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Minimizing Carbon Emissions from Transportation Projects in Sub-Saharan Africa Cities Using Mathematical Model: A Focus on Lagos, Nigeria

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Abstract

One of the major causes of increase in greenhouse gas pollution has been attributed to transportation. In spite of sub-Saharan African's low contribution to the worldwide production of greenhouse gases, the region will suffer more from the effects of climate change in years to come if necessary steps are not taken now. This paper therefore looks at minimizing the carbon emissions (carbon dioxide emission) from transportation which is a channel of greenhouse pollution. Linear programming model is used to model the present situation in Lagos Nigeria. A computer software (LIPS) and excel solver were used to solve the resulting mathematical equations, using simplex method. The data collected and the subsequent analysis carried out show that if the current situation of carbon emission from transportation, is not arrested, it can lead to serious health challenge, such as respiratory diseases, and negative impact on the economic development of these cities.

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Keywords: Greenhouse gases, Sub-Saharan Africa, Carbon emission, Transportation projects, Linear programming

1. Introduction

Urban air pollution is on the rise in sub-Saharan Africa. This is majorly caused by the use of fossil fuel in transport. Africa has the lowest historical greenhouse gas (GHG) emission of any continent, but its emissions are also now growing rapidly and driven by a sharp increase in fossil-fuel use [1]. A very high percentage of the vehicles used in these cities are fairly used vehicles, imported from developed countries. This means poorly maintained vehicles on the roads, increasing exhaust emissions which affect the air quality [1]. It has been identified that the urban air pollution caused by an increase in motorization is responsible for about 49,000 deaths per year in the region. Pollution from vehicles and other means of transportation have a wide range of direct and indirect effects on ecosystems, agriculture and materials. Global warming solution is a reduction in carbon emissions. Unfortunately,

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urban expansion due to development in most cities of sub-Saharan countries has led to an increase in greenhouse gas pollution. This is because of the resulting growth in vehicular traffic, energy use, industrialization and other activities [2] We are faced with intertwined issues: Economic development is required for poverty reduction; at the same time, the greenhouse gas pollution and local air pollution threaten to undermine this development with the increasing evidence of their adverse effect on the effect on the environment and health of the people [2,3]. All the countries in Africa south of the Saharan desert, apart from Sudan, are referred to as the sub-Saharan countries that make up sub-Saharan Africa [4]. Due to urban development in these countries, there is the needs to embark on transportation projects that include road, rail and sea transport. Transportation has been identified as the fastest growing major contributor to global change, accounting for 23% of energy-related carbon dioxide emissions [4,5]. In order to reduce this problem of carbon emissions, suggestions have been made in so many forum that low carbon transportation strategy should be embarked on. This has been identified also as one of the least costly ways to reduce greenhouse gas emissions. This can be achieved, however, by designing the transportation projects such that it reduces the need for travel, to shift trips to often less expensive low carbon modes, and to improve system management by reducing congestion and inefficiency in the use of transport capacity [5]. These, in addition to individual efforts to reduce our personal carbon emissions, our elected leaders are to support and implement a comprehensive set of climate solutions [5,6,7]:

- Expand the use of renewable energy and transform our energy systems to one that is clear and less dependent on coal and other fossil fuels.
- Increase vehicle fuel efficiency and support other solutions that reduce oil use
- Place limits on the amount of carbon that polluters are allowed to emit
- Build a clean energy economy by investing in efficiency energy technologies, industries and approaches
- Reduce tropical deformation and its associated global warming emissions.

Suggestions of Carbon Dioxide (CO_2) Emissions Security of supply and climate change are high on the global energy agenda. The transport sector is no exception as virtually every means of transport by land, air and sea uses fossil fuels and thus emits CO_2. Moreover, energy consumption for transport purposes represents 20% of the world's total energy consumption. The most important thing is to introduce renewable energy in the transport sector and have the sector integrated in the energy system. In transportation by land, air and sea there are plenty of opportunities to reduce CO_2 emissions.

By land: The numbers of cars in the world are growing rapidly. In the short term it is possible to make the cars far more fuel efficient. In the longer term electric cars charged by wind turbines, for instance, seem to be a fine solution for the global energy system. In the long term, cars powered by fuel cells and hydrogen can supplement electric cars. Road charges can also help reduce carbon dioxide emissions, regulate traffic and reduce local pollution. There should be emphasis on more kinds of alternative fuels, so that vital transport activities are not affected by supply failures. For vans and trucks, so far diesel engines have been the most efficient way of freight transportation on highways. A good alternative could be gas. Today's battery technology is not suited for electrically powered trucks. However, the distribution of goods in cities can be done with small electric vans. Drivers can be trained in driving energy cars more efficiently. Taxes and duties can provide better and smarter transport solutions with lower energy consumption.

By sea: International shipping: Accounts for 90% of the global transport of goods. In order to reduce CO_2 emissions, shipping could be adjusted to a slower traffic, as well as a better planning of routes and logistics. This could save 10-15% of CO_2 emissions. The ships can furthermore be constructed with better propellers, hulls with less water resistance and new types of smooth bottom paint be used. Wind and solar power can also be used together with better engine technology. This could save 10-15% of CO_2 emissions. Thirdly, there can be legislation for achieving less CO_2 emissions. This as well could save 10-15% of CO_2 emissions from sea transport. To not distort competition, the legislation must be agreed on internationally.

By air: Passenger air transport by planes can become much more fuel efficient. Construction materials can be lighter. The air drag from planes can be reduced. Hydraulics can be replaced with electric engines. Solar energy can be used in a far better way. Efficient and climate-friendly fuel cells can produce electricity to all the electrical installations in the aircraft. Flight speed can be reduced, that is if the passengers are willing to accept longer flight times. As to routes under 800 kilometres, planes can be replaced with high-speed trains. Fossil fuels for aircraft engines can be replaced with biofuels. The control of air traffic can be optimized so that planes avoid waiting at airports before departure or in the air before landing. The entire airspace can be used better, so that the planes do not have to criss-cross around the forbidden zones. Finally, you can legislate to reduce carbon dioxide emissions from aviation, but it must happen in global agreement in order not to distort competition and "Avoid, shift, improve" strategy.

There is therefore an urgent need to monitor and manage urban air quality in sub-Saharan African cities, and identify the most effective measures to reduce carbon emission from transportation in the region. The transport sector is one of the major sources of carbon dioxide emission. Trucks, cars, buses, airplanes, cargo ship, railroads are overwhelmingly dependent on petroleum. Today transport of goods and people is responsible for about 19% greenhouse gas emission caused by carbon dioxide emissions. With the global car population forecast to soon exceed 1 billion vehicles, Sub-Saharan African countries should start investing in mass transits and join the other part of the world to start thinking of the Hybrid, plug-in hybrid and all-electric vehicles in order to reduce dependence on petroleum. [7,8]. In order to achieve the best way of reducing the problem of carbon dioxide emission which causes pollution, operational research model – linear programming method is used. Linear programming model is a mathematical model. The real life situation of environmental pollution is modelled into objective function and set of constraints, which are in turn solved using simplex method. In this paper, therefore, we identify the suggested strategies, which forms our decision variables. These variables are used to form the objective function. The objective function is then optimized based on a set of constraints. [9,10,11]

2. Formulation of Problem

Transportation has been identified as one of the major sources of carbon emission in sub-Saharan African countries. The four major means of transportation in sub-Saharan African countries are road, rail, air and sea, with road having about 70% in most of the countries.

In this paper, we concentrate on road as means of transportation. In order to minimize road transportation carbon emission, in order to achieve this, the following have to be carried out:

- Investing in Mass transit projects (in order to reduce the number of vehicles on the road per time)
- Proper maintenance of cars (to reduce carbon dioxide for this exhaust)
- Encouraging other means of transportation like bicycles or animals (e.g. horse) (no carbon emission)
- Quality of fuel
- Use of Hybrid electric cars
- Reducing need to travel
- Reducing congestion
- Reducing inefficient use of transport capacity
- Increasing vehicle fuel efficiency

2.1. Decision Variables

Modelling the problem as a Linear programming problem, we represent the above mentioned strategies as our decision variables (x_{ij}):

Let x_{11} represent amount of money invested in acquiring a unit of mass transit equipment
Let x_{12} represent amount of money spent on salary of mass transit workers
Let x_{21} represent amount of money spent on maintaining vehicles
Let x_{31} represent the amount of money spent on acquiring other means of transportation
Let x_{32} represent the value of the extra time used in terms of money
Let x_{41} represent money to produce high quality fuel
Let x_{51} represent amount of spent on acquiring Hybrid or electric cars.
Let x_{61} represent cost of making most things available close to where people live.
Let x_{71} represent cost of constructing good road network
Let x_{72} represent cost of traffic light and other gadgets.
Let x_{73} represent cost of maintaining the road
Let x_{81} represent cost of training people for efficient use of transport capacity
Let x_{91} represent cost of technology to increase fuel efficiency.

2.2. Contributions

We now consider the contributions (c_j) of each of the decision variables to solving the problem of carbon emission from road transportation. Based on the data gathered and some simulation we have the following weights attached to the decision variables
$x_{11} = 20$, $x_{12} = 5$, $x_{21} = 13$, $x_{31} = 3$, $x_{32} = 2$, $x_{41} = 11$, $x_{51} = 4$, $x_{61} = 8$, $x_{71} = 9$, $x_{72} = 2$, $x_{73} = 5$, $x_{81} = 6$, $x_{91} = 12$.

The limitation to the above strategies include funding, people attitude, technology, transportation, network and corruption. These and others form our constraints, to achieving our objective of maximizing the above strategies in order to minimize the problem of carbon emission through road transportation in Sub-Saharan Africa.

A major resource is money. Its availability is usually limited. We assume amount available for road transportation ministry in Lagos State, Nigeria for … About 20% of that amount is 10 billion naira per year is budgeted for road transportation.

2.3. Resource Utilization (a_{ij})

Let a_{ij} represent the amount of available resources used for achieving one unit of x_1

Therefore for our problem and with some simulation gathered, we have the following:

a_{11} = Amount of money invested in acquiring a unit of Mass transit
a_{12} = Amount of money paid as salary to a worker in the Mass transit in a year Average
a_{21} = Amount of money spent on maintaining one car in a year
a_{31} = Amount of money spent on acquiring one unit of other means of transportation
a_{32} = Time value, in money terms for one extra unit of time spent in trekking, in a year
a_{41} = Money spent to produce one unit of high quality fuel
a_{51} = Cost of one unit of Hybrid or electric car
a_{61} = Cost of making a unit of most things available close to where people live
a_{71} = Cos of constructing one unit length of good road network
a_{72} = Cost of producing one unit of traffic light and other gadgets
a_{73} = Cost of maintaining one unit of length of the road
a_{81} = Cos of training one person for efficient use of transport capacity
a_{91} = Unit cost of technology to minimize fuel efficiency

The amount of resources used, from the data gathered, are given as follows:
$a_{11} = 12500000$, $a_{12} = 300000$, $a_{21} = 500000$, $a_{31} = 20000$, $a_{32} = 600000$, $a_{41} = 50$, $a_{51} = 1000$, $a_{61} = 1000000$, $a_{71} = 40000$, $a_{72} = 10000$, $a_{73} = 80000$, $a_{81} = 100000$, $a_{91} = 500000$

3. The Model

$$Maximize\ Z = \sum_{j=1}^{3}\sum_{i=1}^{9} c_j x_{ij}$$

$$= c_{11}x_{11} + c_{21}x_{21} + c_{31}x_{31} + c_{32}x_{32} + c_{41}x_{41} + c_{51}x_{51} + c_{61}x_{61} + c_{71}x_{71} + c_{72}x_{72} + c_{73}x_{73} + c_{81}x_{81} + c_{91}x_{91}$$

subject to

$$a_{11}x_{11} + a_{12}x_{12} \leq 22.4 \text{ million}$$

$$a_{21}x_{21} \leq 83.8 \text{ million}$$

$$a_{31}x_{31} + a_{32}x_{32} \leq 20 \text{ million}$$

$a_{41}x_{41} \leq 10\%$ of 10 billion
$a_{51}x_{51} \leq 10\%$ of 10 billion
$a_{61}x_{61} \leq 110$ million
$a_{71}x_{71} + a_{72}x_{72} + a_{73}x_{73} \leq 5,082$ million
$a_{81}x_{81} \leq 30$ million
$a_{91}x_{91} \leq 5\%$ of 10 billion
$a_{11}x_{11} + a_{12}x_{12} + a_{31}x_{31} + a_{32}x_{32} + a_{71}x_{71} + a_{72}x_{72} + a_{73}x_{73} \leq 7,000$ million
$a_{41}x_{41} + a_{51}x_{51} + a_{91}x_{91} \leq 5,000$ million
$a_{11}x_{11} + a_{12}x_{12} + a_{21}x_{21} + a_{31}x_{31} + a_{32}x_{32} + a_{41}x_{41} + a_{51}x_{51}$
$+ a_{61}x_{61} + a_{71}x_{71} + a_{72}x_{72} + a_{73}x_{73} + a_{81}x_{81} + a_{91}x_{91} \leq 10,000$ million
$a_{ij} \geq 0, \ i = 1,2,\ldots,9; j = 1,2,3$

4. Model Solution

Writing the above model in standard form and substituting the values of the parameters we have:
Maximize

$$z = 20x_{11} + 5x_{12} + 13x_{21} + 3x_{31} + 2x_{32} + 11x_{41} + 4x_{51} + 8x_{61} + 9x_{71} + 2x_{72} + 5x_{73} + 6x_{81} + 12x_{91}$$

subject to

$$12.5x_{11} + 0.3x_{12} + S_1 = 22.4$$
$$0.5x_{21} + S_2 = 83.8$$
$$0.02x_{31} + 0.6x_{32} + S_3 = 20$$
$$0.00005x_{41} + S_4 = 1000$$
$$10x_{51} + S_5 = 2000$$
$$x_{61} + S_6 = 110$$
$$0.04x_{71} + 0.01x_{72} + 0.08x_{73} + S_7 = 5,082$$
$$0.1x_{81} + S_8 = 300$$
$$0.5x_{91} + S_9 = 500$$
$$x_i \geq 0, \ i = 1,2,\ldots,9.$$

4.1. Simplex Method of Solution

Simplex method algorithm was adopted in this study to solve the standardized linear programming model and come up with the following results, with optimum value of 2.21164e+008. The values of the decision variables are as follows:
$x_{11} = 0$, $x_{12} = 224/3$, $x_{21} = 167.6$, $x_{31} = 1000$, $x_{32} = 0$, $x_{41} = 2e+007$, $x_{51} = 200$, $x_{61} = 110$, $x_{71} = 127050$, $x_{72} = 0$, $x_{73} = 0$, $x_{81} = 300$, $x_{91} = 1000$, $S_1 = 0$, $S_2 = 0$, $S_3 = 0$, $S_4 = 0$, $S_5 = 0$, $S_6 = 0$, $S_7 = 0$, $S_8 = 0$, $S_9 = 0$.

5. Results Discussion

Looking at the above table 3, we can see that the following decision variable x_{12}, x_{21}, x_{31}, x_{41}, x_{51}, x_{61}, x_{71}, x_{81}, x_{91} are very important if we want to achieve the optimum value of our objective function. The feasible values of these variables are: 224/3, 167.6, 1000, 2e+007, 200, 110, 127050, 300 and 1000 respectfully. These values, when substituted in the objective function, give the optimal value of 2.21164e+008, approximately. This implies that all these nine areas have to be satisfied before minimization of carbon emissions from transportation projects in sub-Saharan African cities can be achieved. It also important to note that x_{41} which represents money spent to produce high quality fuel is the highest compared to other feasible decision variables. This is because if the quality of fuel is high then we do not need to worry much about the number of automobile on the road per time, as the carbon dioxide (CO_2) emission will be minimal. Next to it is x_{71} representing cost of construction good road network. It is always capital intensive to construct a good road network, but when archived it eases congestion which enhances CO_2 emission. Finally, in most of the sub-Saharan African cities, traditional believes and corruptions are factors capable of hindering the achievement of the objective. They should be guided against seriously.

6. Conclusion

Interest in this paper is on minimizing Carbon dioxide emission from transportation projects, which is on the increase in sub- Saharan African cities. The analysis is carried out using simplex method with the aid of computer software. The peculiar situation is modelled as a linear programming problem with a focus on Lagos Nigeria. It is shown that nine out of the thirteen decision variables are actually critical. These nine decision variables: x_{12}, x_{21}, x_{31}, x_{41}, x_{51}, x_{61}, x_{71}, x_{81}, x_{91} are therefore very significant in the process of minimization. For Carbon dioxide, a greenhouse gas emission to be minimized from transportation projects in sub-Saharan Africa Cities, greater attention should be paid to using high quality fuel for transportation. The technology of producing quality fuel should be acquired even at high cost. Also, good roads should be constructed. Other means of transportation should be introduced. Specifically, amount of money needed to achieve high quality of fuel and construction of good road network should not be compromised.

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