2021)

This study can help us identify the critical factors to be addressed for reduction of carbon emissions coming from a road project construction. It can enable us to do a comparison and make a better choice between conventional road and plastic road based on amount of carbon emissions also it can help us forecast the reduction of carbon emissions and plastic waste from our surroundings. This study can serve as the basis for the formulation of a policy governing the use of recyclable plastic in roads.

1.7 Thesis Organization

- **Chapter 1**

The introduction chapter includes background study, previous studies, research gap, problem statement, research objectives, and significance of study.

- **Chapter 2**

This chapter includes literature review comprising of Utilization of plastic waste in road pavement and Carbon emission estimation from roads.

- **Chapter 3**

This chapter includes methodology of study including the methodology for the framework.

- **Chapter 4**

This chapter includes the results of the study and its discussion.

- **Chapter 5**

This chapter consists of conclusions drawn from the study and this chapter includes the future recommendations.

CHAPTER 2: Literature Review

2.1 Utilization of Plastic Waste in Road Pavement:

Road construction with plastic waste stands out among other methods for using or recycling plastic waste. Although using waste materials in road pavement is not a new concept, it has recently become more popular in the pavement sector as a means of lowering the consumption of virgin and increasingly rare materials as well as preventing landfilling (J. Li, Xiao, Zhang, & Amirkhanian, 2019; Zhao, Xiao, & Amirkhanian, 2020). Plastic waste, which is typically regarded as a pollution threat, used in pavement performs better than conventional roadways. The performance parameters of the bituminous mix were found to be improved by covering the particles with waste plastic (Rahi et al., 2019). The waste management industry has recently become interested in the circular economy concept. Its goal is to use materials more efficiently in a circular loop while lowering the footprint of consumption, hence requiring no landfilling. (European Commission, 2020).

The use of waste materials in road pavement applications, however, has been a recent widespread trend in the pavement industry as a response to the requirement to both reduce consumption of virgin and increasingly scarce materials and avoid landfilling.(J. Li et al., 2019; Zhao et al., 2020) Numerous Life Cycle Assessment (LCA) studies have already been carried out in order to quantitatively assess the possible environmental implications of employing these waste materials in road pavement applications.(Aurangzeb, Al-Qadi, Ozer, Yang, & recycling, 2014; Giustozzi, Crispino, & Flintsch, 2012)

2.1.1 Dry Process for Plastic Road Pavement:

There are two processes known for the preparation of road pavement with waste plastic. Initially a large portion of discarded plastic is employed in the dry process. The greatest method for making use of the high value of plastic garbage is this one. To create a flexible pavement, heated bitumen (160°C) is combined with stone aggregate (170°C) and utilized for rod laying.(Mir, 2015; Raja, Sampath, Suresh, Bhaskar, & Technology, 2020). CMP is an additional method for doing the dry process. By effectively combining the materials and controlling the temperature, you can get a homogeneous coating. It may result in a 10% decrease in the consumption of bitumen. Additionally, it makes the most use of plastic waste. The improvement in the efficiency and durability of the roadways is another benefit. Even after years of construction, they are indestructible.(Bharti & Sharma, 2021)

2.1.2 Wet Process for Plastic Road Pavement:

Firstly, collected and the used plastic is finely chopped while in the Wet Process. To merge the waste plastics, heated bitumen at 160°C is immediately mixed with shreds of plastic. This approach is not widely employed because of the bigger plant size and hefty investment required. Because bitumen and molten polymer have different viscosities, mixing can be challenging. Thus, a mechanical stirrer is needed for this procedure. One advantage of the wet approach is that it may be used to recycle waste materials of any kind, size, or shape.(Mir, 2015; Raja et al., 2020)

2.1.3 Comparison between Plastic and Conventional Road

While discussing the comparison between conventional and plastic roads, it is believed that plastic-bitumen roads can endure up to 10 years, whereas a typical highway only lasts 4-5 years. Rainwater won't leak through any longer because of the plastic in the tar. Plastic's binding properties increase strength so that it can support more weights. When compared to roads made of asphalt from regular blend, the strength of the roads made of shredded plastic waste is significantly higher. The cost of maintaining plastic roads is significantly lower than that of the traditional approach. However, compared to more traditional techniques, building roads out of plastic can cost a little more. We can lessen the amount of non-biodegradable waste by building plastic roadways as well.(Bharti & Sharma, 2021)

The use of plastic waste enhances flexible pavement's abrasion and slide resistance significantly. It also makes it possible to get splitting tensile strength values that meet the required limitations even when the mix's plastic waste content exceeds 30% by weight. Modified bitumen cannot operate well in situ and will fail prematurely if constant mixing time and temperature are not supplied for bitumen-modifier mix. Therefore, for all polymers with a trademark, there are recommended values for mixing time, temperature, and modifier content. When mixing and laying roads with waste plastic, keep all of this in mind. An advantage for India would be plastic roads. Plastic roads offer the biggest benefits in hot, muggy climates. They are long-lasting and environmentally beneficial. The removal of all plastic garbage from the planet will also be aided by this.(Chavan & Management, 2013; Patel, Popli, & Bhatt, 2014)

2.1.4 Advantages Of Using Plastic Waste In Roads

Every ton of waste that is recycled means that there is one ton less material that would otherwise end up in a landfill and one ton less fresh aggregate and/or bituminous binder that needs to be created from limited natural resources. However, if recycling only 20% of waste leads to a 50% reduction in pavement or surface life, the environmental costs and long-term savings are worse than not employing recycled materials. Like the savings associated with the reduction of new material consumption, the cost of selecting, processing, and reincorporating recycled resources is frequently significant. Therefore, it's critical that recycled materials deliver at least equal performance to fresh material utilization at no additional expense.(White & Reid, 2018)

2.1.5 Notable Examples of Plastic Roads

In India, the technology to utilize used plastic bags in the construction of bituminous roads was described by professor R. Vasudevan in 2004 and India already has over 100,000 km of roads made of waste plastic.(Biswas, Goel, & Potnis, 2020) This not only eliminates the issue of disposing of or incinerating them but also results in a higher-quality pavement. The technique developed by R. Vasudevan is being used in numerous nations throughout the world. According to several reported works(Appiah, Berko-Boateng, & Tagbor, 2017; Rajasekaran, Vasudevan, Paulraj, & Research, 2013; Vasudevan, Sekar, Sundarakannan, Velkennedy, & Materials, 2012), plastic roads may have a lower rate of deterioration than traditional bituminous roads.

Also in Ghana, High-density polyethylene (HDPE) was shown to be possibly used for road construction in a 2016 study.(Appiah et al., 2017) A higher softening point and a lower penetration value were obtained through experiments, while the binder's overall dynamic and absolute viscosities were improved. The study also showed that waste plastic modified bitumen has considerable promise as a non-traditional, modified binder for road building and as an alternative recycling strategy for Ghana's plastic waste management (Biswas et al., 2020).

Plastic roads are being constructed using comparable methods with a plastic-asphalt mixture in various places of Indonesia, including Bali, Surabaya, Bekasi, Makassar, Solo, and others. Also, Volker Wessels, a Dutch firm built plastic roads for bikes in Zwolle, in the Netherlands' northeast. The United Kingdom also declared that it would invest £1.6 million for the trial of plastic road technology in cooperation with an asphalt enhancement company that would use technology created by R. Vasudevan and some of the top-secret compounds to extend the lifespan of roads. It is currently being used in places like Durham, London, and Gloucester.(Biswas et al., 2020)

2.2 Carbon Emission from Roads

2.2.1 Carbon Emission From Transportation Sector

The transportation infrastructure, especially the road infrastructure supporting the steadily increasing number of automobiles in developing countries, shows a high potential for the migration of carbon emissions in addition to the tailpipe CO2 emissions produced by operating a vehicle. This is because of the infrastructure's greater resource consumption, higher energy consumption for machinery, and large amount of fuel used for transportation and on-site construction activities.(Muench, 2010) According to(A Jullien, 2014), the total CO_2 emissions from transportation are made up of emissions from the extraction and production of road materials, transportation to construction sites, on-site construction equipment, and other phases during the life cycle of a road, such as road construction, maintenance, and recycling makes up to 5% - 25% of total CO_2 emissions from transport sector. Of these phases, the construction phase was the one that contributed the most to emissions from road projects.

2.2.2 Impacts Of Roads on the Environment

The number of papers released recently reflects the subject's growing popularity. By estimating the CO_2 emissions from a road's whole life cycle, including the extraction of raw materials, the production of construction items, and the construction process, (Stripple, 2001) carried out the first LCA on the environmental effects of the entire road construction project. Even the operation and maintenance of the road as well as its eventual destruction or reuse at the end of its life cycle were covered. Operational carbon (OC) and embodied carbon (EC) are two categories for the carbon footprint.(Kang et al., 2015) Emissions from production, transportation, and construction are referred to as EC. Most studies have assessed how pavement affects the environment. Numerous pavement structures, including asphalt, composite, and cement concrete pavement, have had their environmental effects assessed by (Park, Hwang, Seo, Seo, & management, 2003) and (Treloar, Love, Crawford, & management, 2004). Based on the LCA application, other research groups developed national or regional LCA road tools, some of which were aimed at particular fields, like the PAS2050 model for creating an assessment of the environmental and energy consumption on road projects, the PaLATE model for creating an assessment of the environmental and economic impact of roads, and the SimPro model for life-cycle environmental and energy consumption analysis on road pavement materials.(Santero, Masanet, Horvath, & Recycling, 2011)

According to , (Y. Liu et al., 2017) , understanding the CO2 emissions levels of different types of roads and taking appropriate action to reduce CO2 are critical for decision-makers and builders. As a result of the inclusion of CO2 emissions reduction in global or national development targets, advanced technology and low-carbon approaches, such as renewable energy, carbon capture technology on the coal sector, electrical structure modification, and recycled materials, are being steadily used. All of these new variables could have an impact on certain life-cycle inventory analysis steps for building road infrastructure, which would then have an effect on the CO_2 emissions of those steps. In estimating CO_2 emissions from road development, there are additional unknowns. To identify key elements and comprehend the potential for CO_2 emissions reduction from various types of road road project, it is important to evaluate the quantity of CO_2 emissions from the complete road project, including the road construction and earthwork. Finally, this study's findings on emissions are compared to those of other studies. This data, along with national statistics on the number of kilometers of new roads built each year, contribute to a valid and reliable national inventory of CO_2 emissions and serve as a guide for reducing CO_2 emissions from road infrastructure. Additionally, this study significantly increases the number of case studies to support and contrast with other road project kinds.

2.2.3 Factors in Carbon Emission Measurement

The extraction, processing, and transportation of raw materials are the first steps in the inventory study of emissions from material production. By quantifying the emissions caused by fuel consumption, off-road machinery and transportation vehicle emissions can be practically measured. The sum of the emissions from the three main sources can be used to determine the total emissions of a road project. The road project's length and lane count are then used to standardize the total emissions into functional units. By averaging the different emissions per functional unit data for each type of road project, the emissions per functional unit are determined. The original data on materials, fuels, and vehicle or equipment work time in bridge and tunnel building operations are used to determine the total cost of a road project. (Y. Liu et al., 2017)

According to (Hatmoko, Hidayat, Setiawati, & Prasetyo, 2018) the carbon footprint measurement accounts for both on- and off-site project operations. While on-site activities focus on plant utilisation for asphalt concrete manufacturing and laying for road sub-base, base and surface courses, off-site activities involve the production and transportation of materials. Processing of natural resources including fillers, asphalt, coarse and fine aggregate is a part of the material production process. By using dump trucks for aggregate and filler and tank trucks for asphalt to move natural resources from their sources to the project site, carbon emissions are produced.

The total amount of greenhouse gases (GHGs) emitted into the atmosphere as a result of energy use is referred to as "GHG emissions for the construction stage". It is made up of two fundamental parts. The first is the utilization of materials and resources, which includes waste produced during the construction process and the use of auxiliary engineering supplies.(Xianwei Wang, Duan, Wu, & Yang, 2015). The second is energy use, which includes the energy used by tools, construction-related machinery, and worker living activities. The estimate primarily considers the amounts of petrol, diesel, and electricity used by transportation, construction machines, and equipment.(L. Li & Chen, 2017)

The carbon emissions factor is the energy parameter that deals with the characteristics of greenhouse gas emissions and the consequences of energy on the environment. Correlating GHG emissions with energy use provides crucial baseline data for calculating the carbon emissions of buildings and construction activities. It is the numerical sum of all carbon emissions produced during all processes needed to produce a specific quantity of energy. (L. Li & Chen, 2017), emission factors for the five primary sources—fossil fuels, power, water, building supplies, and machinery were considered.

Vehicles are primarily powered by the two fossil fuels, gasoline and diesel, throughout the construction phase. The CO2 equivalent emissions factors for gasoline and diesel were calculated using the principal greenhouse gas (GHG) calculation methods and emissions factors released by the Intergovernmental Panel on Climate Change (IPCC). (Simon Eggelston, 2006) Construction involves the use of a wide range of materials, including steel, cement, and concrete blocks. Researchers in China and other countries have determined and compiled the emissions factors of the main building materials. The IPCC Guidelines for National GHG Inventories offer the energy consumptions of the equipment and the accompanying carbon emissions components that are used in this paper. (Simon Eggelston, 2006) Based on the actual use of construction machinery, the emissions factors of the main categories of machinery and equipment were determined. The emissions factor of fuel, and construction materials used in the construction process of a pavement are given below in Table 1 (Anderson J, 2011; Giustozzi et al., 2012; Y. Liu et al., 2017; Simon Eggelston, 2006) Whereas the carbon emission from equipment and machinery is dependent on the amount of fuel utilized.

Table 1: Carbon Emission Factors

Material	Unit	CO_2e Emissions
Bitumen	kg/ton	256.5
Crushed aggregate	kg/ton	7.5
Stone dust (Khaka)	Kg/ton	5.3
Diesel	kg/kg	3.68
Gasoline	kg/kg	3.51
Tyre Oil	Kg/kg	2.65

2.3 Life Cycle Assessment

This study (L. Li & Chen, 2017) presents a comprehensive model for the computation and assessment of life cycle inventory (LCI) of construction processes and life cycle assessment (LCA) theories. carbon emissions while building. At this point, the energy contained in building materials is not considered. The paper's primary contents are as follows: (1) developing a framework for calculating greenhouse gas emissions during construction; and (2) calculating greenhouse gas emissions during the building of a sizable residential neighborhood in Shenzhen City.

Through the use of an LCA methodology, this study (Y. Liu et al., 2017) seeks to estimate CO2 emissions in accordance with ISO 14040 (Organization, 2006). Cumulative effects of a road project's development across its life cycle system boundaries are used to estimate the CO2 emissions. Road structures, such as bridges and tunnels, are contained inside the system boundary in this study. The primary source of fuel and power consumption in the construction industry is off-road machinery, which encompasses not only traditional on-site equipment but also machinery or equipment found in asphalt mixing stations and concrete mixing plants.

The research described in this paper(Santos, Pham, Stasinopoulos, & Giustozzi, 2021) uses LCA and looks into the environmental aspects of the procedures that turn waste plastics into a commercial resin that can then be utilized in the creation of asphalt mixtures as an additive or in substitution of raw aggregates. In the end, this can clarify if the so-called "Plastic asphalt roads" might benefit the environment in addition to some of the mechanical benefits that are frequently associated with this technology.

The LCA methodology in this study(Russo et al., 2022) is used to integrate the environmental and mechanical characteristics of a foundation layer of road pavement, whose asphalt mixture adheres to the three asphalt mastics solutions that are recommended one at a time, as well as the natural aggregate grading curve that complies with regional technical requirements. Verifying the resulting improvements in pollution reduction, conservation, and usage of natural resources is the aim. According to the study's conclusion, the objective is to provide an integrated mechanical-environmental method for comparing the performance of asphalt mixtures. The first step in this process is to evaluate the performance of the asphalt mastics, since their inclusion directly affects the performance of the final asphalt mixture.

Through an analysis of three preventative maintenance treatments, the study (Giustozzi et al., 2012) presents the suggested methodology for a whole life cycle assessment of various road maintenance solutions. In all three scenarios, the pavement structure and traffic volume are taken to be constant. Based on pre-established thresholds, performance deterioration models were utilized to determine when preventive maintenance actions were required. For every intervention, agency costs and environmental effects were calculated and added up over the course of a typical analysis period.

2.4 Environmental and Human Health Impacts of Plastic Roads

Prior studies paid less attention to the detrimental effects of plastic roads on the environment and human health, which are now two of their current drawbacks. (Pawar et al., 2021) describes the detrimental effects of plastic roads on the environment and human health. The desorption of bitumen's harmful components could expose the road workers to dangerous substances. Additionally, edible plants' adsorption of microplastics is extremely hazardous. Microplastics may have varied effects when inhaled or ingested and may change the metabolism of people, animals, and aquatic life. Microplastics have the potential to transfer metals and microbes.

The release of microplastics into the environment is one of the key issues with plastic roadways (Abd Karim et al., 2023). Polypropylene and polyethylene, two widely used plastic polymers for road pavement, can degrade under heat, oxidation, light, ion radiation, hydrolysis, mechanical shear, and pollutants like carbon monoxide, sulphur dioxide, nitrogen oxide, and ozone (Appiah et al., 2017; Habib, Kamaruddin, Napiah, Isa, & Engineering, 2011; Ravve & Ravve, 2000). Furthermore, a number of studies (Casey, McNally, Gibney, Gilchrist, & Recycling, 2008; Pérez-Lepe, Martínez-Boza, & Gallegos, 2007; Yin et al., 2020) revealed that plastic polymers and bitumen did not mix chemically well, which caused problems with component phase separation. This was particularly true for polymers with high molecular weight and low maltene fractions. Unwanted polymer phase separation can block pavement pump tubes and nozzles and has a negative impact on the mechanical performance of asphalt at the microscale (Hou et al., 2016; Presti & Materials, 2013). Phase separation may also result in the leaching of recycled plastic from asphalt mixtures, which would then pollute the environment (Abd Karim et al., 2023).

2.4.1 Adverse Effect of Microplastics

Microplastic pollution has grown in importance globally during the past ten years, especially in marine environments (Thompson et al., 2004). Microplastic pollution of waterways, soil, and the atmosphere has received increased attention recently(Jacques & Prosser, 2021; C. Li et al., 2021; Xiaohui Wang et al., 2020). Between 1.15 and 2.41 million tonnes of plastic garbage are thought to enter the ocean each year through rivers, primarily those in Asia (Lebreton et al., 2017). On the other hand, air microplastics are eventually deposited in water and soil environments after being horizontally transported by wind up to 95 km distance (Allen et al., 2019; K. Liu et al., 2019; Yang, Zhang, Kang, Wang, & Wu, 2021).

Microplastic debris is transmitted to higher-trophic level species in a contaminated environment (mostly in the aquatic) via ingestion, bioaccumulation, and biomagnification mechanisms (Bellasi et al., 2020). As a result, it alters the metabolic profile of both people and animals and triggers inflammatory reactions, immunological activity, and alterations (Bellasi et al., 2020; De-la-Torre & technology, 2020). Additionally, edible plants like vegetables have roots that can collect microplastic debris, which can be harmful to people when eaten directly (Yang et al., 2021).

Microplastics could pose chemical and biological threats to environmental species in addition to particle toxicity (Prata, da Costa, Lopes, Duarte, & Rocha-Santos, 2020). The microplastic matrix may allow monomers and chemical additives to seep out, creating toxic chemicals such plasticizers, flame retardants, stabilizers, and biocides (W. Liu et al., 2020). Due to their persistence, potential for bioaccumulation, and toxication hazards, a number of plastic additives, including polybrominated diphenyl ethers and hexabromocyclododecane, have been outlawed in European and North American markets (de Wit, Kierkegaard, Ricklund, & Sellström, 2011). While common plastic additives like bisphenol A and formaldehyde are categorized as hormone disruptors and carcinogens, respectively (Verla, Enyoh, Verla, & Nwarnorh, 2019).

Additionally, dangerous non-intentionally added chemicals in varying amounts and types are present in post-consumer recycled plastics that are typically utilized in the production of plastic roads (Horodytska, Cabanes, & Fullana, 2020). These components are of concern because bitumen is produced at high temperatures (up to 180 °C), which might cause hazardous compounds to desorb and expose road workers to poisonous compounds (Enfrin & Giustozzi, 2022).

Furthermore, because of their large surface area, microplastics can carry both chemicals and microorganisms, such as heavy metals like cadmium, zinc, and plumbum as well as persistent organic pollutants like polyaromatic hydrocarbons, organochlorine pesticides, and polychlorinated biphenyls. (Bradney et al., 2019) . When biotic creatures consume these pathogen- and toxin-loaded microplastic particles, infections and toxicity may result (Masud, Davies-Jones, Griffin, & Cable, 2022). Consequently, research on microplastic pollutants is essential to preserving a healthy ecosystem for people, animals, and plants.

2.4.2 Limited Risk Assessment Study on Plastic Roads

The plastic abrasion mechanism from plastic-modified bitumen and its effects on the ecology have not yet been thoroughly investigated by road building firms or researchers (Conlon & Ecology, 2022). In a recent paper, the Scottish Road Research Board recommended against using waste-derived plastic in the bound and unbound layers of road construction, unless it were being utilised as a test case (Coopland & Winter, 2021). With a life expectancy up to three times greater than that of conventional asphalt paving, the oldest plastic roads currently being constructed are less than eight years old. As a result, their long-term performance is unknown, and there are dangers to the environment and human health (Hashem & Cardiño, 2020).

Numerous common tests experimentally evaluate the performance of asphalt in controlled laboratory settings that do not accurately reflect actual field circumstances (Choi, 2016). Alternative methods for testing asphalt's surface and structural changes include the Pavement Fatigue Carousel or the Heavy Vehicle Simulator (Du Plessis, Ulloa-Calderon, Harvey, Coetzee, & Technology, 2018). Accelerated pavement testing, however, cannot be used to evaluate some parameters, such as the degree of gaseous emissions when laying hot asphalt and the release of microplastics when plastic-modified roads are open to traffic due to abrasion exerted by car tyres (Enfrin & Giustozzi, 2022).

The environmental impact of plastic roadways has been the subject of additional significant but constrained research via its life cycle assessment (LCA), the majority of which rely on secondary data and modelling rather than primary data gathered directly from the plants (Santos et al., 2021). Additionally, there are no LCA data on how traffic and road wear affect the release of microplastic particles from plastic-modified roadways (Enfrin & Giustozzi, 2022). The phenomenon of microplastic release from roads is controversial because it depends on a number of variables, including the methods used to incorporate plastics into bitumen (wet or dry method), the types of plastics used (recycled or virgin plastics), and the external climatic conditions (Enfrin & Giustozzi, 2022).

The integration of plastic particles produces dangerous vapors from both bitumen and plastics (Mo, Wang, Xiong, & Ai, 2019), and plastic road preparation necessitates higher temperatures than plastic melting point. Data on the real-time toxicological evaluation of the total amount of gases emitted by plastic-modified asphalt among roadworkers are currently few (Boom, Enfrin, Grist, & Giustozzi, 2023).

Environmentally speaking, gaseous emissions for both kinds of recovered plastics were reduced by up to 21% as a consequence of producing asphalt at a high temperature and with a larger plastic content. Additional comparative research shows that the production of microplastics from recycled plastic-modified asphalt is similar to that from asphalt products changed with commercial polymers, which have been used by the industry for a long time. All things considered, the utilization of recycled polymers with low melting points as an asphalt modifier is encouraging because it has advantages over traditional asphalt from a technical and environmental standpoint.(Boom, Enfrin, Swaney, et al., 2023).

CHAPTER 3: Methodology

3.1 Research Design

The research methodology shows how researchers carry out their studies to achieve and answer research objectives. The research methodology adopted to achieve this study's objectives is discussed and presented in this chapter. The purpose of this research is to estimate the amount of carbon emissions from a road made by using plastic waste in comparison to a conventional asphalt road. This study aims at finding out if using plastic waste in paving roads results in lesser carbon emission and if it can serve as one of the solutions for dealing with plastic waste. In step one, a research proposal was given utilizing previous studies, research gap and objectives. Based on literature review, critical factors used in calculation of carbon emissions from a road were identified in step two. Data acquisition was done through doing interviews of concerned person regarding the case study project. In step three, a framework will be developed to calculate the emissions from a plastic road taking a case study of a road, "Ataturk Avenue", in Islamabad. In step four, a framework will be developed to forecast the effect on plastic waste accumulation and carbon emission by using plastic waste in paving roads. The proposed methodology is shown in *Figure 1.*

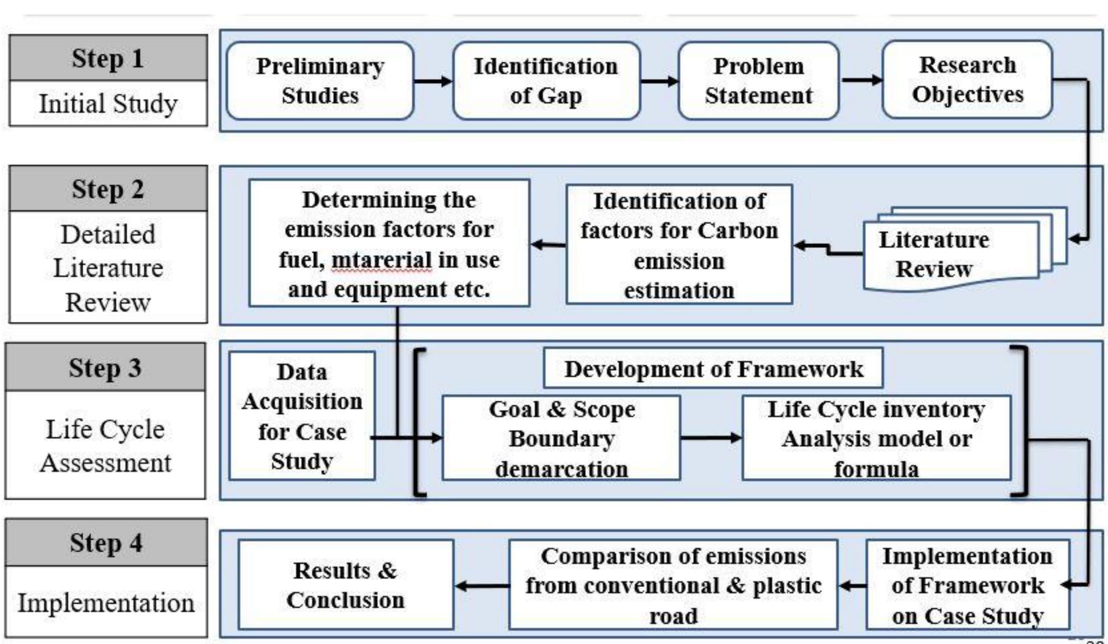


Figure 1: Flowchart of Research Methodology

3.1.1 Case Study

The first plastic road project of Pakistan at Ataturk Avenue, Islamabad is used as a case study in this thesis. As per the data acquired from the Capital Development Authority, Islamabad, Pakistan the said road is 1003 meters long and 7.375 meter wide i.e 2 lane road. It became open to use for public on 21stDecember, 2021. The total amount of fuel i.e diesel required for operation of mixing plant for the preparation of plastic mixed asphalt for the said length was 12000 liter. Total quantity of asphalt required for paving the road was 28294 cft. Total amount of bitumen used was 46 metric tons. Total number of batches of asphalt prepared were 658 batches, each batch weighs about 1500 kg. In each batch as per AASHTO and Marshall Mix Design 96% of the content is aggregate and 4% same standard has been followed with a small change that 1-2% of waste plastic content is added to the mix to replace bitumen. The dry method of mixing was followed for the preparation of asphalt.

3.2 Framework Methodology

3.2.1 Carbon Emission Estimation

3.3.1.1 Life Cycle Assessment

Using LCA methodology, this study seeks to estimate CO_2 emissions in accordance with ISO 14040 (ISO 14040, 2006).(Organization, 2006) When constructing a road, the CO_2 emissions are calculated by the accumulation of effects throughout the system's life cycle boundary. Life cycle assessment (LCA) is a technique for assessing the environmental aspects and potential impacts associated with a product. An inventory of pertinent inputs and outputs of a product system is compiled; potential environmental impacts associated with those inputs and outputs are evaluated; and the results of the inventory analysis and impact assessment phases are interpreted in relation to the study's objectives. The life cycle assessment process must encompass goal and scope definition, impact assessment, and result interpretation, which is shown in *Figure 2*. A range of decision-making processes may benefit from the LCA results as inputs. Life cycle inventory studies must define the objectives and parameters as well as analyse the inventory and interpret the findings. Life cycle inventory studies are subject to all of the requirements and recommendations of this International Standard, with the exception of the impact assessment clauses.

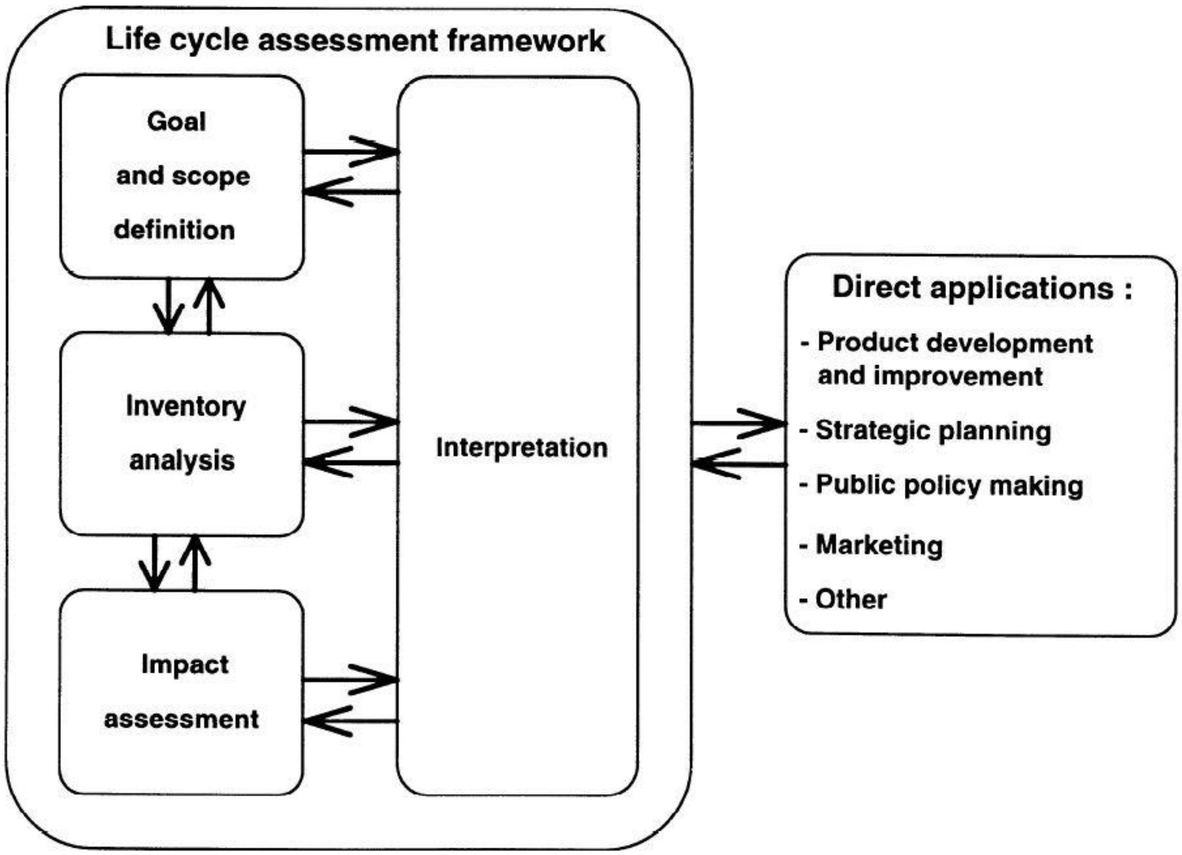


Figure 2: Life Cycle Assessment Framework

3.3.1.2 Life Cycle Assessment Framework

Goal and Scope:

The goal and scope of this study is to quantify carbon emissions emitted from paving roads and compare it to carbon emissions emitted from conventional asphalt roads. It is done to aid in better decision making and understanding whether plastic roads or conventional asphalt roads are better in terms of amount of carbon emissions. This thesis focuses on only the construction stage of pavement.

Inventory Analysis:

Examination of material emissions, the extraction, processing, and delivery of raw materials to the stock ground are the first steps in the production process. emissions produced by off-road vehicles and transportation equipment are practically assessed by calculating the emissions brought on by gasoline use. To sum up total emissions from the three major sources can be calculated. following the normalization of the overall emissions into employing the length and number of lanes of the road as a functional unit project. The emissions per functional unit of each type of road project are calculated by averaging their respective emissions per functional unit figures. The overall emissions of a road project is calculated using the original data on materials, fuels, and vehicle or equipment work time in construction activities(Y. Liu et al., 2017). The detail calculation formula for the carbon emission is shown in Table 2.

Table 2: Total Emission Calculation Formula

Source		Formula	Notes
Total emissions of a road project	Materials E_m	$E_m=\sum_i(f_i*m_i)$	i-Material type ,f_i-lifecycle emission factor of material i; m_i-the amount of material i.
	Equipment (Off site & On site)E_o	$E_o=\sum_i(e_i*v_i)$	i-Machinery type i,e_i-lifecycle emission factor of fuel i; v_i-the consumption amount of fuel per ton of asphalt material i,
	Transportation E_t	$E_t=\sum_i(f_i*v_i)$	i-Vehicle type i,f_i-life-cycle emission factor of fuel i; v_i-the consumption amount of diesel or gasoline per kilometer traveled by vehicle i,
	Total	$E_{total}=E_m+E_o+E_t$	

The Capital Development Authority in Islamabad, Pakistan, gave the construction statistics on material kinds, off-road machinery and transit vehicles, material quantities, and total work time. The Capital Development Authority's estimated estimate norm for road building projects is where the fuel consumption per hour for off-road machinery and transit vehicles is found. A crucial component of the results' accuracy and dependability is the life cycle emission factor. Emission factors from published research reports and peer-reviewed literature are cited in this work. To ensure that it is applicable, this study used the most recent values. Additionally, those emission parameters are given top attention for their thorough, precise calculation, and consistent scope of consideration with this study. Throughout its entire life, fuel went through two stages: "Well-to-Pump" (WtP), which is the extraction, processing, and transportation of crude oil to the fuel station; and "Pump-to-Wheel" (PtW), which is the stage where fuel is burned by the machinery and vehicles.

Impact Assessment:

Based on results drawn and amount of carbon emissions emitted from the plastic roads its impact on the environment will be estimated. This impact assessment can lead to better decision making and effective policy design.

CHAPTER 4: Results & Discussions

The results have been concluded based on data collected from personnel at Capital Development Authority and the reports published on the Pakistan first Plastic Road initiative. Inventory Analysis, a key step in LCA, has been done the collected data.

4.1 Asphalt Material Quantity Required:

As per our case study the amount of Asphalt required will be calculated as follows.

Volume of Asphalt required = L x B x Th = 1003m x 7.375m x 0.0508m (2 inches)

= 375.77 cubic meter

Mass of Asphalt required = Volume x Density

= 375.77 m^3 x 2400 kg/m^3

= 901,848 kg

= 902 tons ≈ 920 tons (Taking 2% wastage in account)

4.1.1 Asphalt Quantity for Plastic Road:

The following table 3 shows the material required for paving wearing course of road at our case study plastic road. The data regarding the material required has been acquired from Capital Development Authority and a project published report (Center, 2021).

Table 3: Material Required for Plastic Mix Road

Material	Qty per ton of Asphalt Mix	Total quantity required for 920 tons Asphalt
Bitumen	42 kg	38640 kg
Aggregate	19 cft	17480 cft = 791840 kg
Stone dust (Khaka)	8.5 cft	7820 cft = 354240 kg
Tyre oil	6 litres	5520 litres = 5062 kg
Diesel	3 litres	2760 litres = 2346 kg
Plastic	10 kg	9200 kg

4.1.2 Asphalt Quantity for Conventional Road:

Following Table 4.2 shows the amount of material required for conventional asphalt road. This data has been procured from Capital Development Authority for a road in similar to the dimensions of plastic road at Attaturk avenue.

Table 4: Material Required for Conventional Asphalt Mix Road

Material	Qty per ton Asphalt	Total quantity required for 920 ton
Bitumen	45 Kg	41400 Kg
Aggregate	19.5 cft	17940 cft = 812800 kg
Stone dust (Khaka)	8.5 cft	7820 cft = 354240 kg
Tyre oil	8 litres	7360 litres = 6743 kg
Diesel	3 litres	2760 litres = 2346 kg

4.2 Quantity of CO_2 Emissions from Materials

CO_2 Emissions will be calculated based on the framework developed in Table 2, using inventory analysis. For the amount of carbon emissions of material, the value would be the product of total material quantity and its individual carbon emission factor which has been taken from peer reviewed research articles and values mentioned in, Table 1. The table shows the carbon emission factors of material utilized in making asphalt mix for paving roads.

4.2.1 Emissions of Materials from Conventional Road

The following Table 5 shows the emissions from conventional asphalt mix. Following table shows the detail of the material utilized in paving of a conventional asphalt road. Also carbon emission factors of each material is listed. Total quantity of a material and its carbon emission factor helps us to calculate the carbon emission factor of each material and eventually for whole patch of the road. Total carbon emission for conventional asphalt mix road comes to be 45094.7 kg as shown below.

Table 5: Carbon Emissions from Conventional Asphalt Mix Road

Material	**Total quantity required for 920 ton**	**CO_2 Emission Factor**	**CO_2 Emission Equivalent**
Bitumen	41.4 ton	256.5 kg/ton	10619.5 kg
Aggregate	812.8 ton	7.5 kg/ton	6096 kg
Stone dust (Khaka)	354.2 ton	5.3 kg/ton	1877.26 kg
Tyre oil	6743 kg	2.65 kg/kg	17868.95 kg
Diesel	2346 kg	3.68 kg/kg	8633.28 kg
			Sum= 45094.7 kg

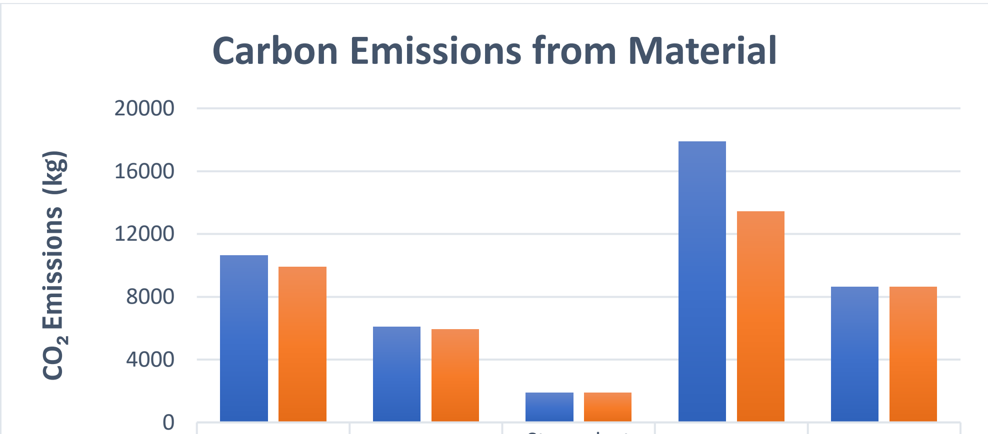
4.2.2 Emissions of Materials from Plastic Road:

The following Table 6 shows the emissions from plastic mix asphalt. The following table shows the detail of the material utilized in paving of a plastic mix asphalt road. Also, carbon emission factors of each material is listed. The total quantity of a material and its carbon emission factor helps us to calculate the carbon emission factor of each material and eventually for whole patch of the road. Also, we see that the amount of material utilized is less in comparison to that of conventional asphalt mix road as the plastic mix asphalt utilizes 10 kg of recycled plastic per ton. This amount of plastic makes up for the reduced amount of bitumen aggregate and tyre oil. That is why it results in less carbon emissions because it uses less non-recyclable materials. Total carbon emission for conventional asphalt mix road comes to be 39764.24 kg as shown below.

Table 6: Carbon Emissions from Plastic Mix Asphalt Road

Material	Total quantity required for 920 ton	CO_2 Emission Factor	CO_2 Emission Equivalent
Bitumen	38.6 ton	256.5 kg/ton	9900.9 kg
Aggregate	791.8 ton	7.5 kg/ton	5938.5 kg
Stone dust (Khaka)	354.2 ton	5.3 kg/ton	1877.26 kg
Tyre oil	5062 kg	2.65 kg/kg	13414.3 kg
Diesel	2346 kg	3.68 kg/kg	8633.28 kg
Plastic	9200 kg	-	-
			Sum= 39764.24 kg

The following figure 3 shows the comparison between the carbon emissions emitted from the materials of plastic mix asphalt and conventional asphalt road.



	Bitumen	Aggregate	Stone dust (Khaka)	Tyre oil	Diesel
Coventional	10619.5	6096	1877.26	17868.95	8633.28
Plastic	9900.9	5938.5	1877.26	13414.3	8633.28

Figure 3: Carbon Emissions from Materials

4.3 Quantity of Carbon Emissions from the Equipment

It has been observed that there is no difference as far as the onsite and off-site machinery/equipment is considered for the production of conventional asphalt and plastic mixed asphalt. So, the amount of fuel or energy needed for the kind of asphalt will be the same.

4.3.1 Fuel Required for Off-site Machinery:

The off-site machinery means the Asphalt plant where the asphalt mix is prepared. Asphalt plant comes in various categories based upon the batch capacity, Generator size and efficiency. Our concerned asphalt plant operated by a private contractor bear following specifications:

Batch Capacity: 1 ton

Generator size: 350 kVA

Efficiency: 100 tons per hour

Fuel Consumption: 60 litres per hour

Total fuel(Diesel) consumption for 920 tons = 551 litres = 468.35 kg

4.3.2 Fuel Required for On-Site Machinery:

On-site machinery required for laying and paving asphalt conventionally and also in the case of plastic roads is one paver and tow PTR rollers for laying 1 kilometer of said road. Approximate fuel required for laying of said dimensions of road require consumption of 2 litres of diesel per ton of the asphalt mix.

Fuel required by on site machinery : 2 litres x 920 tons = 1840 litres = 1564 kg

Hence the total carbon emissions from the total fuel required from the both off site and on site equipment is as follows:

Table 7: Carbon Emission from the Equipment

Material	Total quantity required for 920 ton of Asphalt Mix	CO_2 Emission Factor	CO_2 Emission Equivalent
Fuel for equipment (Diesel)	(468.35+1564) kg	3.68 kg/kg	7479.6 kg

4.4 Quantity of Carbon Emissions from Transportation of Asphalt:

Fuel required in transporting the asphalt mix will be the same in the case of both conventional asphalt and plastic mix asphalt. According to data acquired the fuel required for a single truck with the capacity of 30 ton is 1 litre per 1 kilometer. So calculating the total fuel required for transporting total asphalt quantity per kilometer of distance traveled. As per our case study the distance traveled by the trucks was approximately 25 km .

Total Trucks Required: 920 tons Asphalt / 30 ton Asphalt per truck

= 31 Trucks Approx

Fuel required for trucks: 31 trucks x 1 liter / km x 25 km

= 775 litres

Hence the total carbon emissions emitted from transportation of asphalt is shown in Table 8 as follows and this value is taken for the distance of 20 kilometer per transporting vehicle driven.

Table 8: Carbon Emission from the Transport of Asphalt Mix

Material	Total quantity required for 920 ton of Asphalt Mix	CO_2 Emission Factor	CO_2 Emission Equivalent
Fuel for Transportation (Diesel)	775 litres	3.68 kg/kg	2424 kg

4.5 Discussion:

As discussed in Table 2 the total emissions is the sum of emissions from material, equipment and transport for both kind of asphalt mix roads , plastic and conventional. The total emissions and their comparison are shown in figure 4 below.

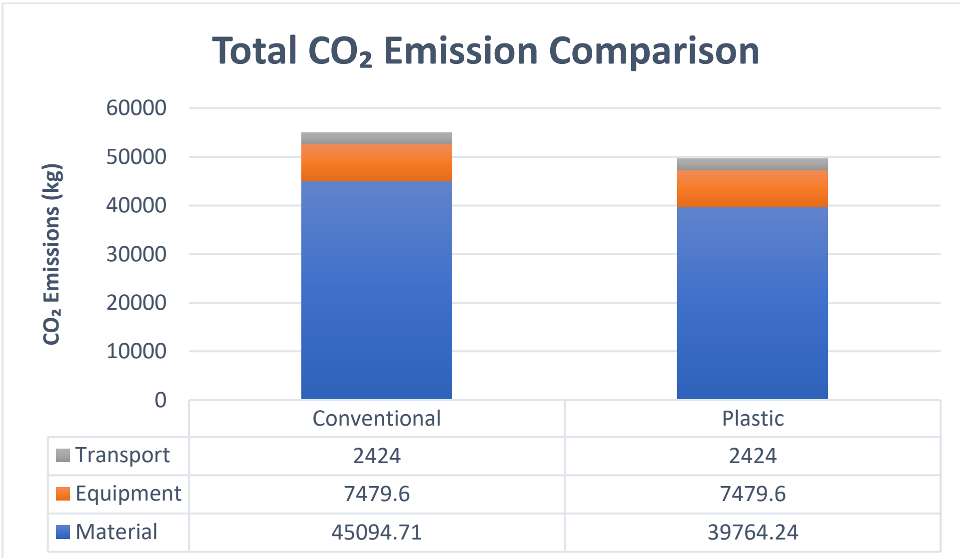


Figure 4: Total Carbon Emission Comparison between Conventional and Plastic Mix Asphalt.

From the results we see that the plastic road imparts lesser emissions in comparison to conventional road. We observe a difference of over 5 tons of emissions for a road of 1 km in length. This on a larger scale and for hundreds of kilometers can result in difference of hundreds of tons lesser carbon emission. It can be a potential solution to combat climate change. This concept can also be a way to achieve targets of reaching net zero emissions.

Figure 4 shows the total emission comparison between conventional and plastic mix asphalt. It shows that total emission is the sum of emissions from material , equipment (on-site & off-site) and transport.

Through the results obtained it has been observed that the difference in the amount of carbon emissions from conventional and plastic mix asphalt has majorly been observed associated to the material. Whereas the carbon emissions associated with the on site, off site machinery and transportation is similar in both the cases of conventional and plastic mix asphalt. This suggests that the process for paving plastic mix asphalt is like that of conventional asphalt. This can prove to be a positive point in the adaptation of plastic mix asphalt as it does not require any different step or process, or any specialized machinery hence does not add to the cost.

This study only examines carbon emissions during the construction phase only; it does not quantitatively evaluate the emissions throughout the life cycle of a road project. The LCA theory and framework will be utilized to evaluate the carbon emissions from construction phase only as it has been done by other researches like (Y. Liu et al., 2017) and (L. Li & Chen, 2017).

The literature has suggested that carbon emissions in bulk amount has its environmental impacts. The results show that road paving with plastic mix asphalt emit lesser carbon emissions and can be introduced and implemented as a viable alternative to conventional asphalt roads.

This study has given a framework to compare a new parameter such as that of carbon emissions which have not been discussed in the context of plastic roads prior to this study.

CHAPTER 5: Conclusions & Future Recommendations

5.1 Research Conclusion

This research has presented a comparison of life cycle assessment of plastic mix asphalt and conventional asphalt to study the carbon emissions from each type of road. The aim of this study was to estimate the carbon emissions of a plastic road. It has also presented us with the critical factors that are important and that affect the estimation process. Case study was performed on an actual road by obtaining data and implementing Life Cycle Assessment. This research has also presented a new basis of comparison of roads and their performance. Many studies have studied overall environmental performance and comparison of plastic roads, but no conclusive study has been done to study the carbon emissions of plastic road. In its literature this study has also discussed the benefits and negatives associated with plastic roads. This study aims at helping in making an informed decision regarding the policy making and adaptation of plastic roads to address the issue of climate change, waste management and carbon emission mitigation. This study also aims to provide any help towards the strategic planning and future endeavors of infrastructure development in the country and worldwide.

The salient features and eminent conclusions resulting from this research are as follows:

- This study provides the framework to estimate the calculation of carbon emission of plastic roads which had not been discussed prior to this study. It will lay the foundation of associating plastic roads as a potential strategy for climate change and carbon emission mitigation.
- This study reiterates through the case study that there is not much of a difference between the processes of making plastic road as compared with conventional road, this makes it as a lesser of a barrier and adaptation of plastic road as an alternative easier.
- This study also suggests that only 1km of plastic road comparison results for over 5 ton lesser carbon emission at the grand scale where hundreds of kilometer roads can lead to be a potential step towards combating climate change in our country.

5.2 Future Recommendations

This study has successfully achieved its objective of providing a framework based on life cycle assessment to estimate carbon emissions of a plastic road. However, there are other avenues, which could be incorporated into studies for future enhancement of this research study:

5.2.1 Implementation to other kind of projects

This framework can also be extended to any other kind of project such as building construction and infrastructure development to evaluate its carbon emission efficacy. This study has given a methodology following this methodology can help other researcher undertake analysis and comparison of similar kind which is not limited to road infrastructure only. It can be a helpful basis for analysis of any further studies.

5.2.2 Life cycle assessment

Life cycle assessment is targeted to construction phase only in this study and in numerous previous studies. However, for future studies the complete 'cradle to grave' approach of life cycle assessment can be implemented to all the stages of a project. Future research can incorporate the analysis on complete project from initiation to demolition stage. It can result in a better and overall analysis which is not limited to the stage marked by construction activities only but for complete project lifecycle as well.

5.2.3 Climate Change Mitigation

Further research can be done to estimate that if plastic roads concept adapted on a grand scale how largely it will affect the carbon emission amount. Research can also assess that whether it can prove to be a resourceful method to deal with changing climate and if it can provide with substantial results through different estimation and analyses that if it can help in any way to reach a goal of net zero emissions.

5.2.4 Waste Management Problem

Future research can be done on the topics regarding whether the use of plastic in roads as it imparts lesser emissions will it also be helpful in tackling the issue of waste management affectively. Analyses with this new angle can also be undertaken.

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