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An assessment of the underlying relationship between land transportation and climate change: Case study Mauritius

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ABSTRACT

Introduction: Land transportation encompasses the movement of people and goods and is therefore a major contributor of global greenhouses gases. The main share of such emissions is mostly from the release of carbon dioxide into the air as a result of burning transportation fuels obtained from petroleum, a major driver of climate change. While today the defining issue is a changing climate, the number of vehicles on roads keep on rising around the world.

Materials and methods: This study assessed the relationship between land transportation and climate change using a system dynamics model based on a 3-layered taxonomy using Mauritius Island as case study. Over 100 papers were analyzed and the variables that link land transportation and climate change in the Mauritian context were selected and a taxonomy divided into sub-units was built.

Results: This innovative taxonomy was divided into 3 sections related to the land transportation sector including a vehicle layer, transport system layer and society layer. Using these variables, three stock and flow diagrams were constructed on Vensim, namely climate change impacts, transport related carbon dioxide and socio-economic models.

Conclusion: While there is a complex relationship between land transportation and climate change globally, Mauritius must find ways to become more climate friendly in the land transportation sector.

Introduction

Mobility is an important human need for the current generation. Humans with society interaction strongly depend on the ability to move people and goods from one place to another and thus efficient transportation systems help in the economic and social development of a country. Cities could not exist and global trade could not occur without the systems of transport throughout the world. In fact, transportation systems have been described as the 'lifeblood' of cities due to this vital role. Land transportation is considered as the backbone of economies and is essential for almost every business worldwide. For example, global truck production reached 4.02 million units in the year 2017 compared to 3.60 million units in 2015, global bus production increased from

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390,466 units in 2015 to 429,838 units in 2018, and the number of cars sold worldwide, has considerably increased since the past decades accounting to 39.2 million units in the 1990's to reach a peak of 79 million units in year 2017 [1, 2].

Today, it is agreed by most climate scientists that climate change has been occurring in scientifically measurable ways with the Intergovernmental Panel on Climate Change (IPCC) body stating that warming of the climate system is unequivocal and can now be firmly attributed to human activity [3]. Globally, transportation is one of the human activities that utilizes the most energy, especially the combustion of fossil fuels [4]. The transportation sector has contributed to around 20% of the global energy consumption and was the largest consumer of oil in the world in 2016 [4]. There exist two linkages between transportation and climate change: global transportation is responsible for a significant amount of emission of greenhouse gases and a changing climate invariably has serious consequences on the resiliency and performance of transportation systems. Hence, there is an urgency to mitigate the impacts of transportation-related greenhouse gases while at the same time adapting to changes that are bound to occur to an already changing climate system. In line with the Paris Agreement and the sustainable development goals, a proper strategy for the adaptation of transport to the future climate is now vital to ensure that global trade and development can go on smoothly both for developed nations as well as small island states like Mauritius.

Today, the transport sector represents the third major contributing sector to the Mauritian economy and is considered as one of the most important drivers for economic growth of Mauritius as other sectors rely on land transportation. Mauritius has experienced a considerate economic growth in the last decade and as a consequence, the standard of living of its people has also hiked resulting in a high mobility of people accompanied by an unavoidable rise in the number of vehicles. From 2016 to 2017, there was an increase in the number of vehicles by 4.8% and a subsequent increase in the amount of greenhouse gas emission (GHG), from the transport sector by 1.9% [5]. Like in all developing countries, issues like traffic congestions, rising levels of private car-use, urban sprawling and lack of sufficient facilities for other road users like cyclists and pedestrians worsen the problem of climate change. According to the latest GHG inventory in Mauritius, GHG emission rose for the period 2000 to 2013 with the energy sector (including land transportation) as the main source of GHGs [6]. While Mauritius contributes to only 0.1% of GHG emissions globally, it is also vulnerable to the global impacts of climate change such as sea level rise, violent and encroaching waves, flooding and higher temperatures. Thus, as a rapidly developing island in the face of climate change, Mauritius has no option but to adapt its land transportation sector in such a way to ensure population safety and environmental friendliness. As the number of vehicles rise every year on the island, it is crucial to understand the underlying relationship between land transportation and climate change so as to better formulate adaptation policy strategies and monitor GHG emissions. Hence, the aim of this study was to assess the underlying relationship between land transportation and climate change using a system dynamics model based on a transport taxonomy.

Materials and methods

A quantitative approach was selected as appropriate to carry out this study based on two main methodologies: transport taxonomy formulation and system dynamics.

Transport taxonomy formulation

To build the system dynamics model in order to visualize the impacts of climate change on the land transportation sector and vice versa, the variables that play a role in land transportation and climate change were first identified. To this end, a search was conducted for the years 2009-2019 on Google Scholar as it is a free database that provides a range of academic materials. A ten-year period was selected so as the grab the maximum literature on land transportation and climate change. Keywords like 'land transportation' and 'climate change', and 'Mauritius', 'effects of land transportation' and 'climate change', 'climate change effects on land transportation' were searched for in Google Scholar. As these keywords grabbed a large amount of information, a large portion of which was not related to the present study and were in other languages besides English, a screening process was carried out based on the relevancy of the papers to the present study. Some 100 papers were thus deemed suitable and variables that pertain to the land transportation sector and climate change were identified. Common variables were classified into a 3-layered taxonomy.

System dynamics model

Based on these variables, a stock and flow diagram was built for the system dynamics model. The stocks represent the entities that can accumulate or decrease; flows represent the entities that cause the stocks to increase or decrease and are variables that affect the stocks [7]. Stock and flow diagrams differentiate between different elements of the system taking analysis to a higher level. Basically, the stock and flow diagram forces the researcher to ponder more on the relationships between the variables, to consider how the units of measure combine and pushes him/her to discover overlooked variables [7]. Given the vast coverage of stock and flow diagrams, a simple model analysing climate change impacts, transport related emissions and a socio economic relationships was developed. The model was built using the Vensim, which is an industrial-strength software for improving the performance of real systems. Vensim is used to develop, analyse and package dynamic feedback models, emphasizing high quality consistency, sophisticated calibration methods, flexible model publication and model analysis [8].

Data reliability and limitations

The reliability of the data for identifying the variables was based on the reputation of the sources used while validity was according to the papers' relevance to the topic. Limitations that were incurred during the study was that there were few studies on the link between land transportation and climate change in Mauritius. So, the general impacts of land transportation and climate change and vice versa globally were taken into consideration and the more probable relationships that exist in the context of Mauritius were analysed. Additionally, due to the limited time frame of the study, only preliminary stock and flow diagrams were created using Vensim.

Results and discussion

Taxonomy formulation

Analysis of the common variables in the land transportation sector and climate change were found to fall into the following categories:

1. Vehicle
2. Transportation System
3. Society

Based on these variables, the 3-layered taxonomy was formulated (Fig. 1).

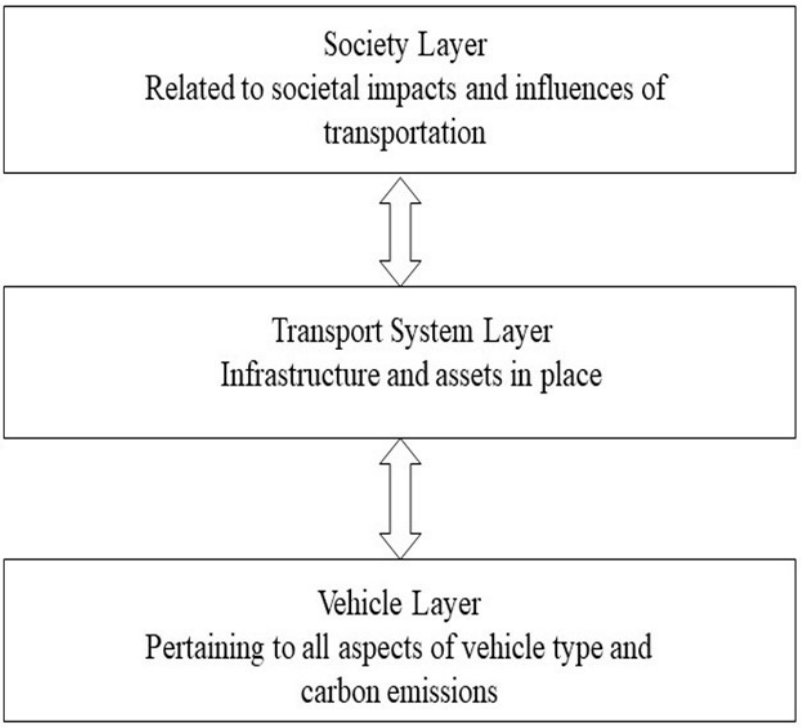

Fig. 1. 3-layered taxonomy for the land transportation sector

Table 1. Parameter, description and unit of measurement

Parameter	Description	Unit
Vehicle operation	Whether it is of public or private use.	N/A
Number of vehicles	The number of vehicles on the road.	Unit
Fuel	Category of fuel that is used in the vehicles, whether it is gasoline, diesel oil, fuel oil or liquefied petroleum gas (LPG).	Ktoe
Mileage	Distance travelled by the vehicles per year (miles travelled).	Miles
Carbon emission	The amount of carbon released by the vehicles.	Millions metric tons

Layer 1: Vehicle

The vehicle layer is the first layer of the taxonomy and encompasses energy efficiency of the transportation means and their nature. It is sub divided into more layers namely:

1. Vehicle operation
2. Number of vehicles
3. Fuel
4. Mileage
5. Carbon emission

Layer 2: Transportation system

The second layer is the transportation system and is concerned with all the infrastructure and assets that are used in the transportation sector. They are critical for the proper and safe functioning of the vehicles and usually set the baseline for a proper transport network. This layer is broken down into:

1. Road capacity
2. Congestion
3. Land use
4. Travel costs
5. Changed mobility services
6. Road type

Table 2. Parameter, description and unit of measurement

Parameter	Description	Unit
Road capacity	Number of vehicles that a particular road can carry at any given period in time and includes such characteristics as road length, width and total coverage over a given surface area.	Km
Congestion	Extra time spent on traffic by commuters because of traffic congestion.	Km
Land use	Surface area of land in use for movement in terms of roads and railways, the number of passenger stations for both buses and LRT and their operation centres.	Km
Travel costs	Cost will determine which type of vehicle that people will use and the availability of the preferred mode of transport	US$
Changed mobility services	Determines how far people will use the same or different modes of transport over time based on their particular interest.	N/A
Road Type	Characteristics of the different roads, whether they are paved or unpaved, the type of material used to construct them, the amount of time taken to do so and the average life time of the roads before maintenance.	Km

Table 3. Parameter, description and unit of measurement

Parameter	Description	Unit
Behavioural response and travel shift pattern	Determines how people view and interact with the transport means. It includes society's preference for public and private transportation, the advantages and disadvantages associated with each one and how they choose their transportation mode.	N/A
Vehicle occupancy	Related to the number of persons in a vehicle at any given time, whether it is at full capacity or per driver only.	Unit
Shared consumption	Leasing of vehicles for monetary exchange as the owner may not make frequent use of them. While some people may not have the funds to buy their own vehicles, through shared consumption, they can drive and be actively involved in the transport sector.	Unit
Workforce population	The workforce population determines the number of people who can afford vehicles and their preference for the different vehicle types.	Unit
Carbon tax	It is a form of pollution tax which levies a fee vehicle emission. The amount of money generated will determine if the nation can improve its transport system or encourage private transportation.	MUR
GDP	GDP of the nation is crucial in determining the type of transportation system that it can afford and its associated assets.	MUR

Layer 3: Society

The third layer is the society layer. Basically, it is society that drives the transportation system. As it is, when a nation's standard of life changes, it can also upgrade its transportation modes. Society and its demands and preferences are at the centre for making the transportation sector work. The society layer includes:

1. Behavioural response and travel shift pattern
2. *Vehicle occupancy*
3. *Shared consumption*
4. *Workforce population*
5. *Carbon tax*
6. *Gross domestic product (GDP)*

Relationship between the variables that affect the land transportation sector

A taxonomy is typically a classification system which consists of arrangements and hierarchies of superior and subordinate groups that helps to examine the relationship between different elements in a system and to evaluate proposed constructs [9]. Without this sort of classification, it would be very difficult to understand complex systems and know where to look for what is needed. Even though the literature covers much on the land transportation sector and relationships with society, economics and the environment (e.g. Geography of transportation), to date, there has not been an attempt to classify the various components into a taxonomy. This is understandable since the dimensions of the transport sector are quite vast ranging from vehicle emissions to the GDP of a nation. Through the analysis of over 100 papers, the general variables that affect the land transportation sector and climate change were picked out and grouped into a 3-tiered taxonomy (Fig. 1) namely vehicle, transportation system and society.

Vehicle layer

This category can be broken down into vehicle operation, number of vehicles, fuel, mileage, and carbon emission. The starting point for examining the relationship between land transportation and climate change is the vehicle component itself. The WHO reports that the transportation sector is the fastest growing contributor to climate change as it is highly dependent on fossil fuels. Even in Mauritius, an increase in the release of carbon dioxide emissions in the transport sector for the years 2000 to 2013 has been observed [10]. GHG emission from the transport sector can be viewed as a three-legged stool relating to vehicle fuel efficiency, the carbon content of the fuel, and the amount of driving or vehicle miles travelled [11].

Transportation system layer

The transportation system was classified into road capacity, congestion, land use, travel costs, changed mobility services and road type. This category encompasses all the equipment and logistics related to the transport of vehicles. It provides the infrastructure needed to satisfy the mobility needs of society [12]. The transport system is one of the largest infrastructure system in the world and plays a crucial role in allowing development in the emerging economies [13]. In Mauritius, the government is investing heavily in the transportation system to enable the nation to move safely and quickly around the island while decreasing traffic congestion.

Society layer

This group was divided into behavioural response and travel shift pattern, vehicle occupancy, shared consumption, workforce population, carbon tax and GDP of the nation. In both rural and urban communities around the world, there is a challenge for movement, be it people or freight, in a safe and sustainable manner. Transportation is the key element for development and this movement has permitted a change in the way people live and travel. Typically, the aspirations of a society like mobility and accessibility is reflected by its transportation in order to expand its horizon [14].

System dynamics model

Based on the parameters discussed above, the stock and flow diagram was developed which presents the corresponding relationships between these variables and climate change in Mauritius. Three different models were developed to analyze the relationship between climate change and land transportation. These include a climate change impacts model, a transport related carbon dioxide emission and a socio-economic model.

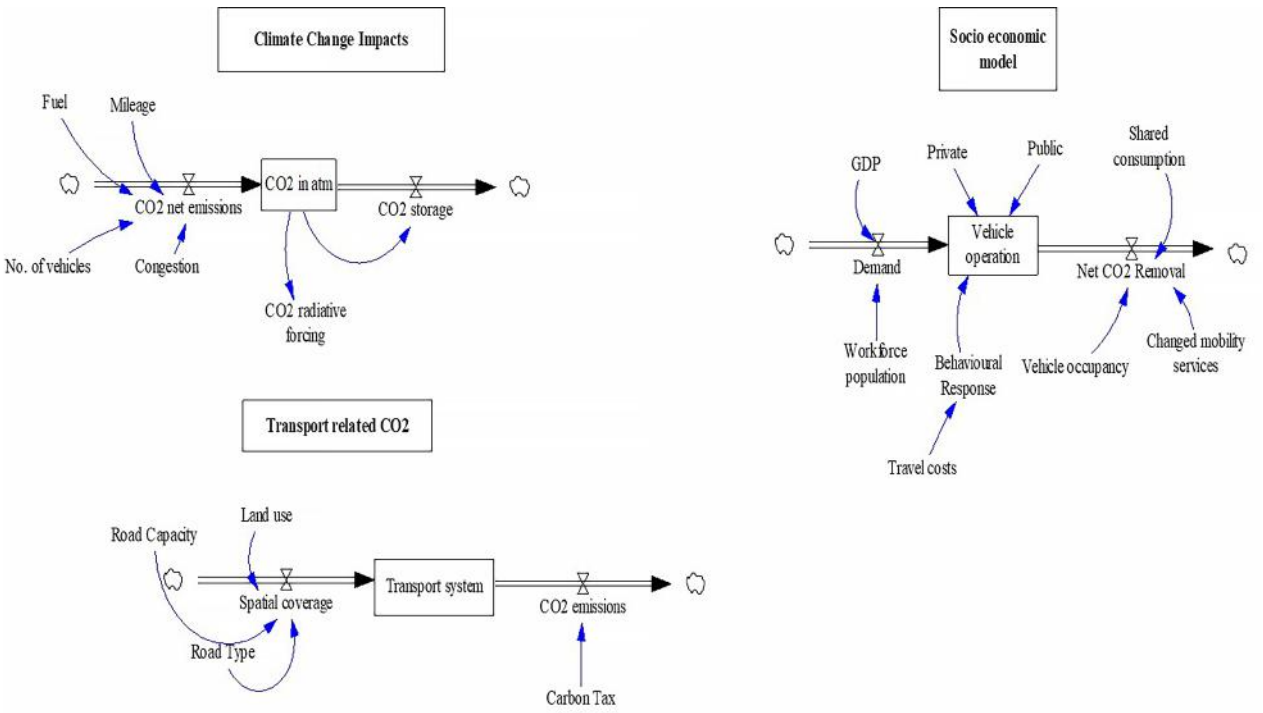

Fig. 2. Stock and flow diagram of the overall road transportation related CO_2 emissions, climate change impacts and a socio economic model

Analysing the link between land transportation and climate change in the Mauritian context

System dynamics is a holistic and dynamic simulation approach that has been used in modeling processes for more than 30 years [15]. Though in the past system dynamics was rarely used to assess causal relationships between the land transport sector and environmental sustainability, in more recent years, the relationship between climate change and road transportation has attracted much attention. For instance, the impacts of climate change on pavement performance and maintenance activity using a system dynamics model was undertaken by these authors [16]. Also, the future effects of climate change and factors affecting road accident was visualized on a system dynamics model by these researchers [17]. Likewise, in order to compare the effects of active cycling as a means to decrease carbon emission between bicycle and car-dominated variables, a group of researchers also used the system dynamics model [18]. In this study, the model considered the climate change impacts of road transportation, transport related carbon dioxide and socio economic models in the Mauritian context.

Climate change impacts

Taking carbon dioxide in the atmosphere as the stock, it can be seen that the mileage covered by vehicles, the fuel they use, the number of vehicles and congestion all directly affect the amount of carbon dioxide that is already present. The number of vehicles on roads indeed have a great impact on carbon emission. It can be seen from statistics for Mauritius that as the number of vehicles increased in Mauritius, the amount of carbon emission also increased [19]. According to the National Land Transport Authority, 580,629 vehicles were registered in 2019 compared to 556,001 vehicles in 2018 which represents a 4.4% increase or 24,628 vehicles. This is directly linked in an increase in GDP for the same period [20]. Likewise, as families and individuals possess their own transport vehicles, they cover more miles without destination distance being a matter. With the rising number of vehicles on roads, the congestion problem has been worsening in Mauritius, thus the initiative of the government to embark on the Light Rail System

and construct new roads. Likewise, the type of fuel invariably plays an important role in carbon emission. Mauritius does not have any natural resources and so depends heavily on imported petroleum products to meet the requirements of the energy sector. This high dependence on imported fossil fuels has been a major concern for the government given the fluctuating price and supply of fossil fuels. The land transport sector is currently the main mode of land transportation with the Light Rail System still in construction. Road transportation caters for both the passenger and freight transport needs of the country. It is reported that in 2017, the vehicle fleet by type of fuel represented 83% gasoline, 16% diesel, 1% hybrid and 0% other (LPG and electric) [21]. Also, it is noted in the National Greenhouse Gases Inventory Report that the main source of GHG in Mauritius is the transport sector with carbon dioxide being the dominant gas [19]. Consequently, all of the above mentioned factors amalgam to raise the overall amount of carbon dioxide in the world's atmosphere. As a result, the radiative forcing caused by these carbon dioxide molecules further increases global warming. Over time, as problems like the dependency of fossil fuels, polluting vehicles with worsening congestion time increase, the amount of carbon dioxide that is stored in the global atmosphere increase thus enhancing the climate change phenomenon.

Transport related carbon dioxide

In this model, the transport system itself is taken as the stock as the system influences carbon emissions. The different variables affecting the physical spatial coverage of the road transportation system include land use, road capacity and road type. In Mauritius, there is around 2,772 km of roads including 1140 km as primary roads, 913 as secondary roads, 104 km as motorways and 615 km as other types of roads. But as the lifestyle of people change with better salaries and more leasing opportunities, the number of roads cannot accommodate the hiking number of vehicles leading to horrible congestions. As it is, most of the land area of the island is still under sugarcane plantations, forests areas, built areas and roads. Massive development is currently ongoing in Mauritius to make way for new roads and enlarge older ones. While land dedicated to vegetation acts as an important sink of carbon dioxide, clearing of such places lead to accumulation of carbon dioxide in the air. It is reported that since the 1990s, carbon dioxide emissions associated with land use were 0.5 to 2.7 GtC/yr [3]. While road development represents 5-10% of GHG emission, they are growing rapidly around the world. In 2009, the Road Decongestion Programme was put forward in Mauritius so as to tackle the island's traffic problem; in this respect, several road improvement projects to increase road capacity, road types and road construction projects have been undertaken where, in many cases, there has been massive land change to make way for new roads. As the transport system causes an increase in carbon emissions, the carbon tax including mileage covered by vehicles on roads is an important tool to regulate carbon emissions.

Socio economic model

What actually drives the transportation system in the world including Mauritius is society and economy. The socio-economic factor associated with road transportation is a crucial element in establishing the link with climate change. This model represents how the transportation sector depends on the vehicle operation which can be private or public. This choice of transportation mode depends on the behavioural response of society which in turn is influenced by travel costs. Basically, the cost of travel influences a person's choice of transport. For instance, it is stated in a study that tourists are more likely to opt for public transportation because they are cheaper compared to renting vehicles or private taxis [22]. What's more, the actual demand for vehicles in any nation is driven by the workforce population and the GDP of the nation. As the

GDP of Mauritius has increased over the years, there has also been an increase in the number of road vehicles.

Interestingly, ever since Karl Benz invented the first automobile in 1866, it has changed the way people commute every day from seeing it as a materialistic possession to a daily necessity. As society drives the vehicle demands and carbon emissions, it is also societal reform that can change the automobile industry, hence carbon dioxide removal being the stock. More people are becoming conscious of environmental impacts of transport emission resulting in changed mobility services and eventually leading to shared consumption amongst passengers and higher car occupancy. In this respect, modern cars could be among the cleanest mode of transport if shared instead of being used alone while a switch to public transport is actually the best cleaner alternative [23]. Thus all these variables could eventually lead to a carbon decrease in the transportation sector and stabilizing climate change in the long run.

Making the land transportation sector of Mauritius more climate friendly

In light of the above, there is clearly a very complex relationship between land transportation and climate change. While the set of parameters will vary from place to place, by all means, transportation heavily adds to climate change from government measures to individual choices. Being a signatory to the Paris Agreement and set to achieve the different Sustainable Development Goals (SDGs), it is of utmost importance for Mauritius to make its land transportation sector more climate friendly. Policy measures are potential means for achieving greenhouse gas emission reductions from the transport sector. Increasing vehicle performance and efficiency through mandatory inspections and maintenance programmes as well as fuel economy standards are a few examples. Policies, particularly car-restriction policies and heavy vehicles including private buses, are quite important as complementary measures in supporting public transport and non-motorized options.

Despite the fact that buses are put at service at regular intervals, the spectre of rapidly growing private vehicle ownership and usage in developing nations casts a worrying shadow on future greenhouse gas emissions. Policies like a city entrance fee for privately owned vehicles will influence how people view and interact with transport medium selection. A more accurate coordination is needed on the part of regulating bodies to meet the objective. Improving the quality of service of public modes of transport by the provision of an improved service in terms of cleanliness, comfort, travel time, service coverage and security can be considered as reliable attempts to increasing the share of public transport ridership. Also, erecting segregated bus ways that permit uninterrupted bus movements without delays from mixed traffic, using pre-board fare-collection systems that reduce dwell times, and most usefully managing the fleet through global positioning satellite (GPS) technology and thus allowing the optimization of demand and supply during peak and nonpeak periods are smart measures that are musts for the island of Mauritius.

Despite the fact that the entrance of hybrid electric vehicles (HEVs) in the Mauritian economy has been government encouraged by lowered road taxes for such vehicles and is mainly subjected towards the importation of cars which ultimately is designed contribute in a decrease of carbon dioxide emissions generated from cars, a very low comparative number of other types of vehicle modes have been so far catered by the State which generally absorbs the net benefit that might have been generated in terms of decrease emissions. Besides, trucks and buses operating mostly in urban areas with many stop and go trips due to congestion, equipped with electric hybrid drive trains technology can achieve a reduction in fuel consumption by up to 20-30%. The government should at the most urgent consider such strategies to alleviate emissions

of carbon dioxide. Additionally, there has been much concern and reluctance on the part of many people as to the price and life time of batteries of hybrid vehicles at saturation point. Likewise, the emergence of electric vehicle in the market has come to a freeze with issues like the absence of charging facilities at refill stations. Ironically, the sources from which the energy is derived are hardly from green sources that are supposed to compensate for their emissions. Ideally, as a smart concept, charging facilities adopted from renewable sources of energy would cater for carbon reduction if same is made accessible at all service stations. Often, there is delay between the time new technologies are introduced in developed countries and the time they reach developing countries, which usually import second-hand vehicles. Small Island Developing States like Mauritius are nations that are the most exposed to the exacerbated impacts of climate change and therefore need prompt address to the issue of sea level rise which is amongst the most feared in particular. As such, international panels and advocates on climate change should show more concern towards island nations due to the fact that they are the most susceptible and also assist in technology transfer and capacity building with regards to climate friendly modes of transportation.

Conclusion

GHG emissions from the land transport sector is a major issue around the world including small island nations like Mauritius. Typically, it is clear that as a country thrives well financially, its carbon emissions from the transport sector also increases. This study used a novel approach to analyse the underlying relationship between the land transportation sector and climate change using Mauritius as a case study. The different variables that link land transportation and climate change were assessed through the literature and common factors were listed into a 3-layered taxonomy namely society, transport system and vehicle. Using these variables, stock and flow diagrams were built using Vensim that represent the relationships between climate change and land transportation factors in Mauritius. Three diagrams were constructed that represent the impact of transportation on climate change, transport related carbon emissions and a socio-economic model. To be sure, there is a complex relationship between land transportation and climate change even for a small island like Mauritius. Nonetheless, there is an urge to curb carbon emissions by all possible means in the transportation sector so as to mitigate the effects of climate change which will only worsen in the future.

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Competing interests
The authors declare that there is no conflict of interest that would prejudice the impartiality of the study.

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Ethical considerations

Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/ or falsification, double publication and/ or submission, redundancy, etc) have been completely ob-served by the authors.

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