Electric Mobility Transition Assessment for Antigua and Barbuda

Scoping and Technical Feasibility

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for the Department of Environment in the Ministry of Health and the Environment of Antigua and Barbuda

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EXECUTIVE SUMMARY

The economy of Antigua and Barbuda is exposed to many of the same vulnerabilities as most Small Island Developing States (SIDS), including a geographical constraint and limited natural resources. As a consequence, the economy is strongly dependent on imports of goods and commodities, and vulnerable to external shocks. The energy sector exemplifies these vulnerabilities. Antigua and Barbuda meets about all of their energy needs for both transportation and electricity generation from imported petroleum fuels. This context is aggravated by system inefficiencies and the subsidies to electricity-intensive water desalination. All this affects energy prices. The price of electricity reached USD 0.44 per kilowatt-hour in 2013.

Antigua and Barbuda is particularly rich in native renewable sources of energy, like solar and wind, which have become competitive on a levelized cost basis with fossil generation. It was estimated that up 400 megawatts (MW) of wind power 37.5 MW of solar capacity could be readily integrated into the existing grid. To date, 3.8 MW of solar capacity have been deployed, with plans to expand this capacity to 10 MW in the near future. A potential investment in an 18 MW wind farm at Crabbs Peninsula is also contemplated. These initial investments start moving Antigua and Barbuda toward its Conditional Mitigation Target of an energy matrix with 50 MW of renewable capacity by 2030. While a number of policy and regulatory steps have been taken toward the support of clean electricity (e.g. Renewable Energy Act of 2015), important challenges remain around the financing of renewable capacity projects.

The transport sector is also witnessing dramatic developments, pivoting about three rising trends: electrification, shared mobility, and vehicle automation. These trends are interrelated and have tremendous implications on how people and goods will be moved in the coming decades. In particular vehicle electrification, the center of this study, is finally making inroads in a few markets around the globe.

On average, the vehicle fleet in Antigua and Barbuda has high emission factors of greenhouse gases and criteria pollutants. This is in great part driven by the lack of vehicle efficiency standards, and the lax enforcement of emissions limits on vehicles on the road, as well as on used imported vehicles. Road transport represents 29 percent of the energy related carbon emissions in A&B. The chart below shows the discrimination across vehicle fleet segment of greenhouse gas (GHG), nitrous oxides (NOx), and particulate matter (PM) emissions.

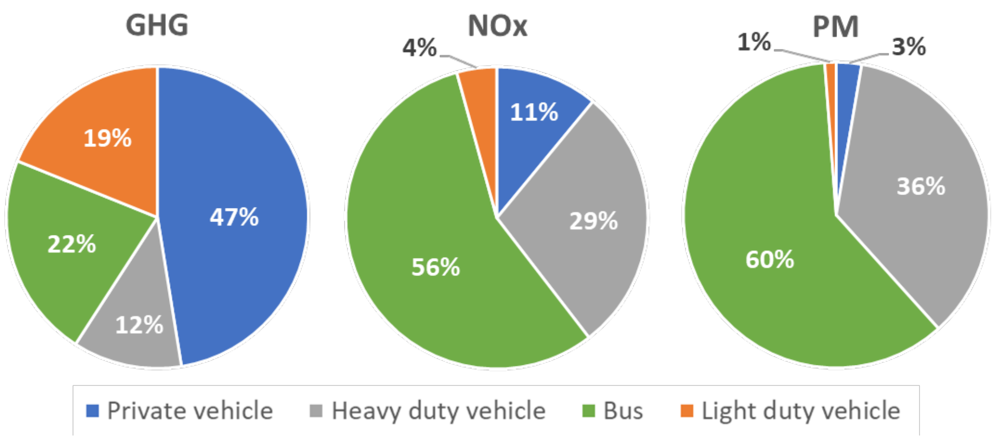


FIG. I - ROAD TRANSPORT SECTOR GHG, NOX AND PM EMISSION DISTRIBUTION BY FLEET TYPE [LOGIOS].

The recent wave of plug-in electric vehicle commercialization started in 2008-9, catalyzed by the economic downturn and spikes in oil prices in those years, and the consequent policy interest in alternatives to petroleum fuels. Sustained improvements in electric drive technology, including battery cells, electric motors, power electronics, manufacturing, and supply chain processes are making the economics of plug-in electric vehicles more competitive vis-à-vis conventional internal combustion vehicles.

Plug-in electric vehicles (PEV), or simply electric vehicles (EV), encompass two broad platforms: battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV). Unlike PHEVs, BEVs are not assisted by an onboard combustion engine and draw motive power exclusively from an onboard battery that is recharged from a source external to the vehicle, typically the electric grid. In addition to the higher upfront costs, the consumer value proposition of EV has historically been harmed by battery charging times and constraints in vehicle range. While technology continues to make strides in these two areas, smaller island states like Antigua and Barbuda offer a physical environment constraining of trip distances, which can be conducive to market acceptance.

Driving on electric mode means that there is no combustion of fuels in the vehicle and thus these vehicles have no tailpipe emissions. This immediately translates into improvements in local air quality, reducing pernicious effects on human health, agriculture, and the natural environment. Given the lax control of automotive emissions in Antigua and Barbuda, the marginal effect of EV market adoption on air quality can be significant.

The current matrix of electricity generation however would significantly cripple any benefits that EV could bring in terms of carbon emissions in Antigua and Barbuda. Therefore, in the context of a climate strategy, a plan for vehicle electrification ought to be embedded into a broader plan to integrate cleaner generation of electricity. As a matter of fact, this would likely be a sensible approach from a macroeconomic standpoint as well, for the reasons described earlier.

A variety of measures could be adopted to reduce the carbon intensity of electricity. The chart below shows the evolution of the GHG intensity factor of baseline electricity, along with the improvements that could be achieved by 2035 in two specific scenarios as described in the country's Intended Nationally Determined Contributions (INDC): a) reducing losses in the distribution system would reduce carbon intensity by 13%, and b) additionally incorporating renewable generation, under the estimated future generation requirement, would reduce the carbon intensity of electricity by 37%.

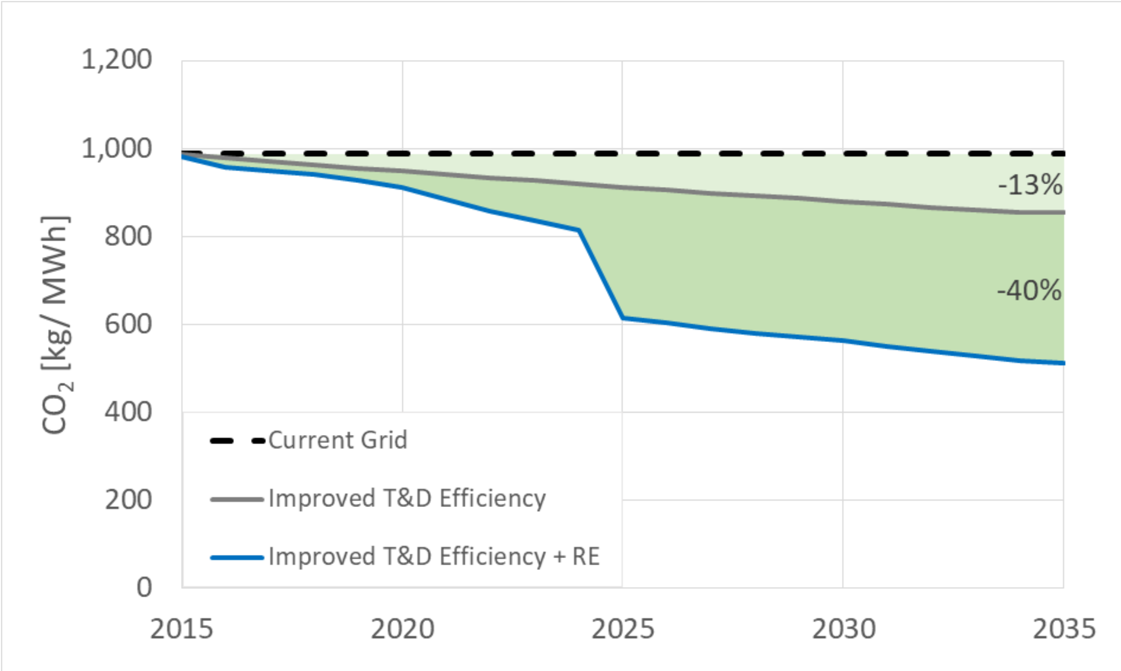


FIG. II - ELECTRIC GRID GHG EMISSIONS FACTOR PROJECTIONS FOR AN IMPROVED TRANSMISSION AND DISTRIBUTION EFFICIENCY SCENARIO AND IMPROVED T&D EFFICIENCY PLUS RENEWABLE ENERGY PENETRATION SCENARIO VERSUS CURRENT GRID EFFICIENCY.

Recent trends of vehicle fleet growth in Antigua and Barbuda are alarming. From 2010 till 2014 the fleet of private cars, light duty vehicles and heavy-duty vehicles all grew at an astonishing average annual rate of 8%. In 2015, this trend stopped sharply, with fleet growth that year down to only 2.5%. This was most likely due to the impact that Hurricane Danny had on the isle's economy. In the mentioned period vehicle ownership went 0.39 -0.45 cars per person, which is already a very high index when compared to other countries of similar GDP and GNI per capita. There are many factors that could explain these trends. To start with, when considering arrivals from all ports, in 2017 the country received over one million visitors: stayover arrivals (247,320), buoyant cruise (801,787) and yachting industry (19,543). Stayover arrivals alone were three times the country´s population. This means that road infrastructure and vehicle capacity need to be in far excess of that required by locals. Furthermore, the GNI of most visitors, which come from the US and Canada, is likely to be higher than that of the average local population. Making estimations of vehicle ownership based on local GDP (gross domestic product) and GNI (gross national income) misleading.

Another very relevant matter when projecting the growth of a given fleet, are used vehicle market regulations. In most developed countries the vehicle per capita index reaches a saturation point not due to a reduction in the number of new cars sold, but when the entry of new cars and the scraping of used vehicles attain an equilibrium. Most developed countries and some developing countries have regulations in place that require used vehicles to undergo a technical, safety and emission revision for these to be roadworthy. As vehicles get old, passing these revisions becomes more and more expensive, which coupled with the drop of the vehicles value results in its operation becoming uneconomic and therefore the vehicles get scraped or exported to countries with more lenient roadworthy regulations. Antigua and Barbuda is one of the latter. The country has no roadworthy or emission regulations in place and currently imports vehicles of in average 5 years old. This makes vehicle scrapping not common as vehicles will stay on the road as they are mechanically capable to do so.

All the above, in addition to the that fact that relevant reliable information about the fleet composition and evolution is not available, makes establishing future fleet projections complicated. If historic annual fleet growth rates are maintained into the future, by 2035 Antigua and Barbuda´s vehicle fleet would more than triple. On the other hand, if vehicle ownership models, which consider the country's GDP and GNI amongst others, are applied the fleet growth rate should slow down and reach a more conservative overall growth. However, as shown on the figure below, even in this case the country´s fleet doubles by the year 2035.

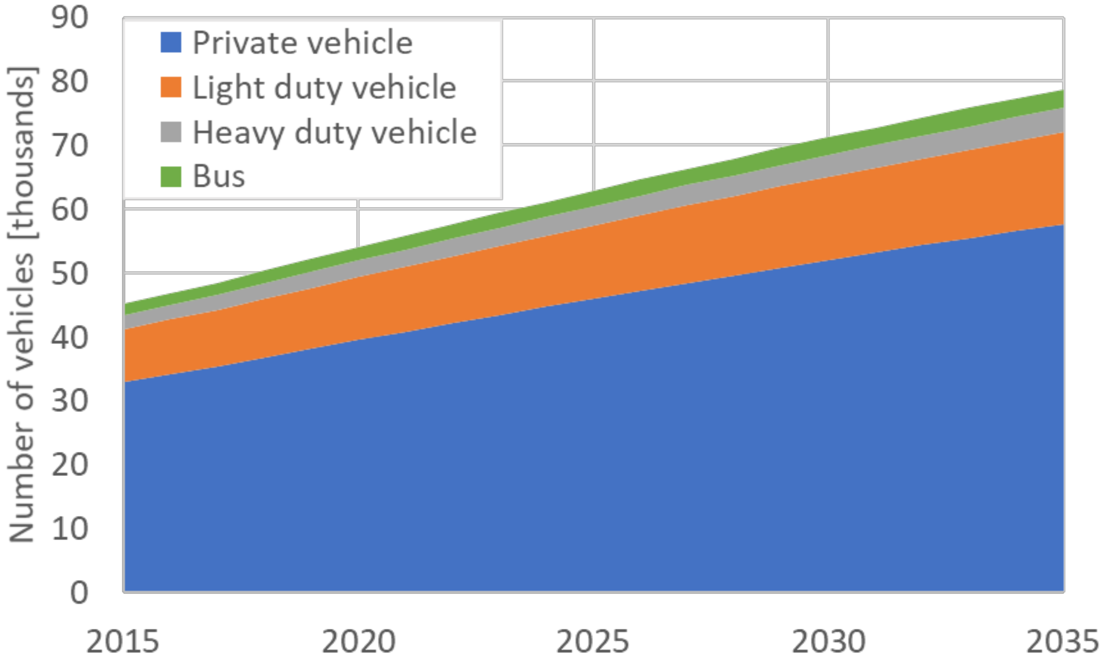


FIG. III - BUSINESS AS USUAL SCENARIO GROWTH OF THE THE ROAD TRANSPORT SECTOR OF ANTIGUA AND BARBUDA TO THE YEAR 2035 BY VEHICLE CATEGORY

It is important to recognize that the trends described in this report are representative of current conditions, but that are amenable to change, with the right set of policies and strategies. While direct extrapolations of the current trends may suggest a future with very large ratios of car ownership, vehicle miles travelled, and emissions of greenhouse gases and criteria pollutants, all these are affected by local and external factors. For example, motorization can reach saturation at different levels depending on GDP, active population, transportation infrastructure, transportation options, fuel prices, geographic area, overall transportation planning and policy, etc.

As illustrated in the following chart., under the above projected vehicle utilization trends, Antigua and Barbuda would similarly almost double its carbon emissions by 2035.

The definition of saturation profiles is critical from a strategic standpoint. As the growth of motorization finds its inflection point, the focus of policy and investments can start shifting from expansion to maintenance and modernization. Defining the saturation point ought to be part of

Antigua and Barbuda's strategy to curb emissions. For this, the right set of policies and market signals should be identified and adopted.

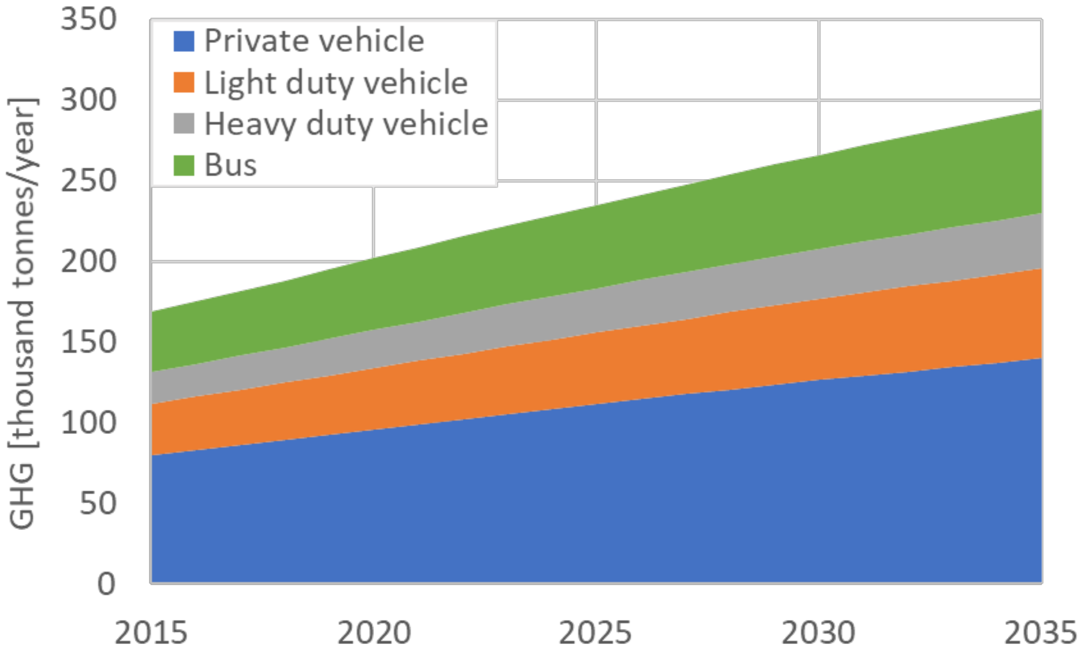


FIG. IV -. BUSINESS AS USUAL SCENARIO OF THE GHG EMISSIONS GENERATED BY THE ROAD TRANSPORT SECTOR OF ANTIGUA AND BARBUDA TO THE YEAR 2035 BY VEHICLE CATEGORY

As discussed earlier, EVs have the potential of bringing about significant carbon mitigation benefits, but such benefits will depend on the extent to which the carbon intensity of electricity is reduced. For example, if the projected improvements in transmission and distribution efficiency improvements are implemented as indicated in the INDC, displacing a conventional internal combustion vehicle with an electric vehicle would reduce the vehicle carbon emissions as shown below, for each of the different transport fleets. It should be noted that these figures do not take into account the emissions resulting from the production and delivery of the petroleum fuel used by conventional vehicles.

The cumulative emission benefits of a transition to electric vehicles can be estimated with the use of scenarios of market penetration. In this study three scenarios were adopted, namely optimistic, moderate, and pessimistic, for each of the vehicle fleet segments. The charts below show, for each of the scenarios, the shares of electric vehicles of the vehicles that enter the market each year and of the entire fleet as electric vehicles penetrate the market.

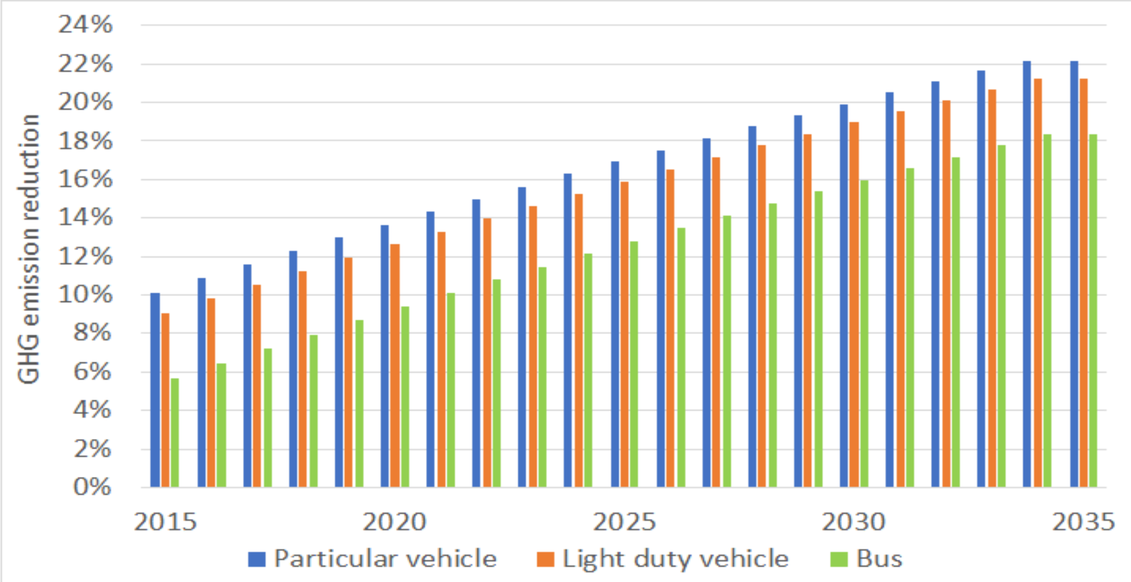


FIG. V - ESTIMATED GHG EMISSIONS MITIGATION OF AN ELECTRIC VEHICLE RELATIVE TO AN EQUIVALENT CONVENTIONAL VEHICLE UNDER THE ASSUMED OPERATING CONDITIONS OF THE DIFFERENT FLEETS IN ANTIGUA AND BARBUDA BETWEEN 2015 AND 2035.

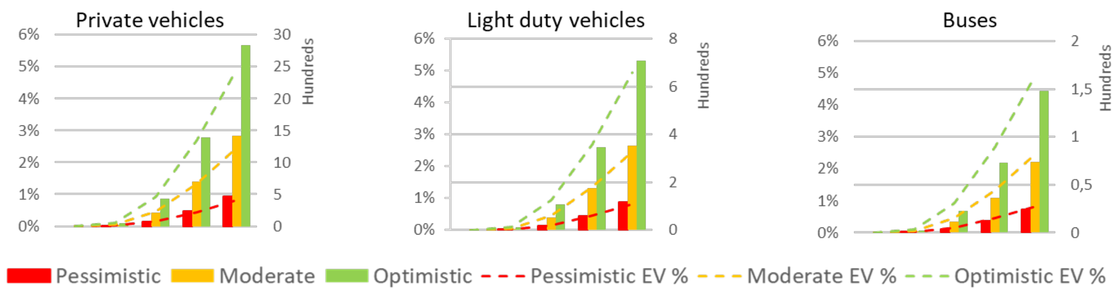


FIG. VI - PENETRATION OF ELECTRIC VEHICLES INTO THE DIFFERENT TRANSPORT FLEETS UNDER THE DIFFERENT PENETRATION SCENARIOS.

For example, the optimistic scenario proposes that by the year 2035 30% of all car sales in the country are electric vehicles, these would result in an overall fleet participation of almost 6%. These scenarios were developed to serve as reference cases, and it is important to note that they are not prescriptive. Antigua and Barbuda could, for example, decide to adopt more aggressive electrification strategies that resulted in higher market penetrations by 2035, for any or all the vehicle fleet segments. Because of numerous factors affecting innovation systems, the macro adoption of new technologies generally starts at a slower rate—the scenarios described above reflect this type of progression.

Under these proposed EV penetration scenarios, the aggregate mitigation of carbon emissions from transportation is rather marginal, as illustrated below. Overall, emission benefits would amount to just 1.4% under the more optimistic scenarios. The main culprit in the meagre carbon emission benefits is the high carbon intensity of the electricity that would be used to charge EVs.

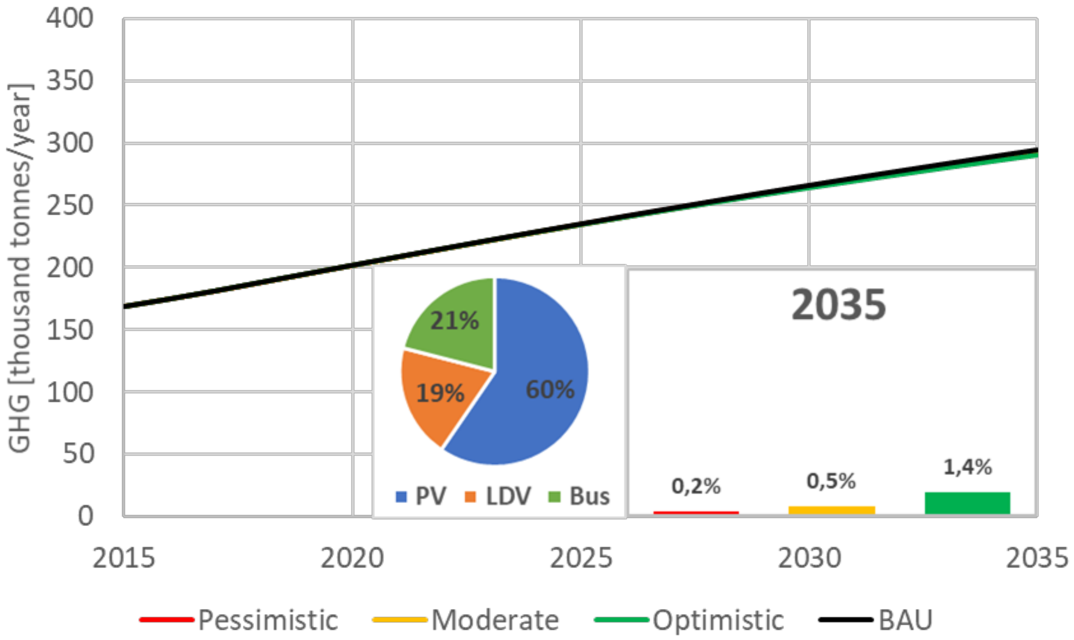


FIG. VII - VEHICULAR GHG EMISSIONS PROJECTIONS OF THE IMPLEMENTATION OF PESSIMIST, MODERATE AND OPTIMISTIC ELECTRIC VEHICLE PENETRATION SCENARIOS, FROM 2015 TO 2035, COMPARED TO BUSINESS AS USUAL PROJECTIONS.

While this study focuses on the environmental impacts of vehicle electrification, as discussed above, the prospective benefits to Antigua and Barbuda of integrating renewable sources of energy and transitioning to electric vehicles are also related to economic growth and public health, and consistent with foundational documents such as the Energy Action Plan and the Barbados Programme of Action.[1] Materializing this multifaceted opportunity will require Antigua and Barbuda to embark on a process of deep transformation of the electric grid.

The results clearly suggest that no single measure or line of action can, by itself, bend emissions and petroleum dependency in Antigua and Barbuda into the needed trajectories. As discussed in this report and elsewhere, emissions are, in broad terms, determined by four factors, namely population, vehicle miles travelled, vehicle fleet efficiency, and quality of fuels. Each of the last three broad factors is amenable to various forms of policy intervention.

This study presents a variety of actions that could complement vehicle electrification in a general strategy to reduce emissions and petroleum consumption in the transport sector. Looking holistically at this set of options (which by no means is presumed to be comprehensive), public transport arises as a market where vehicle electrification could have a comparatively high positive impact. The modernization of public transport would support the goal of curbing rates of growth in personal vehicle ownership and use. The adoption of electric buses would greatly increase fleet efficiencies and facilitate the integration of new renewable generation capacity.

Public transport is also an effective way to expose the general public to new vehicle technologies. Critical to market adoption of new technologies, and EVs are no exception, is end-user legitimation. This in turn is related to direct and indirect exposure to the technology. The vulnerability of Antigua and Barbuda to climate change and to ups and downs of fuel markets offers an opportunity to empower a campaign to educate the public about electric vehicles and

[1] Department of Sustainable Development of the General Secretariat of the Organization of American States (2013) Sustainable Energy Action Plan. March.

native renewable energy, and the benefits that they could carry to the islands in terms of climate change mitigation, climate/natural events resiliency, and decompressing the trade balance. Public transit also serves a more diverse population, creating opportunities for positively impacting disadvantages segments. In developing countries, for example, women are disproportionally dependent on public transport.

Regardless of the strategy adopted for vehicle electrification, Antigua and Barbuda ought to take a systemic approach. Beyond the necessary investments in modernization of the fleet and generation capacity, and the need for end-user legitimation, there is a need to generate adequate legal and regulatory frameworks, capacity building, sustained monitoring and planning, etc.

1. INTRODUCTION

Antigua and Barbuda is one of the 52 countries that have been classified as Small Island Developing States (SIDS), a group of countries that were recognized to have unique needs in the United Nations Conference on the Environment and Development (the Rio Summit) of 1992. The uniqueness of the SIDS is described and discussed in the Barbados Programme of Action of 1994. Almost 25 years ago, this document pointed to the vulnerability of SIDS to the effects of climate change, despite the comparatively marginal contribution of these countries to global greenhouse gas emissions.

The economy of Antigua and Barbuda is exposed to many of the same vulnerabilities as most SIDS, including a geographical constraint and limited natural resources. As a consequence, the economy is strongly dependent on imports of goods and commodities, and vulnerable to external shocks. The energy sector exemplifies these vulnerabilities. Antigua and Barbuda meets about all of their energy needs from petroleum fuels. In the absence of local resources of fossil fuels, the country is exposed to price shocks and the volatility in this market. In excess of 10 percent of Antigua and Barbuda's GDP is annually allocated to the importation of fuels. This context is aggravated by severe system inefficiencies and the subsidies applied to desalination for the supply of water that consumes about 10 percent of the total electricity production. As a consequence, energy prices are high. The price of electricity reached USD 0.44 per kilowatt-hour in 2013.[2] These economic vulnerabilities are compounded by the exposure to natural hazards that often result in significant disruption to the economy. In this context, the Barbados Programme of Action recognizes that strategies for economic development in SIDS ought to identify opportunities to enhance self-reliance and resiliency, emphasizing key areas, including human capital, services and tourism, and sustainable development.

In line with the rest of the world, over the past decade Caribbean countries have intensified their efforts towards mitigating their emission of anthropogenic greenhouse gases. Based on current projections the mean temperature of the region will see an increase of 2 to 3 degrees centigrade by 2050 [1] and a decrease of 30-50% in rainfall by 2090 [2]. Furthermore, the region is particularly vulnerable to climate hazards such as hurricanes and droughts. The expected surge in the regions mean temperature will increase the frequency and intensity of these events [3]. It will also increase heat stress related problems affecting mainly people with cardio-respiratory problems and the elderly, promote the presence and formation of bacteriological and epidemiological agents, which favour the spreading of diseases. Drought conditions, on the other hand, heighten the risk of underground water storage contamination from sewage, reducing the quantity and quality of the water supply. This would constrain plant growth, affecting agriculture in the island, which would undoubtably put strain on its food supply [2].

The above projected scenario would have an overwhelming negative impact on the region's quality of life, economy and environment. In line with global Climate Change mitigation contributions announced in the Paris Climate Change Summit of 2014 and then ratified in Marrakesh 2016, the Government of Antigua and Barbuda has committed, through its Intended Nationally Determined Contributions (INDC), to mitigate its greenhouse gas emissions (GHG)

[2] APUA (2013) Production Summary July 2013. Available on the web at http://www.apua.ag/wp-content/uploads/2013/09/july-2013.jpg

and put in place a plan to address climate change adaptation [4]. The country´s INDC include the following goals, which may, to various degrees, be related to the electrification of transport:

- "Enhance the established enabling legal policy and institutional environment for a low carbon emission development pathway to achieve poverty reduction and sustainable development" (unconditional target).
- "By 2020, establish efficiency standards for the importation of all vehicles and appliances" (conditional mitigation target).
- "By 2020, finalize the technical studies with the intention to construct and operationalize a waste to energy (WTE) plant by 2025" (conditional mitigation target).
- "By 2030, achieve an energy matrix with 50 MW of electricity from renewable sources both on and off-grid in the public and private sectors" (conditional mitigation target).
- "By 2030, 100% of electricity demand in the water sector and other essential services (including health, food storage and emergency services) will be met through off-grid renewable sources" (conditional adaptation target).

Meeting these targets and others included in the INDC declaration, requires putting in action a range of measures that will affect all energy and carbon-intensive sectors of the isle´s economy.

The transport of people and goods is a key component of the world's economy, with vehicle fleets ever growing as global GDP is increased. The sector is highly dependent on fuels derived from petroleum, with these accounting for around 95% of its energy demands and is currently responsible for around 25% of world´s energy-related GHG emissions [5]

In developing countries, where the level of motorization is still relatively low, the growth of the transport fleet is considerably faster than in developed parts of the world. For example, in Latin American and Caribbean countries, over the past decade the fleet of road vehicles has registered annual growths of around 6-7%. This is in far excess of the region annual GDP growth, which was around 1.7% in 2017 [6].

In correlation with the above, over the same period, transport GHG emissions in the region grew faster than that of any other energy-intensive sector of the economy, with these expected to almost double by the year 2030 [7]. This is a clear obstacle to achieving the emission reduction targets, set forward by the latest IPCC report, required to avoid the more extreme consequences of climate change [1].

In addition to problems related to GHG emissions, the growth of urban transport fleets, and in consequence their toxic tail pipe emission (NOx, PM2.5, PM10, SOx, CO), are partly responsible for the deterioration of air quality in urban areas [8].

In line with the above and in addition to the already mentioned INDC, the Government of Antigua and Barbuda, in collaboration with the Caribbean Community (CARICOM), has initiated the *"Electric School Bus Pilot in Antigua"*, one of the first public sector electric vehicle initiatives of the region. The initiative is intended to promote green technology education and to advance the "Public Transport Sector Low Emission Action Plan" [9].

The work at hand will help decision makers identify measures to transform the country´s transport sector towards a cleaner, more efficient and more inclusive system.

First, the current transport fleet will be evaluated to establish the relative impact of the different vehicle types on the overall GHG and toxic emissions of the sector. Subsequently, based on historical vehicle growth rates, a Business As Usual (BAU) projection will be made for the period of 2015 to 2035. The purpose of this is to understand the direction and future impact of the system on the isles GHG and toxic emissions and to establish a baseline over which the different mitigation measures will be evaluated against. The latter include:

- Technological shift: promoting the penetration of electric vehicles;
- Enforcement of stringent emission standards on future vehicle imports;
- Banning the import of high sulphur fuels for road transport applications;
- Establishing an energy efficiency standard for future vehicle imports;
- Modal shifts: promoting public transport and car sharing.

The GHG emission reductions and toxic emission abatement of each of the above will be calculated over the proposed period, to determine which measures result in the biggest environmental benefit. This will lay the ground work for the second part of this program (Deliverable 2), which will focus on establishing the cost effectiveness of each of the proposed measures (i.e. dollars invested per ton of emission abated).

Whilst, all measures proposed have a direct impact on the transport sector, to understand the technical feasibility and true environmental performance of promoting a technological shift towards electric vehicles it is imperative to understand the current and future composition of the country´s electric grid. Therefore, before boarding the above proposed analysis a brief description of the current electric grid will be undertaken followed by the projection of the future generation system that will result from the completion of the A&B INDC goals.

2. ENERGY SECTOR

As mentioned above, to fully understand the environmental benefits associated to promoting the incorporation of electric vehicles into the road transport system of a given country, it is crucial to have a clear understanding of its electricity generation matrix and its carbon intensity.

Antigua and Barbuda´s energy system is highly carbon intensive. Electricity generation, heating, water desalination and transport applications are all based on imported fossil fuels. However, as highlighted by several experts from different national and international entities [10], the isles show considerable potential for the incorporation of renewable energy sources, such as: wind, solar, bio-energy, and waste to energy systems.

Throughout this section the Antigua & Barbuda's energy supply and consumption profile will be assessed, with the primary objective of understanding the potential emission implications of incorporating electric vehicles into the transport fleet. The analysis includes the prospective emission intensity of a future grid that integrates large-scale deployments of renewable energy capacity.

2.1 ENERGY SUPPLY AND CONSUMPTION

Figure 1 illustrates the fuel distribution of Antigua and Barbuda's energy supply during 2012 Heavy fuel oil, used for electricity generation, represented 35% of total energy imports; diesel and gasoline imports, used for road transportation, were also around 35% of the overall energy consumption; whilst the remaining 30% was mostly Kerosene/Jet Fuel used in aviation applications [11]. It is important to note that the high imports of jet fuel (10 times higher than the region's average) are due to the fact that LIAT airlines headquarters are in Antigua.

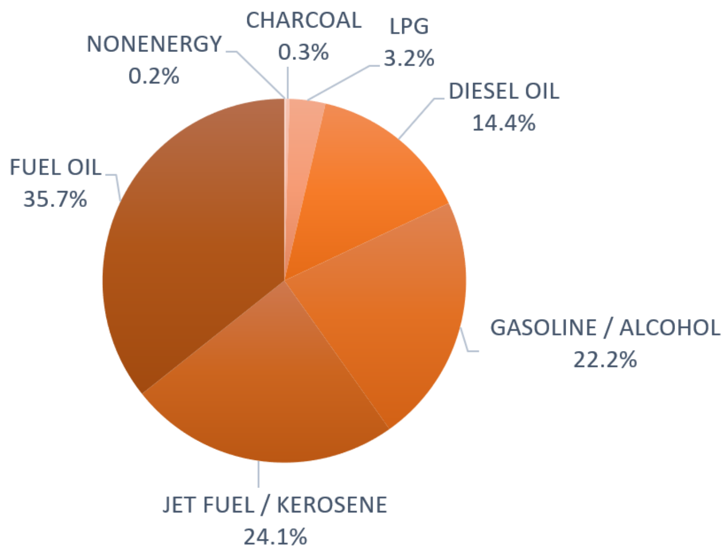


FIGURE 1 - ENERGY IMPORTS DISTRIBUTION BY FUEL TYPE IN 2012, IN THOUSANDS OF OIL EQUIVALENT BARRELS (KBOE) [11]

Fuel imports are a significant portion of the country's incoming trade and put significant pressure on its commercial balance. In 2013 these were equivalent to 13,7% of the country's GDP [10]. To put this into context, the European union imports around 40% of its energy requirements, with these representing around 1.5% of the economic block GDP [12]. This highlights the necessity for the isles to reduce energy imports and improve the efficiency in which these are used to further reduce their impact on its trade balance and ultimately on its economy.

Fuel importation and local wholesale distribution are done by West Indies Oil Company Limited, of which the government of Antigua and Barbuda is the largest shareholder. Last-mile fuel distribution to service stations and commercial/industrial consumers is done by private companies [13].

2.2 ELECTRICITY GENERATION AND CONSUMPTION

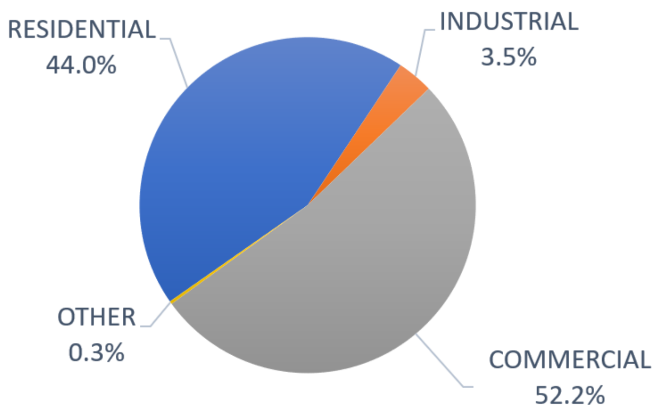


FIGURE 2 - ELECTRICITY CONSUMPTION DISTRIBUTION BY ECONOMIC SECTOR [11].

Figure 2 shows the isles electricity consumption distribution by economic sector [11]. It shows that commercial activities, which include tourism and public services, represent more than 50% of the country´s electricity usage, reflecting the importance of tourism in the economy.

In terms of GDP, tourism is Antigua and Barbuda´s second most important activity. The number of restaurants and hotels almost doubled between 2003 and 2013. This expansion brought about an increase of the sectors electricity demand, which in turn resulted in the need for investments in both power generation and distribution infrastructure [2].

TABLE 1 - CONVENTIONAL POWER GENERATION INSTALLED CAPACITY [14].

Power Plant	Generator	Power [MW]
Blackpine	Blackpine 1	6.5
	Blackpine 2	6.5
	Blackpine 3	7.5
	Blackpine 4	7.5
Wadadli	WPP GE 1	5.1
	WPP GE 2	5.1
	WPP GE 3	5.1
	WPP GE 4	5.1
	WPP GE 5	5.1
	WPP GE 6	5.1
JVP	JVP GE 1	17
	JVP GE 2	11.4
	JVP GE 3	11.4
	JVP GE 4	11.4
Subtotal Base Power		**110**
Back-up/Emergency		**14**
VC Bird Airport PV Plant		**3**
Distributed PV Power Capacity		**0.8**
Total		**128**

Almost all of the electricity is produced in three thermal power plants, all of which run banks of internal combustion engines that use fuel oil. Table 1**Error! Reference source not found.** details the installed capacity inventory of the system. Electricity distribution, on the other hand, is done by Antigua Public Utilities Authority (APUA), which is a government-owned corporation.

As shown in Table 1**Error! Reference source not found.**, the country has a total installed capacity of 124 MW, out of which 110 MW are of base load capacity. However, due to distribution constrains, only 93 MW are considered dispatchable [14].

A recent study shows that the base and peak power demands are of around 41 MW and 51 MW, respectively [14]. Meaning that the overall interconnected system has close to 80% excess installed dispatchable capacity and 143% spare peak capacity. Although this seems to be high, it is expected in a grid of this size, given that if any of the existing power plants goes down, the remaining must be able to maintain the electricity supply throughout the entire day. In bigger interconnected systems, more players are responsible for smaller portions of the installed capacity and therefore the gap between peak demand and installed capacity can be reduced to around 20%. Having said this, when grids incorporate additional non dispatchable, renewable variable power generation, this spare capacity might be further increased, depending on the schedule of retirement of older diesel units.

Using the electricity consumptions projection presented in a recent study, it is possible to estimate the future peak power demands of the system [10]. These are shown in Figure 3*Error! Reference source not found.*. The forecasts shows that peak power demand is expected to grow to 55 MW by 2025 [10], and to 58 MW in our projection to 2035. The distinct difference between electricity generated and electricity sold, shown on the left vertical axis of Figure 3*Error! Reference source not found.* is primarily due to high losses at the distribution level, which today account for almost 28% of the generation. A&B has already committed plans to reducing these losses to 15% by 2035 [15]. The kink seen in the projection of generation is simply an artefact of the assumptions that had to be made, given lack of more precise data.

The country's future need for further dispatchable installed capacity will depend on the reliability of the existing power plants, the schedule of retirement of older units, as well as the strategy adopted for the integration of renewable non-dispatchable capacity. This will be analysed in the following section.

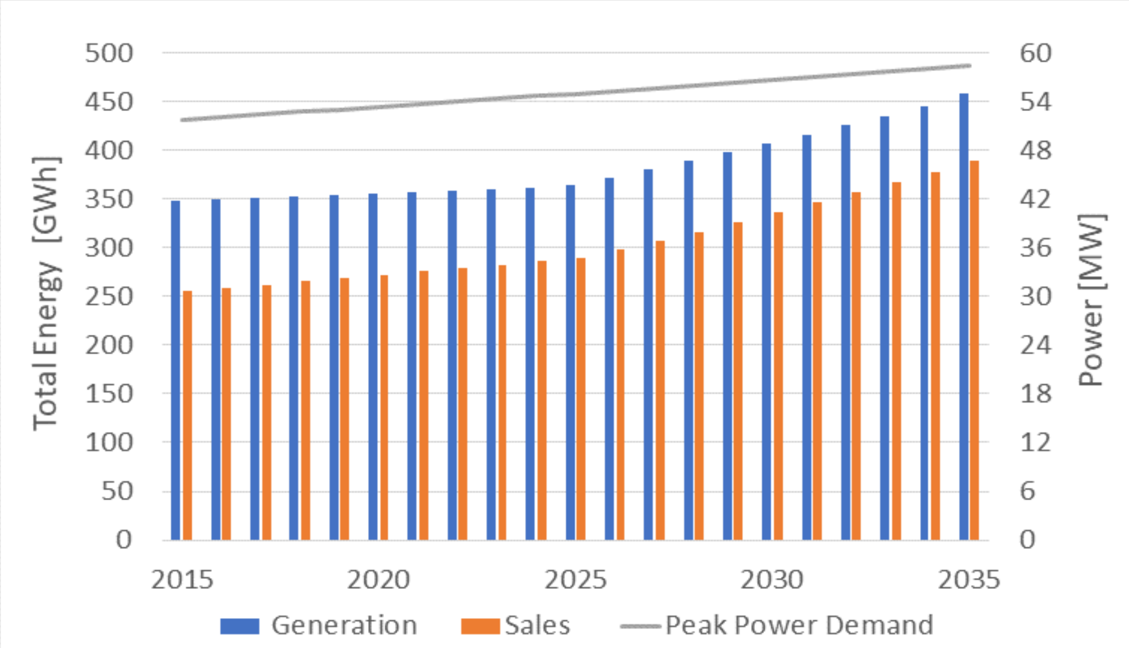


FIGURE 3 - ELECTRIC ENERGY SALES, GENERATION AND PEAK POWER PROJECTION TO 2035 [15] [10].

2.3 FUTURE RENEWABLE ENERGY INSTALLED CAPACITY

In view of the isles´ INDC and future targets, several projects must be considered to ensure their capability to meet increasing shares of electricity demand with renewable generation.

Today Antigua and Barbuda has 3.8 MW of renewable power installed capacity. This includes 3 MW of solar photovoltaic panels installed at the VC Bird International Airport Terminal and 800 kW of aggregated solar capacity distributed across government buildings in both islands. Although the government has set a solar power target of 10 MW, the financing for the remaining capacity remains to be identified, and thus no specific completion date has been formally adopted. This renewable capacity target includes, in addition to the current installed capacity, a deployment of another 3 MW of PV panels to be installed on public buildings, a new 3 MW private solar PV power plant and 1 MW of distributed solar panels across Barbuda.

Another important Conditional Adaptation Target stated in Antigua and Barbuda's INDCs is the construction of a waste-to-energy power plant. The technical feasibility study of the latter is due to be completed by 2020 and the plant is set be operational by 2025. Based on a preliminary review of sanitary landfills, 80,000 tons of waste per year could be available for conversion to energy [4]. Assuming that waste has a lower heating value (LHV) of 10 MJ per kilogram and the waste-to-energy plant has a conversion efficiency of 25%, an 8 MW plant could produce 55 GWh of dispatchable low emission electricity per year.

In addition to renewable and low GHG emission power capacity installation has also established targets regarding climate change adaptation that have implications for energy. Water is a strategic resource and therefore desalination plants need to be seriously considered when assessing future energy demand requirements: on an average year, 60% of Antigua and Barbuda’s water supply comes from desalination, and this share can climb to 100% in drought months. The country has set Conditional Adaptation Targets for the incorporation of water desalination plants. These state that by 2025 water production capacity must be increased by 50% compared to 2015 levels and that by 2030 all of the electricity demand from water production and other essential services (including health, food storage and emergency services) must be supplied by 100% off-grid renewable power. According to a study done by NREL, achieving this target will require producing 16,9 GWh per year of renewable electricity [15]. Producing this amount of electricity could require an additional installed renewable capacity of approximately 6.5 MW, depending on capacity factors.

Overall, the country has already identified approximately 21 MW of additional renewable power generation capacity that would be deployed. It is balanced evenly between 1/3 non-dispatchable grid connected renewable power, 1/3 dispatchable grid connected power and 1/3 off-grid variable renewable power. This is in direct correlation with the Conditional Mitigation Targets, which states that by 2030 its energy matrix should have incorporated 50 MW of renewable electricity from both on and off grid generation.

2.4 POTENTIAL FOR GRID INTEGRATION OF VARIABLE POWER GENERATION

As described above, out of the 50 MW overall renewable energy target, 21 MW have already been identified: 8 MW are dispatchable (waste to energy power plant), 6.5 MW are for off-grid applications and 7 MW are additional non-dispatchable grid connected PV generation.

Prevalent wind patterns and solar radiation profiles show that Antigua and Barbuda has a strong potential to produce power from these renewable sources. According to a recent study [14], the current electric grid can integrate up to 37,5 MW of renewable capacity within parameters of performance. Given the 3.8 MW already deployed, this leaves approximately 33.7 MW of solar capacity that could still be added.

Therefore, considering the already allocated projects, the grid could handle an additional 30 MW of renewable capacity. This is enough to meet the country´s conditional mitigation targets with requirement of no mayor adjustment to its electricity system. To the extent of our knowledge, no studies have been conducted to evaluate the impact that additional capacity deployments could have on the price of electricity. All else equal, a reduction in the effective capacity factor of the conventional power plants could result in higher levelized costs of electricity generation. However, given the extant spare capacity, renewable deployments are expected to first displace conventional capacity, and probably enable Antigua and Barbuda to retire older generators to reduce constant costs in the system.

Based on the above and taking into account the country's expected future energy demand Figure 3**Error! Reference source not found.**, it is possible to make a projection of the future renewable electricity generation. To do this the following assumptions are made:

1. The waste to energy power plant comes online in 2025 as indicated in the INDC;
2. The additional 30 MW of renewable energy required to meet the country's INDC will be assumed to be of equal parts of solar PV and wind turbines.
3. The deployment of solar panels and wind turbines occurs gradually over time.
4. The capacity factor of solar PV panels and wind turbines is assumed to be of 20% and 40%, respectively.

Results are shown in Figure 4**Error! Reference source not found.**.

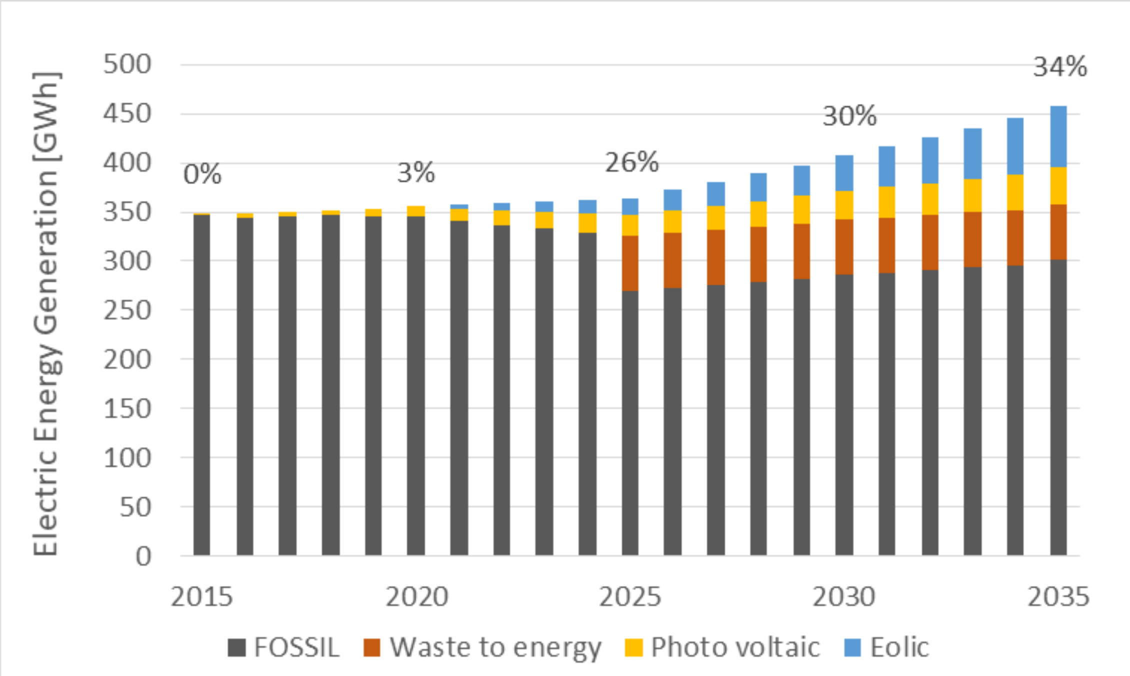


FIGURE 4 - ELECTRIC ENERGY GENERATION PROJECTIONS TO 2035 INCLUDING POTENTIAL RENEWABLE ENERGY GENERATION SOURCES INPUTS [LOGIOS].

If all INDC are met, by 2035 around 34% of the projected power generation requirements of the country will be produced by renewable power plants. This would be a significant achievement and would result in a considerable reduction of GHG emissions.

2.5 GHG EMISSIONS GENERATED BY THE ENERGY SECTOR

In 2014, Antigua and Barbuda's total annual GHG emissions were of around 640,000 metric tonnes of CO_{2e}, out of which almost 80% were due to the use of fossil fuels [14]. Figure 5**Error! Reference source not found.** shows the total energy related GHG emission distribution by both fuel type and economic sector.

According to the 2010-2012 Energy Balance [11], Antigua and Barbuda's largest source of GHG is the use of fuel oil for electricity generation, which accounts for 38% of all energy related GHG emissions.

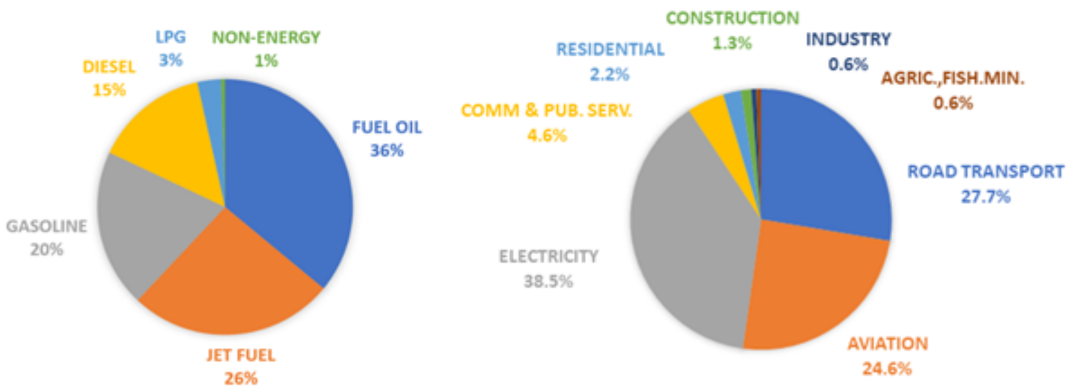


FIGURE 5 - ENERGY SECTOR GHG EMISSIONS DISTRIBUTION BY SOURCE AND BY SECTOR [11].

The electric energy generation matrix is determined by the amount of electricity that is produced by each power source. The higher the carbon intensity of this matrix, larger the GHG emissions per unit of electric energy consumed.

To analyse the impact of the above proposed measures on the carbon intensity of the electric generation and distribution system, two projections are presented. The first considers the improvement of transmission and distribution efficiency of the electric grid, decreasing losses from 28% in 2015 to 15% in 2035. The second adds to this scenario the progressive penetration of 24 MW of PV capacity and 18 MW of wind capacity between 2018 and 2035. It also considers the coming online of an 8 MW waste to energy plant in 2025. Overall, a renewable energy capacity penetration of 50 MW as stated in the country's INDCs.

Figure 6*Error! Reference source not found.* shows the evolution of the electric grid and distribution system GHG intensity factor, under the above projections. As expected, reducing distribution losses by 13% has an equal reduction on the GHG emission intensity factor of the grid. On the other hand, the incorporation of the renewable power capacity intended in the country's INDC, under the estimated future generation requirement (Figure 4**Error! Reference source not found.**), would reduce the carbon intensity of the grid a further 37% by 2035.

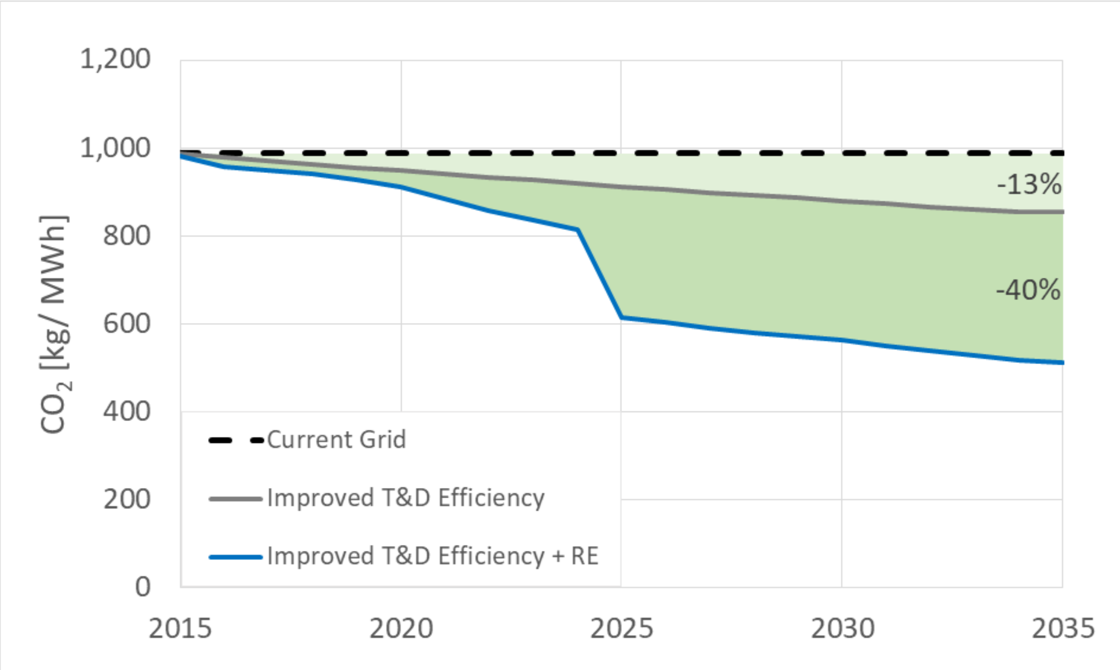


FIGURE 6 - ELECTRIC GRID GHG EMISSIONS FACTOR PROJECTIONS FOR AN IMPROVED TRANSMISSION AND DISTRIBUTION EFFICIENCY SCENARIO AND IMPROVED T&D EFFICIENCY PLUS RENEWABLE ENERGY PENETRATION SCENARIO VERSUS CURRENT GRID EFFICIENCY.

3. ROAD TRANSPORT IN ANTIGUA & BARBUDA

To propose the most cost-effective solution to reduce both the GHG and toxic emissions of A&B transport fleet, it is first crucial to have a proper understanding of its composition, age distribution, working conditions and emission standards, amongst others. The latter have a considerable impact on the emission intensity of a given fleet and vary from one country to another, making the understanding of the local fleet more important as extrapolations from work done in other countries cannot be considered representative.

Throughout the present section the road transport fleet of Antigua and Barbuda will be analysed, characterized and categorized. The average fuel consumption, usage intensity and emission intensity factor of each fleet, will be estimated. Finally, both GHG and air pollution emissions generated by each vehicle category will be assessed based on the methodology described on the flow chart below (Figure 7*Error! Reference source not found.*).

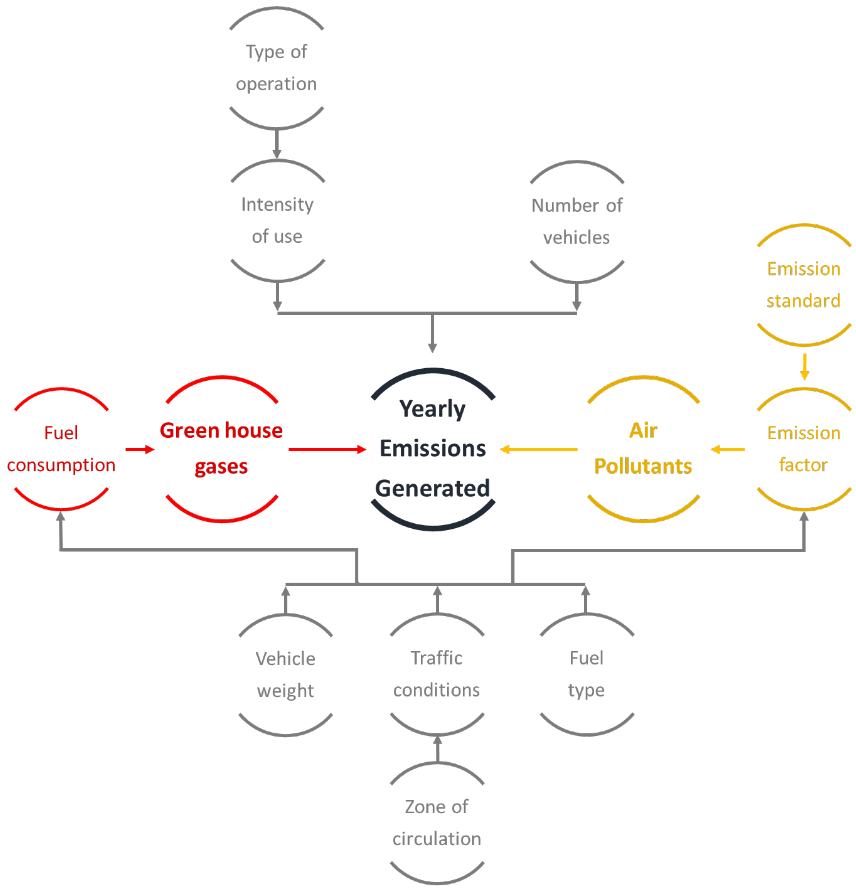


FIGURE 7 - FLOW CHART FOR THE CALCULATION OF EMISSIONS GENERATED BY THE ROAD TRANSPORT SECTOR.

Subsequently, using the historical growth rate of each fleet, a BAU scenario will be projected to the year 2035. This will help understand the future composition and emissions profile of the overall fleet in the coming years and establish a base line over which the impact of different emission reduction measures can be quantified and parametrically compared.

3.1 ANTIGUA & BARBUDA ROAD TRANSPORT FLEET

As mentioned above, the first part of the current analysis requires analysing, characterizing and categorizing the current vehicle fleet. First the fleet composition is established. After this, based on the islands' road infrastructure and urban centres distribution, the different fleets operating conditions and use intensity are estimated. Finally, the average fuel consumption and emission intensity factors are estimated for each individual fleet.

3.1.1 Fleet composition

A given fleet can be categorized based on different vehicle attributes, the most common being; weight segment, fuel type or operating condition. Based on data provided by the Transport Board of Antigua and Barbuda fleet was divided into motorcycles, private vehicles (PV), light duty vehicles (LDV), heavy-duty vehicles (HDV) and buses. Table 2**Error! Reference source not found.** shows the number of vehicles in each of these categories and specifies fuel type, purpose and weight segment of each of them. Moreover, as shown below, the age fleet distribution of each sector (PV, LDV, HDV) is estimated with information provided by the Road Transport Board of A&B. This is then used to calculate the usage intensity of the different vehicles as a function of their age.

Table 2. Road transport sector fleet composition in the year 2015, categorized by type of weight, fuel and operation.

Category	Weight	Fuel Type	Operation	Quantity (% of total)
Motorcycles	Light	Gasoline	Private passenger	570 (1%)
Private vehicles	Light	Mostly gasoline	Private passenger	35,350 (72%)
Light-duty vehicles	Light	Gasoline/Diesel	Products and services	8,800 (18%)
Heavy-duty vehicles	Heavy	Mostly diesel	Products and services	2,330 (5%)
Buses	Heavy	Diesel	Public passenger	1,840 (4%)
			Total fleet	**48,900**

3.1.2 Traffic conditions and vehicle usage intensity

The average fuel consumption of a vehicle, as well as its emissions intensity factors, is highly dependent on the traffic conditions under which the vehicle operates. For example, under saturated traffic conditions the vehicle is constantly starting and stopping. This results in the vehicle engine operating under a highly transient regime where its efficiency is reduced, and its emissions increased. Furthermore, the energy required to get the vehicle moving is subsequently dissipated as heat during braking events. All of this results in high fuel consumption and high toxic emission intensity factors. On the other hand, free-flow traffic allows the vehicle to operate under almost constant load conditions, enabling the powertrain to work more efficiently, thus reducing fuel consumption and emissions. Dynamic forces like drag start to impact negatively on vehicle efficiency as driving speeds increase.

Start & stop traffic conditions are common in certain urban areas, particularly in Saint John's. On the other hand, free flow traffic is representative of highway and rural road driving conditions. Figure 8**Error! Reference source not found.** and Figure 9 show zones with recurrent traffic congestion and urban areas of Antigua, respectively. They also show the main roads and highways connecting the different urban settlements. Since little information was found regarding the typical distances covered daily by drivers operating the different vehicles types, these had to be estimated.

Table 3*Error! Reference source not found.* shows the distance between the main urban centres and Saint John's (National capital and largest city of the island), as well as the population of each town. Using this information, an average weighted distance per journey (AVDJ) can be estimated. The latter is calculated based on the following equation:

$$AVDJ = \frac{\sum_i P_i * D_i}{TP} \qquad (1)$$

where P_i is the population of city ***i***, D_i is the distance from city ***i*** to Saint John's centre and TP is the total population of all towns included in Table 3**Error! Reference source not found.**. The expression above yields an AVDJ of 4.6 km.

TABLE 3. POPULATION OF THE MAJOR CITIES OF ANTIGUA AND THE ROUTE DISTANCES TO SAINT JOHN'S CENTRE.

City	Population	Distance to Saint John's centre [km]
Saint John's	24,000	2.2
All Saints	3,400	12
Piggotts	1,300	3.2
Liberta	2,200	15.4
Bolands	1,800	9
Potter's Village	2,100	6.8

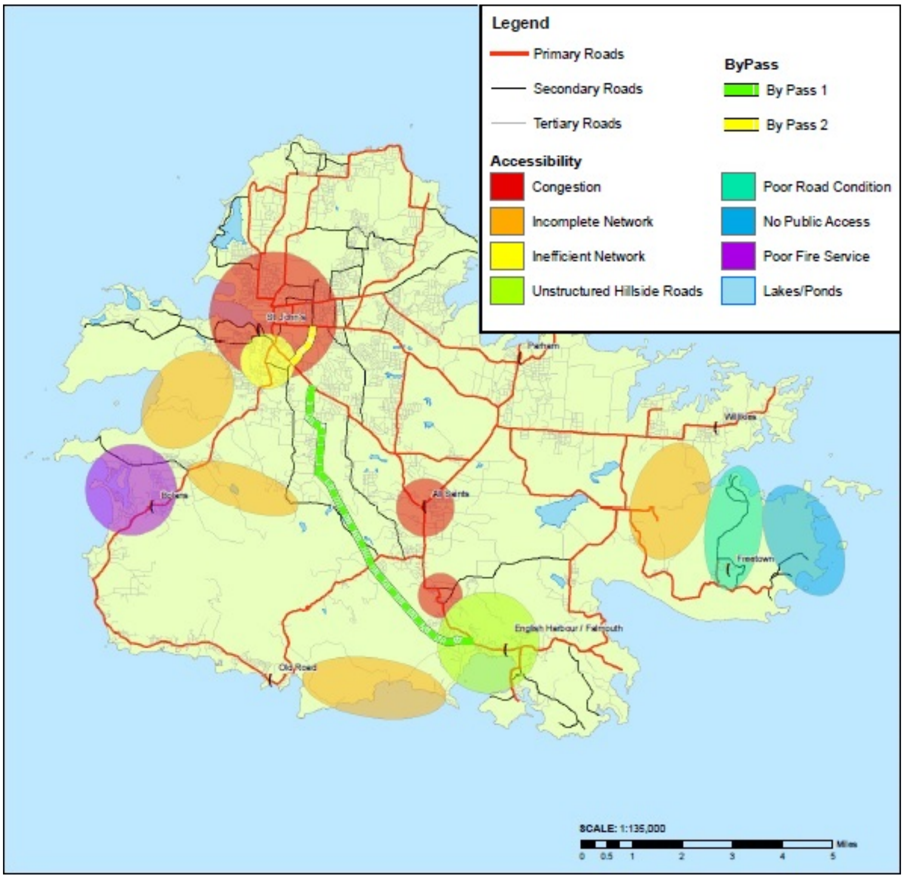


FIGURE 8 - TRANSPORT CONGESTION ZONES OF ANTIGUA. [16]

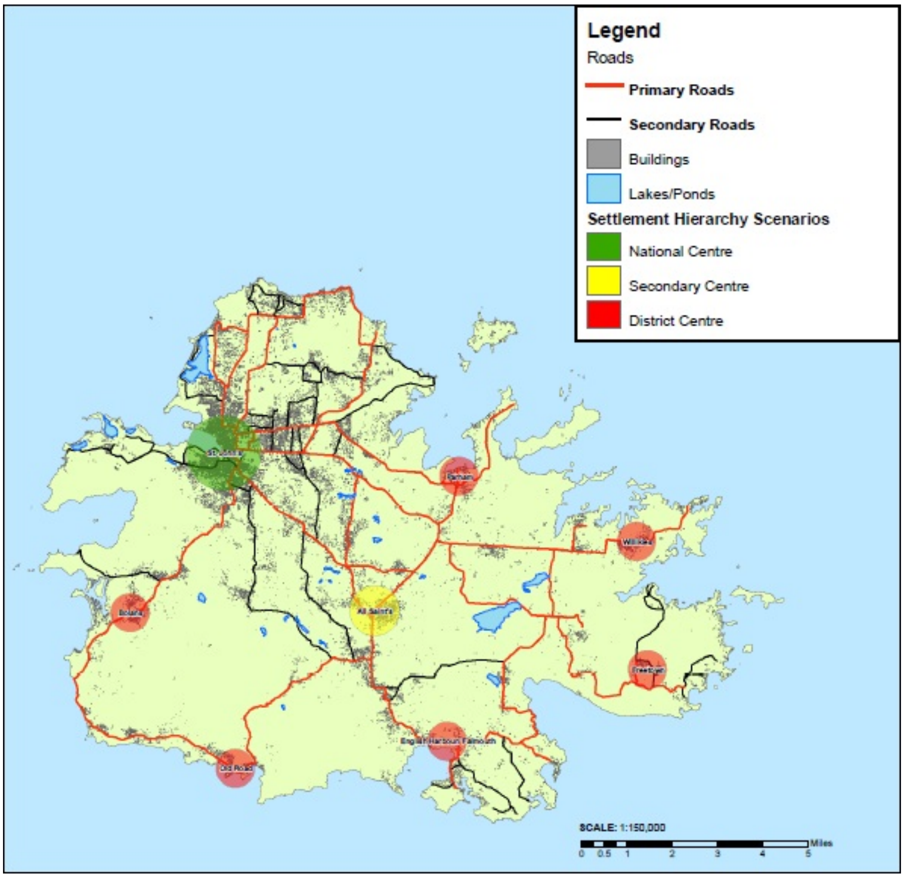


FIGURE 9 - PRIMARY AND SECONDARY URBAN CENTRES OF ANTIGUA [16].

Based on the category of each fleet, an annual distance covered is calculated assuming a given number of journeys per vehicle per day and a usage factor (days used per year). All these are shown in Table 4.

TABLE 4. DAILY DISTANCE TRAVELLED AND DAYS OF USE PER ANNUM FOR EACH VEHICLE CATEGORY OF THE ROAD TRANSPORT SECTOR FLEET OF ANTIGUA AND BARBUDA.

Category	Journeys/day	Days of operation	Yearly distance [km]
Motorcycles	3	300	5,000
Private vehicles	5	300	9,000
Light duty vehicles	15	330	23,000
Heavy duty vehicles	10	330	15,000
Buses	20	330	35,000

It is well known that there is a correlation between vehicle age and vehicle usage. To account for this effect, a usage factor is calculated for light-duty and heavy-duty vehicles (see Figure 10).

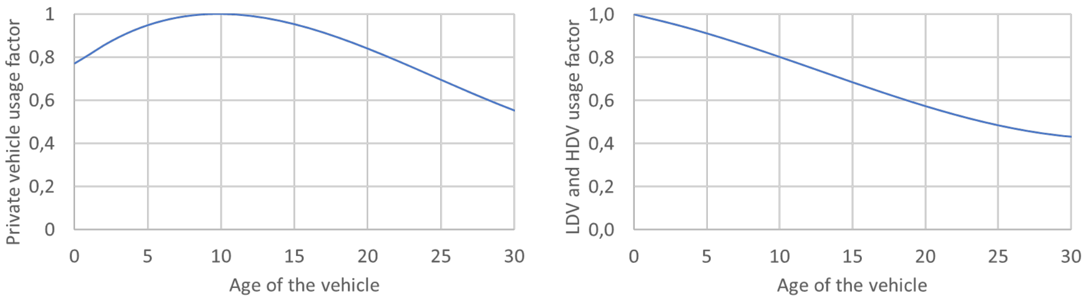


FIGURE 10 - USAGE FACTOR FOR PRIVATE AND LIGHT AND HEAVY DUTY VEHICLES

3.1.3 AGE FLEET DISTRIBUTION

Given the lack of information regarding the age distribution of the different road transport fleets, the latter had to be estimated based the only data available information provided by the Road Transport Board. This detailed the type and age of vehicles imported between 2013 to 2017. Incorporating this information into the ownership model developed in section 3.3.1 an age distribution can be estimated for PC, LCV and HDV. Results are shown on Figure 11. Note that the percentage of the fleet with more than 30 years is high (around 16%) because no scrapping is assumed.

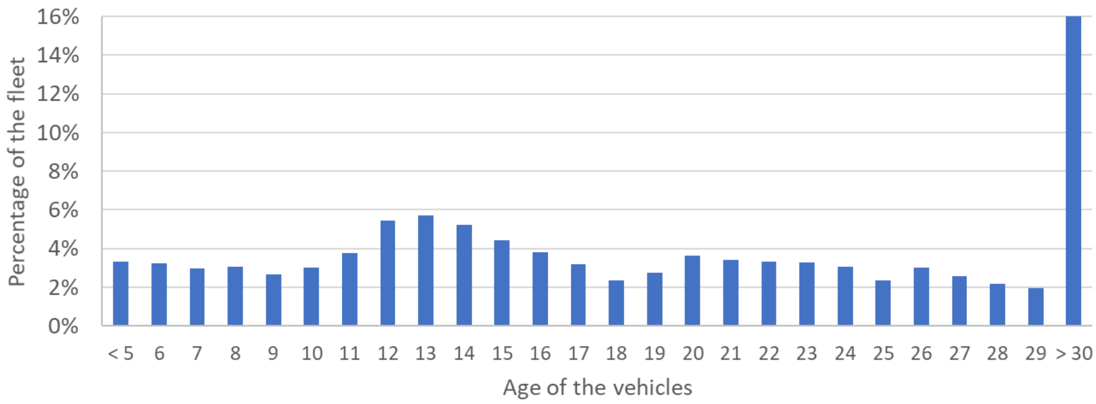


FIGURE 11 - AGE DISTRIBUTION OF PRIVATE VEHICLES, HEAVY AND LIGHT DUTY VEHICLES

The average age of the entire fleet results in approximately 15 years. These results will be used in section 3.3 to estimate the average fuel consumption and emission factors of the different road fleets.

3.1.4 FUEL CONSUMPTION

As mentioned above, vehicle fuel consumption depends on several factors such as vehicle technology and age, mean speed, weight, type of operation and traffic conditions. The Handbook Emission Factors for Road Transport (HBEFA) is an experimentally validated database that can be used to establish the fuel consumption and emission intensity factors of a given fleet, based on all the above [17].

Figure 12 shows the specific vehicle fuel consumption for each fleet detailed on Table 5, as a function of the vehicles driving profile mean speed. Based on the road infrastructure and urban distribution of the isles', as well as the operating characteristics of each vehicle fleet, a mean velocity is estimated for each transport sector. These are indicated as larger circles in **Error! Reference source not found.**. Results are summarized on Table 5*.*

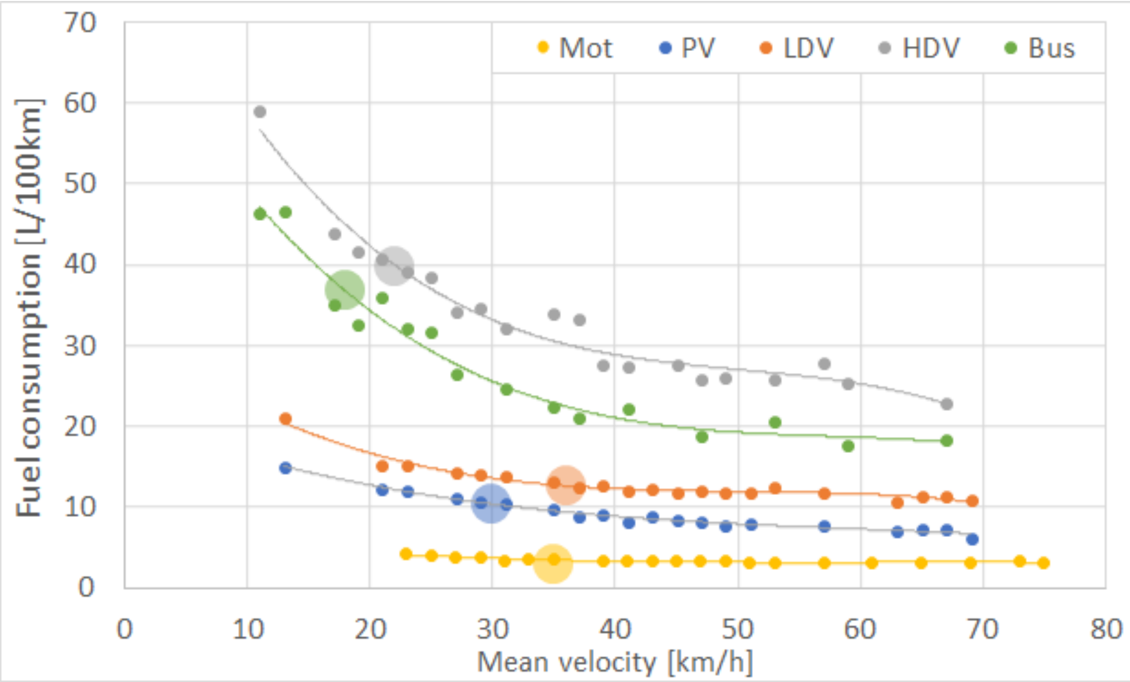


FIGURE 12 - TYPICAL FUEL CONSUMPTION OF DIFFERENT VEHICLE CATEGORIES AS A FUNCTION OF MEAN SPEED/TRAFFIC CONDITION. HIGHLIGHTED AREAS REPRESENT THE AVERAGE OPERATING CONDITION OF THE DIFFERENT FLEETS.

TABLE 5. AVERAGE FUEL CONSUMPTION EXPRESSED IN L/100 KM FOR EACH VEHICLE CATEGORY AND TRAFFIC CONDITION.

Category	Mean velocity [km/h]	Mean Fuel consumption [L/km]
Motorcycles	35	3
Private vehicles	30	10
Light-duty vehicles	36	13
Heavy-duty vehicles	22	40
Buses	18	37

3.1.5 FLEET GHG AND TOXIC EMISSION FACTORS

Direct, or tailpipe, vehicle emissions are broadly divided in two types: those with significant impact on climate change (GHG), such as carbon dioxide (CO_2) and methane (CH_4), and those responsible for deteriorating ambient air quality, such as nitrous oxides (NO_x), particulate matter (PM10 and PM2.5), carbon monoxide (CO), unburned hydrocarbons (HC), and sulphur oxides (SO_x).

Emission intensity factors for each of these pollutants depend on vehicle factors; such as fuel type, weight, age, maintenance, and emission certification, but also on operational factors such as traffic conditions and intensity of use. In the case of conventional internal combustion vehicles, such as gasoline and diesel vehicles, GHG emissions are mostly related to fuel consumption, with some influence of N_2O emissions due to their high GHG potential, and are collectively expressed as quantities of CO_{2e}, or carbon dioxide equivalent. Both GHG and toxic emissions can change drastically from one car to the next.

EURO standards (EURO I to VI) where developed by the European Union and TIER standards (TIER I to III) by the United Stated. These are the most common used standards worldwide and both aim to progressively reduce air pollution produced by the transport sector by setting legal limits for the different species of exhaust toxic emissions that new vehicles can produce over a given driving cycle.

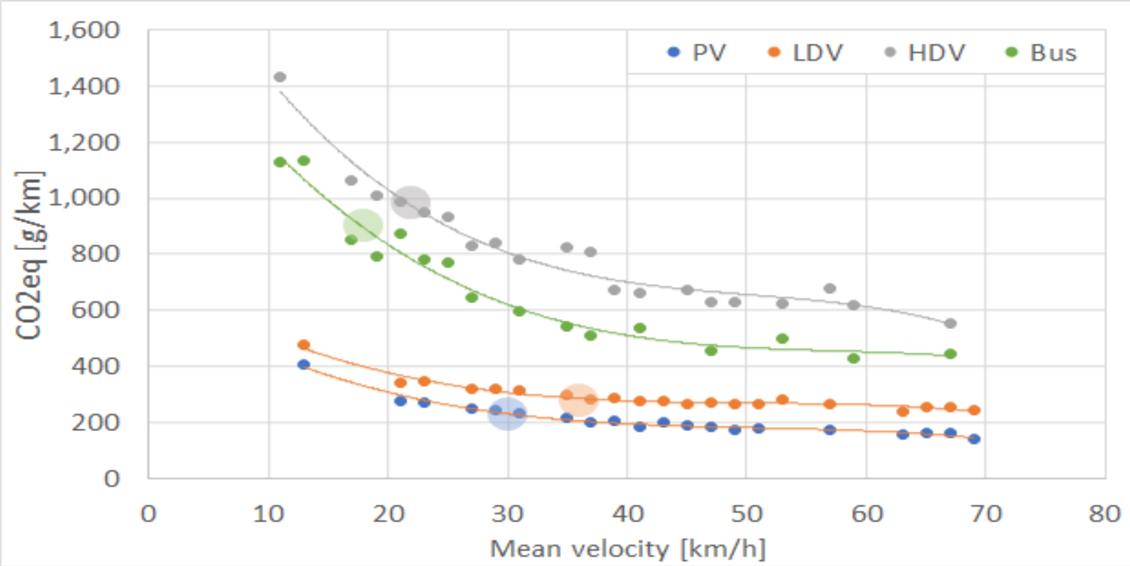
As for fuel consumption estimations, toxic and GHG emission intensity factors of the different vehicle fleets will be calculated using the HBEFA database [17].

Since no information is available regarding typical emission standards of each vehicle category in Antigua and Barbuda, it was assumed that the average emissions standards adopted by the countries of Latin America and the Caribbean [18] are representative of the country's Road Transport Sector (RTS). This, in combination with the age distribution specified in the previous section, yields a fleet of EURO II, Euro III and a small proportion EURO IV vehicles for PC and LDV, and a fleet of mainly Euro 0 to Euro II heavy vehicles.

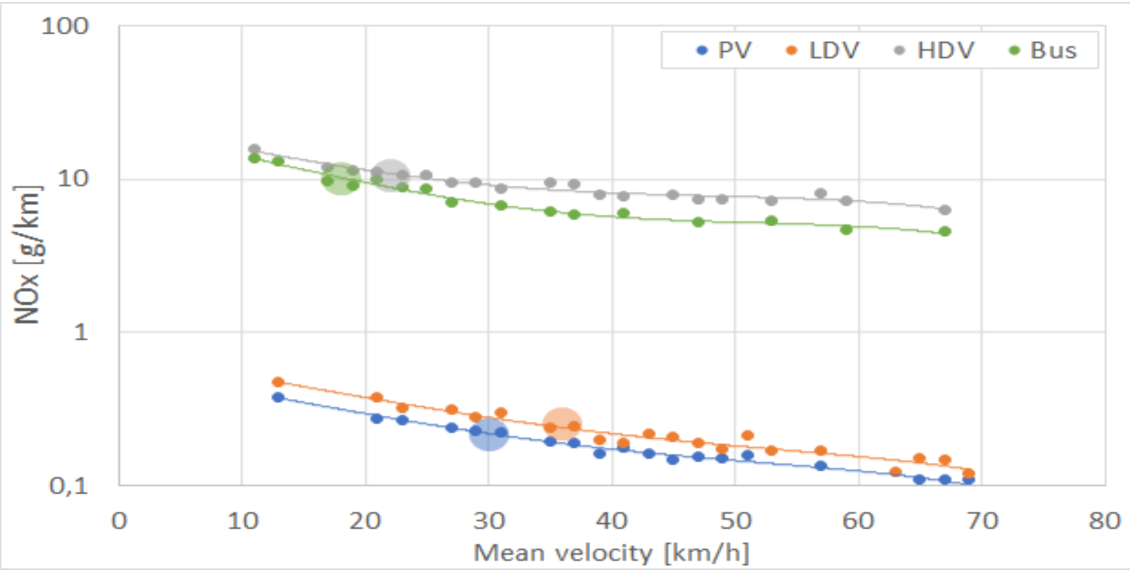
Based on the above, the emission intensity factors for CO_{2eq}, NO_x and PM10 of each vehicle category as a function of vehicle mean velocity are shown on **Error! Reference source not found.**. It is noted that Motorcycles are not included in the analysis as their relatively low quantity and specific emission yield a negligible impact on the overall analysis.

As expected, CO_{2eq} results show a similar tendency to those of fuel consumption and are highly dependent on mean vehicle speed and increase linearly with vehicle weight. In the case of NOx and PM emissions the impact of vehicle fuel type is considerable. Heavy-duty diesel vehicles have 1 and 2 orders of magnitude higher emission factors of NOx and PM, respectively, than private cars.

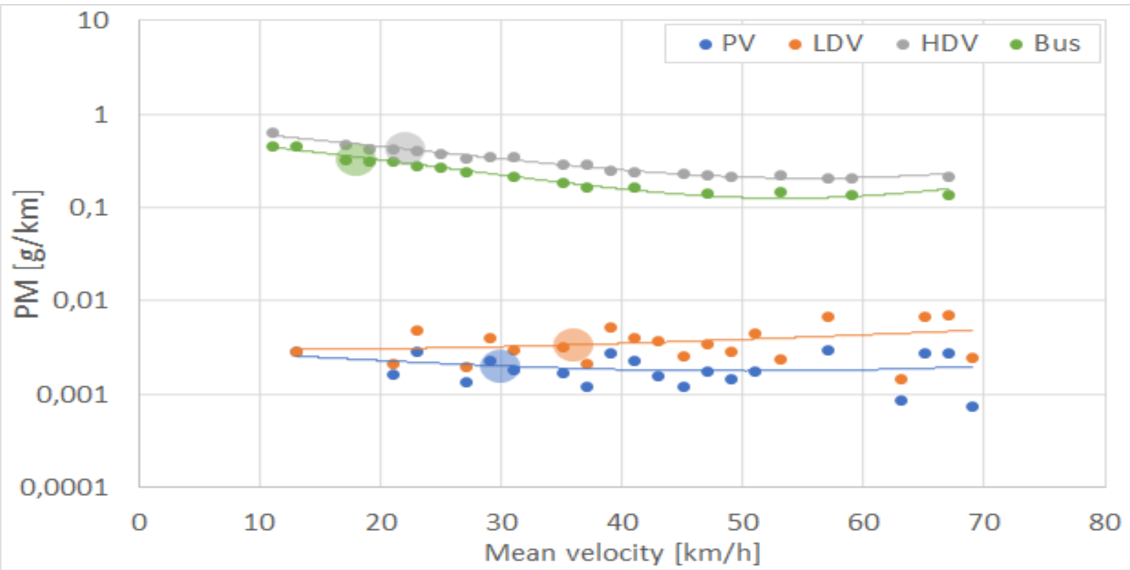
Using the same average mean velocities, as those used to estimate the fuel consumption factors of the different fleets, the different emissions average fleet emission intensity factors can be estimated. These are highlighted in the respective figures and condensed on Table 6*.*



13.a. CO2eq emission factors



13.b. NOx emission factors



13.c. PM emission factors

FIGURE 13 - EMISSION INTENSITY FACTORS OF THE DIFFERENT VEHICLE FLEETS AS A FUNCTION OF MEAN SPEED/TRAFFIC CONDITION

Table 6. Average emission factors of each vehicle category assumed for the Road Transport Sector of Antigua and Barbuda.

Category	CO_{2eq}	NO_x	PM
Private vehicles	220	0.374	0.002
Light-duty vehicles	277	0.284	0.002
Heavy-duty vehicles	977	10.805	0.418
Buses	799	9.235	0.307

3.2 OVERALL FUEL CONSUMPTION AND EMISSIONS GENERATED BY THE ROAD TRANSPORT FLEET

Using the emission intensity factors and specific fuel consumption factors of the different vehicle fleets, estimated in the previous sections, it is possible to evaluate the overall environmental annual impact of each vehicle group as well as that of the entire road transport fleet. The annual fuel consumption and emissions g of each vehicle category i, AFC_i and $AE_{i,g}$ respectively, are calculated according to the following:

$$AFC_i = \sum_j NV_{i,j} * AD_i * UF_{i,j} * FC_i \qquad (2),$$

$$AE_{i,g} = \sum_j NV_{i,j} * AD_i * UF_{i,j} * EFA_{i,g} \qquad (3),$$

where $NV_{i,j}$ is the number of vehicles of category i with age j, *AD* is the average annual distance travelled by a vehicle of category i [km], FC_i *FC* is the average vehicle fuel efficiency [L/100km], *UF* is the vehicle usage factor and *EFA* are the emission intensity factors of the different pollutants [g/km] (GHG, NOx and PM).

Finally, the total fuel consumed ($TAFC$) and emissions (TAE_g) generated by the RTS can be calculated as:

$$TAFC = \sum_i AFC_i \qquad (4),$$

$$TAE_g = \sum_i AE_i \qquad (5).$$

Results are shown in **Error! Reference source not found.**.

Table 7. Fuel consumption and emissions generated by each fleet category of the Road Transport Sector of Antigua and Barbuda in the year 2015.

Category	Fuel consumption [MM gge]	CO_{2eq} [TON]	NO_x [TON]	PM [TON]
Motorcycles	0.1	322 (0%)	0 (0%)	0 (0%)
Private vehicles	32.3	79,964 (47%)	84 (11%)	0.6 (3%)
Light-duty vehicles	18.8	31,847 (19%)	33 (4%)	0.3 (1%)
Heavy-duty vehicles	8.4	19,669 (12%)	218 (29%)	8.4 (36%)
Buses	13.4	37,020 (22%)	428 (56%)	14 (60%)
Total	**73**	**168,822**	**762**	**24**

Results shown onTable 7, regarding the total annual fuel consumption of the fleet and that of the gasoline and diesel fleets independently, are consistent, within less than 5%, to the annual fuel import quantities declared in both the *Antigua & Barbuda Renewable Readiness Assessment report* and the *Antigua & Barbuda Energy Balance report*, [11] [10]. The consistency between results is considered validation of the presented assumptions and overall proposed methodology.

To put results into context, *Error! Reference source not found.* shows the country's percentage distribution of energy related GHG emission [11] [10] and the contribution of the different road transport fleets.

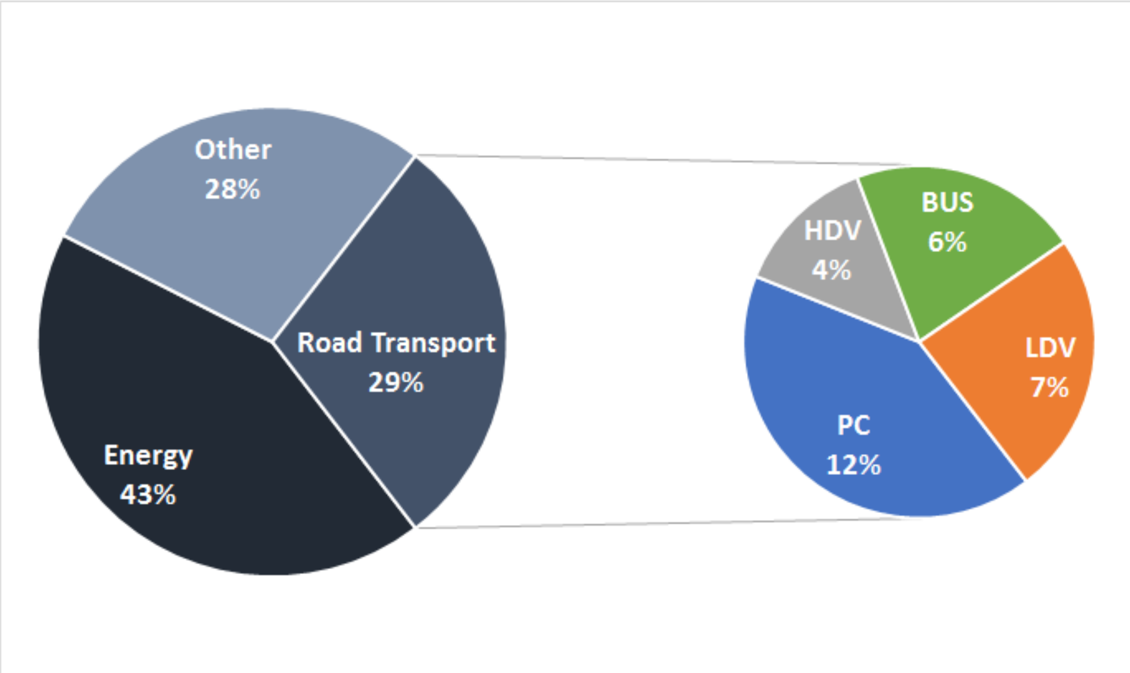


FIGURE 14 - EMISSIONS GENERATED BY THE ENERGY RELATED SECTORS. ROAD TRANSPORT SECTOR IS SEPARATELY CATEGORIZED BY VEHICLE TYPE [LOGIOS].

Private cars and light duty vehicles are responsible 12% and 7% of the country's energy related GHG emissions, respectively. This highlights the importance of reducing the emission intensity of this sector to achieve the country's overall emission reduction goals.

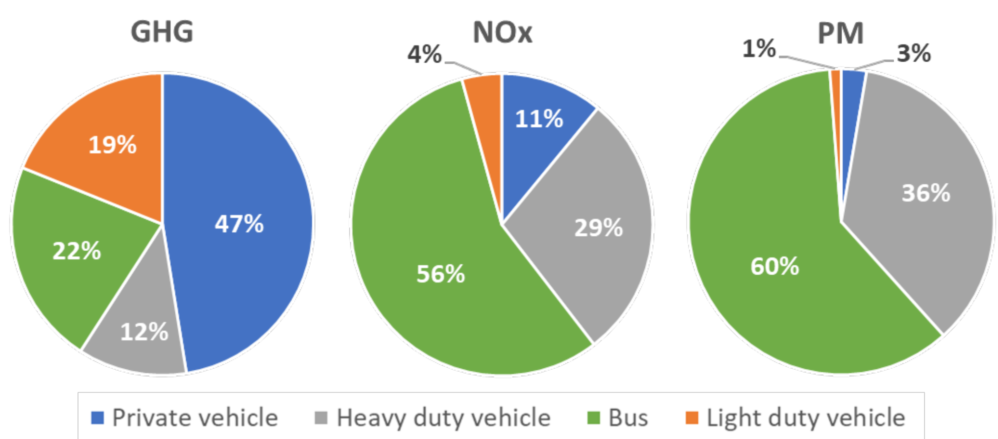


FIGURE 15 - ROAD TRANSPORT SECTOR GHG, NOX AND PM EMISSION DISTRIBUTION BY FLEET TYPE [LOGIOS].

Error! Reference source not found. shows the road transport sector GHG, NOx and PM emission distribution by fleet, results clearly show that while the main aggregate source of GHG emissions are light vehicle fleets, heavy duty vehicles and buses are responsible for 85% and 96% of the fleets NOx and PM emissions, respectively.

In the case of private cars their high contribution towards GHG emissions is mainly due to their large share of the total fleet. These represent 72% of the overall fleet (*Error! Reference source not found.*). In the case of light duty vehicles and buses, these are only 18% and 9% respectively of the overall fleet, however, given to their use profile (they cover longer distances and carry heavier loads) the emission intensity of each vehicle is higher. The same analysis can be posed to explain the higher impact of buses over heavy duty vehicles. Whilst the number of vehicles is almost the same in both fleets, the start & stop operation of buses results in a higher GHG emission intensity factor.

Regarding toxic emissions, the high impact of the heavy vehicle fleets is mainly due to the fact that these run on high sulphur diesel and the emission standards adopted in Antigua and Barbuda are low or not existing. This results in emission intensity factors of more than 30 times those of gasoline vehicles.

Motorcycles do not contribute significantly to GHG generation nor air pollution generation. This is mainly due to the fact that these vehicles are a small percentage of the overall fleet, they are light weight, and have a low operation intensity.

The above analysis shows that, as in most road transport fleets of the world, the emission source of GHG is completely different to that of pollutant agents. Understanding this enables the implementation of specific emission reduction measures and helps comprehend the potential impact of them. To reduce both GHG and toxic emissions the applied measures need to be fleet and emission oriented.

TABLE 8. COMPARISON OF THE GREENHOUSE GASES EMISSIONS FROM THE ROAD TRANSPORT SECTOR OF DIFFERENT COUNTRIES NORMALIZED PER CAPITA [19]

Country	Tonnes per capita of GHG from the RTS
Germany	1.92
United Kingdom	1.77
France	1.83
Belgium	2.11
Antigua and Barbuda	1.91

Finally, to put matters into context, Table 8 shows the GHG emissions per capita of Antigua and Barbuda's RTS and those of Germany, The United Kingdom, France, and Belgium. Results show that with a considerably lower motorization rate, Antigua and Barbuda RTS has comparable GHG emissions to those of highly developed countries. This puts into plain view the inefficiency of the current fleet and its use. However, it also shows that considerable improvements could be achieved by implementing a cost-effective emission reduction program. To do this, throughout the following section a business-as-usual (BAU) scenario is projected as to establish a reference against which the different emission reduction strategies will be compared.

3.3 ROAD TRANSPORT BUSINESS AS USUAL PROJECTION (2015-2035)

This section presents the development of a business as usual (BAU) scenario of fuel consumption and emissions to the year 2035. BAU scenarios are a representation of expected activities, assuming that there are no significant changes from present conditions in terms of people's preferences, the policy landscape, and technology. The analysis presented theretofore is the basis for the development of the BAU scenario, with the addition of a vehicle ownership model, included in section 3.3.1.

The BAU scenario embeds the following assumptions:

1. The same growth rate is assumed for every vehicle fleet segment;
2. No regulations on vehicle emission or fuel economy standard are adopted;
3. The quality and sulphur content of the Imported fuel remains the same as in the present;
4. Imports of used vehicles continues to be allowed as in the present;
5. Driving patterns and their associated energy intensity remains the same.

Before entering the details of the vehicle ownership model used to project the BAU scenario into the future, it is pertinent to point out that recent trends of vehicle fleet growth in Antigua and Barbuda are alarming. From 2010 till 2014 the fleet of private cars, light duty vehicles and heavy-duty vehicles all grew at an astonishing average annual rate of 8%. In 2015, this trend stopped sharply, with fleet growth that year down to only 2.5%. This was most likely due to the impact that Hurricane Danny had on the isle's economy. In the mentioned period vehicle ownership went 0.39 -0.45 cars per person, which is already a very high index when compared to other countries of similar GDP and GNI per capita. There are many factors that could explain these trends. To start with, when considering arrivals from all ports, in 2017 the country received over one million visitors: stayover arrivals (247,320), buoyant cruise (801,787) and yachting industry (19,543). Stayover arrivals alone were three times the country´s population. This means that road infrastructure and vehicle capacity need to be in far excess of that required by locals. Furthermore, the GNI of most visitors, which come from the US and Canada, is likely to be higher than that of the average local population. Making estimations of vehicle ownership based on local GDP (gross domestic product) and GNI (gross national income) misleading.

Another very relevant matter when projecting the growth of a given fleet, are used vehicle market regulations. In most developed countries the vehicle per capita index reaches a saturation point not due to a reduction in the number of new cars sold, but when the entry of new cars and the scraping of used vehicles attain an equilibrium. Most developed countries and some developing countries have regulations in place that require used vehicles to undergo a technical, safety and emission revision for these to be roadworthy. As vehicles get old, passing these revisions becomes more and more expensive, which coupled with the drop of the vehicles value results in its operation becoming uneconomic and therefore the vehicles get scraped or exported to countries with more lenient roadworthy regulations. Antigua and Barbuda is one of the latter. The country has no roadworthy or emission regulations in place and currently imports vehicles of in average 5 years old. This makes vehicle scrapping not common as vehicles will stay on the road as they are mechanically capable to do so.

All the above, in addition to the that fact that relevant reliable information is scares, makes establishing future fleet projections complicated. If historic annual fleet growth rates are maintained into the future, by 2035 Antigua and Barbuda´s vehicle fleet would more than triple. On the other hand, if vehicle ownership models, which consider the country's GDP and GNI amongst others, are applied the fleet growth rate should slow down and reach a more conservative overall growth.

3.3.1 Historical Road Transport Sector fleet growth

Error! Reference source not found. shows the growth of the different road transport fleets in Antigua and Barbuda from 2011 to 2015 [20]. These tendencies show an annual growth rate of 6.5%, 6.8%, 8.7% and 7.6% for PV, LDV, HDV and Bus fleets, respectively (Table 9).

TABLE 9. LINEAL VEHICLE FLEET GROWTH RATES OF THE ROAD TRANSPORT SECTOR OF ANTIGUA AND BARBUDA BY VEHICLE CATEGORY.

Category	Growing Rate
Private vehicle	6.5%
Light duty vehicle	6.8%
Heavy duty vehicle	8.7%
Buses	7.6%

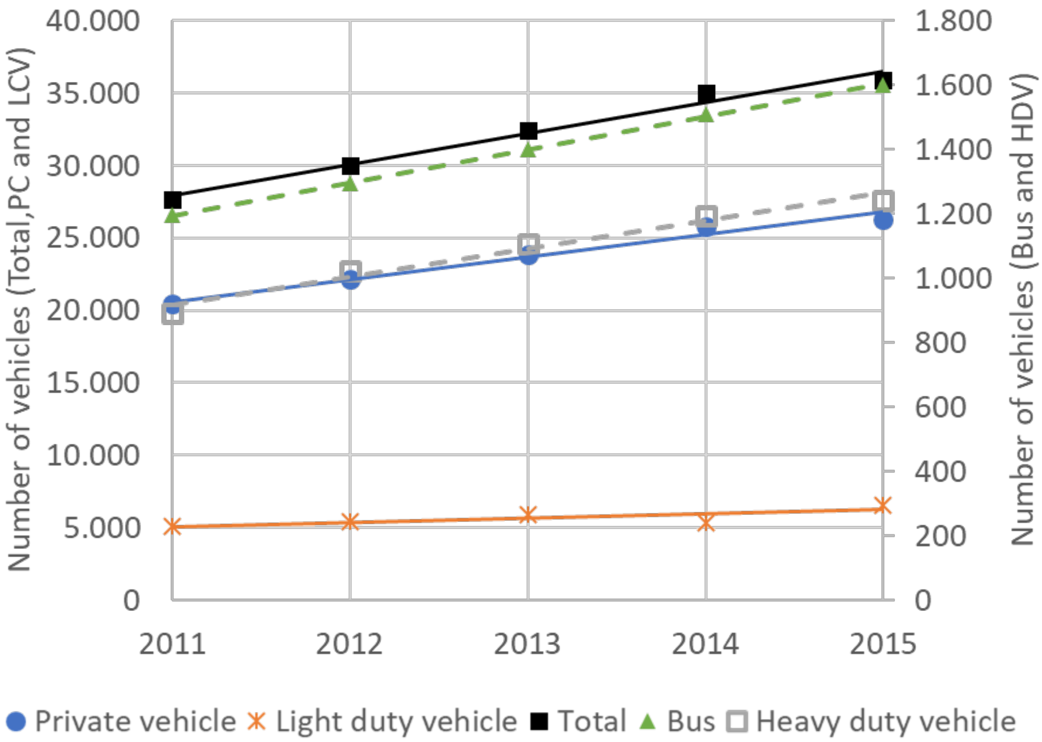


FIGURE 16 - HISTORICAL VEHICLE FLEET GROWTH OF THE ROAD TRANSPORT SECTOR OF ANTIGUA AND BARBUDA CATEGORIZED BY VEHICLE TYPE. CONTINUOUS LINES CORRESPOND TO THE LEFT AXIS, WHILE DASH LINE TO THE RIGHT AXIS

Discrepancies of number of vehicles are found when comparing the information provided in the Terms of Reference and the one reported in [20], even when the source cited for both is the Road Transport Board. The total number of vehicles reported for 2015 differs by more than 10,000 units in these documents representing approximately 35% of the total fleet. For this analysis, we use the number of vehicles provided in the Terms of Reference.

The data available are not sufficient to develop a model of vehicle ownership specific to Antigua and Barbuda. Long-run projections of vehicle ownership are generally made by means of functional relationships of this variable with socio-economic variables such as per-capita income and environmental constraints such as urban density. A widely adopted model is the Gompertz model, which can be specified as follows:

$$V_t = \gamma e^{\alpha e^{\beta GDP_t}}$$

In this expression, γ is the long-term number of vehicles per 1,000 people, also known as the saturation level. GDP_t is the per-capita income at a point in time *t*, which is typically measured using the gross domestic product adjusted for purchase power parity (PPP). The other two parameters, α and β define the shape of the curve. All the parameters are estimated econometrically.

While many studies have assumed the parameter γ to be constant across countries, more recent work has modeled it as a function of environmental factors, such as urbanization and population density. Another improvement over the basic model has been to recognize that it takes time for vehicle ownership to follow changes in income. When all this is incorporated, the model specification can be written as follows:

$$V_{it} = \left(\gamma_{ref} + \lambda d_{it} + \kappa u_{it}\right)\theta e^{\alpha e^{\beta_i GDP_{ti}}} + (1-\theta)V_{it-1} + \varepsilon$$

The various parameters and variables in the above are defined as follows:

γ_{ref}: a value of γ taken as a reference, in general the value for the United States, given the high dependency on the automobile observed in that country;

d_{it}: the population density of country *i* in year *t*;

u_{it}: the urbanization of country *i* in year *t*;

θ: a parameter used to adjust the reactiveness of vehicle ownership to changes in income;

ε: the error term.

The parameters λ, κ, θ, α, and β are estimated econometrically. For the purposes of estimation, the first four parameters in this list can be constrained to be the same for all countries, while β can be considered to vary across countries (as suggested by the *i* subscript in the expression above). A more detailed discussion of this analysis framework can be found, for example in [21] and [22].

The variables in the model, we use data from the World Bank specific to Antigua and Barbuda, and for the parameters, we draw values from the literature. While typically studies use per-capita GDP as a measure of income, the use of per-capita GDP for the estimation of vehicle ownership in some cases may lead to distortions when compared to empirical data. In the case of Antigua and Barbuda, using per-capita GDP leads to values of vehicle ownership well above what can be observed in the limited data that are available (see **Error! Reference source not found.**). Antigua and Barbuda is an example of a country where gross domestic product has been significantly different than gross national income (GNI), as shown in **Error! Reference source not found.**. This suggests that GNI may be a better index of income, and indeed the use of GNI in our model renders values of vehicle ownership for 2015 closer to data points available for that year.

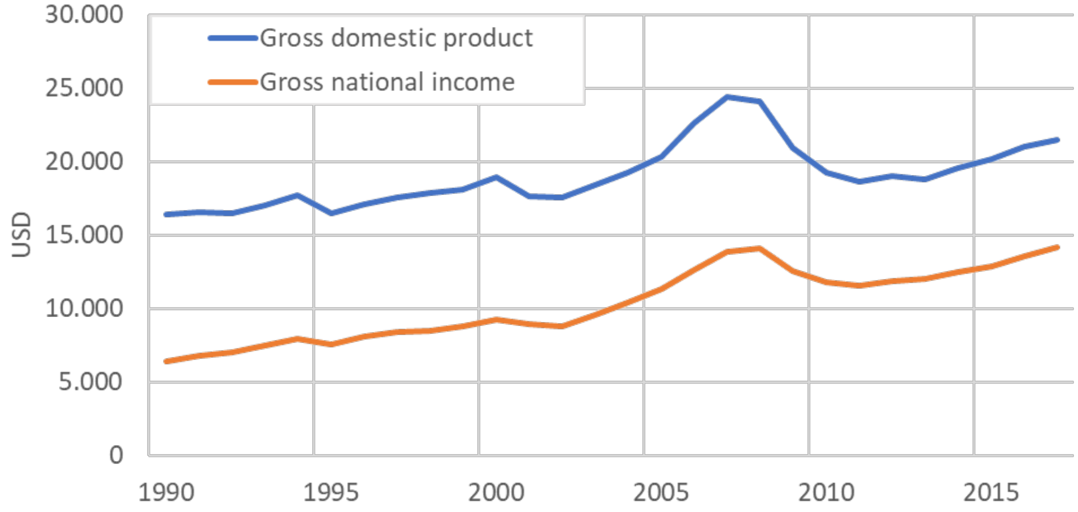


FIGURE 17 - GROSS DOMESTIC PRODUCT AND GROSS NATIONAL INCOME IN ANTIGUA AND BARBUDA, 1990-2017 (WORLD BANK)

We have moved from the basic Gompertz model in which per-capita income is the only explanatory variable, to a more sophisticated model. In the original Gompertz model, the long-run saturation value (γ) is assumed constant for all countries. It is, instead, logical to expect for this saturation to depend on local factors, and in fact the empirical evidence shows that the saturation level differs significantly across countries. We include in our model reference value of γ, measured as the saturation level for the United States, and apply to it a functional adjustment of γ that depends on population density and urbanization, measured as normalized values of people per square kilometer and percentage of the population living in urban areas, respectively.

This model yields the projection of vehicle ownership shown in **Error! Reference source not found.**, from which we obtain the projection of fleet size shown in **Error! Reference source not found.**. Our projection estimates the number of vehicles in Antigua and Barbuda by the year 2035 at about 80,000; essentially doubling the size of the current fleet.

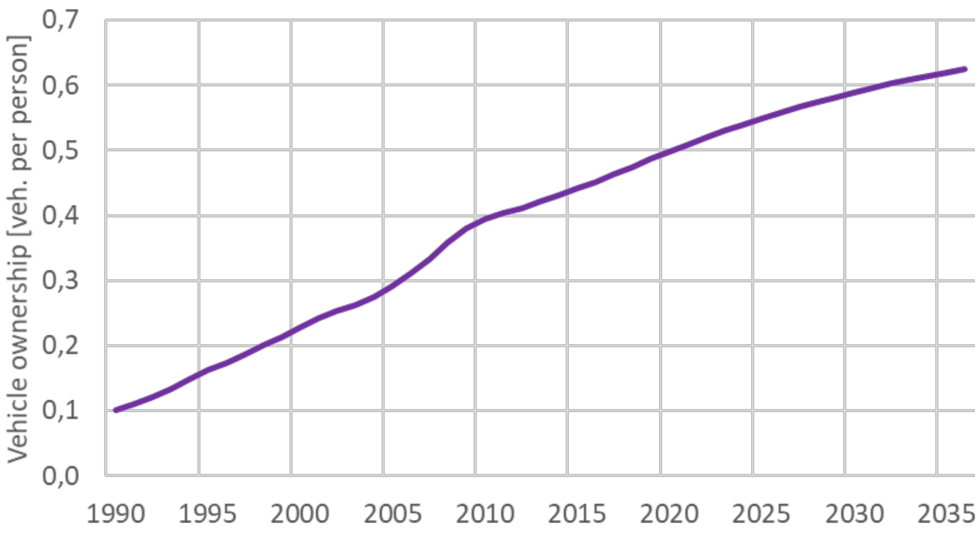


FIGURE 18 - ESTIMATION OF VEHICLE OWNERSHIP IN ANTIGUA AND BARBUDA, UNTIL THE YEAR 2035

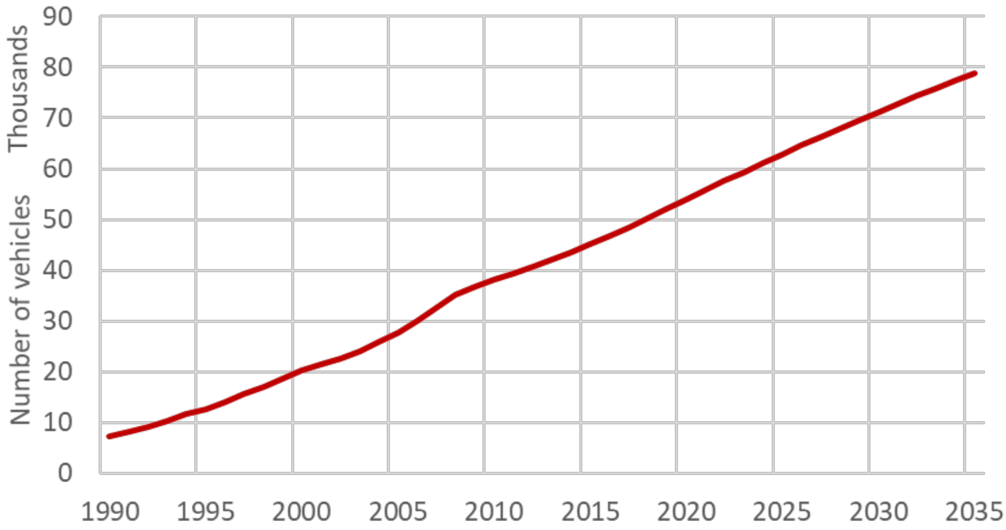


FIGURE 19 - PROJECTION OF NUMBER OF VEHICLES IN ANTIGUA AND BARBUDA UNTIL THE YEAR 2035

Also important to the estimation of emissions, is an estimation of the *composition* of the fleet over time. The limited data available suggests that the fleets of heavy duty vehicles and buses are growing at a slightly faster pace than the fleets of private and light duty vehicles. However, there is no sufficient information to make inferences about any differences in growth rates over the next two decades. Thus, for the purpose of this study, we assume that the relative ratios of the different fleets remain unaltered.

Such expansion in the population of vehicles, particularly in the context of an island, immediately opens questions with regards to the potential impact on traffic flow in the road system, and the related potential implications on fuel consumption and emissions. These potential effects are not explicitly considered for the present analysis, but we briefly describe the impact that increases in vehicle ownership could have in average driving speeds.

A model for road speed, proposed by Greenberg [23], that has yielded results correlated with field data, has the following form:

$$u = u_m \ln\left(k/k_j\right)$$

In this relation, u_m is a constant defined as the speed of maximum flow, k is the density of vehicles expressed as number of vehicles per mile of road, and k_j is the density of jam. This model does not hold for very small vehicle concentrations as the ratio in the logarithm increases rapidly.

The difference in speed between successive points in time (e.g. year to year) can be directly obtained as

$$\Delta u = u_t - u_{t-1} = u_m \ln(k_t/k_{t-1})$$

Given that more specific data is not available, we use the ratio of successive vehicle populations as a proxy for the ratio of successive values of vehicle density, under scenario that includes no significant additional road capacity. The resulting projected change in average driving speeds over time, taking $u_m = 25 \text{ mph} = 40 \text{ kph}$, is shown in **Error! Reference source not found.**.

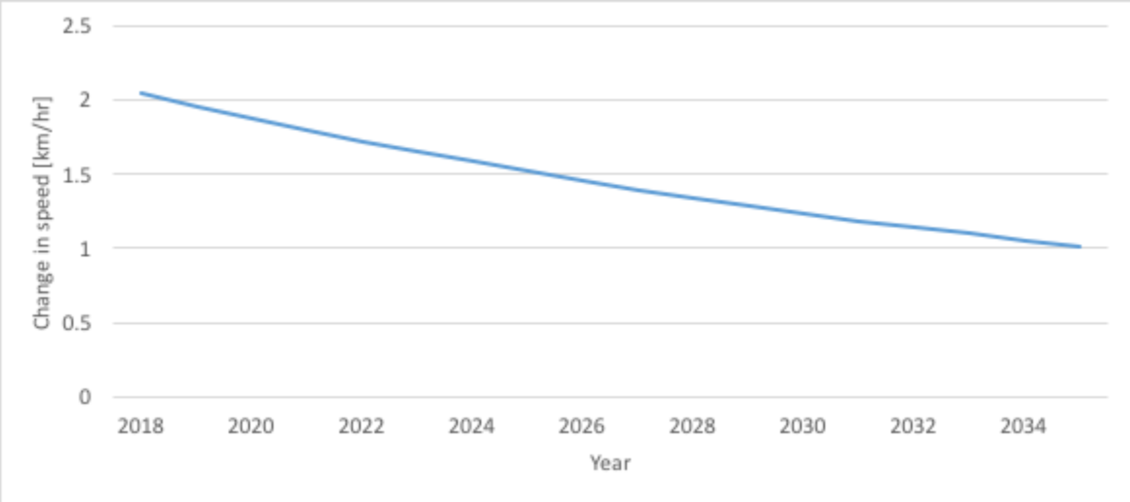


FIGURE 20 - PROJECTED CHANGE IN AVERAGE DRIVING SPEEDS IN ANTIGUA AND BARBUDA RESULTING FROM INCREASES IN VEHICLE DENSITY, UNTIL 2035

Consistent with the logarithm form of Greenberg's model, **Error! Reference source not found.** shows successively smaller decreases in mean driving speeds. However, over the next two decades, it projects cumulative decreases of about 22 kph. Thus, doubling the vehicle population (**Error! Reference source not found.**) could have dramatic impacts on traffic conditions in the islands, unless road capacity is correspondingly expanded and/or travel demand management measures are implemented. Of relevance to this study, significant decreases in average driving speeds will result in corresponding increases in fuel consumption (**Error! Reference source not found.**) and emissions (**Error! Reference source not found.**).

3.3.2 FUTURE FLEET FUEL CONSUMPTION UNDER BAU CONDITIONS

Based on the current fleet composition and its fuel consumption and the vehicle growth projection discussed in the previous section the BAU future fleet is projected to 2035. The latter is presented on **Error! Reference source not found.** and Figure 22 respectively.

Results show that the size of the automotive fleet of Antigua and Barbuda will double by the year 2035, putting considerable pressure on the isle's road infrastructure, energy imports and environmental wellbeing. This puts even further emphasis on the needs of the country to enable a road transport emission mitigation plan, which should focus primarily on the implications of the growth rate of the fleet, whilst improving mobility across the country and reducing the environmental impact of the transport system.

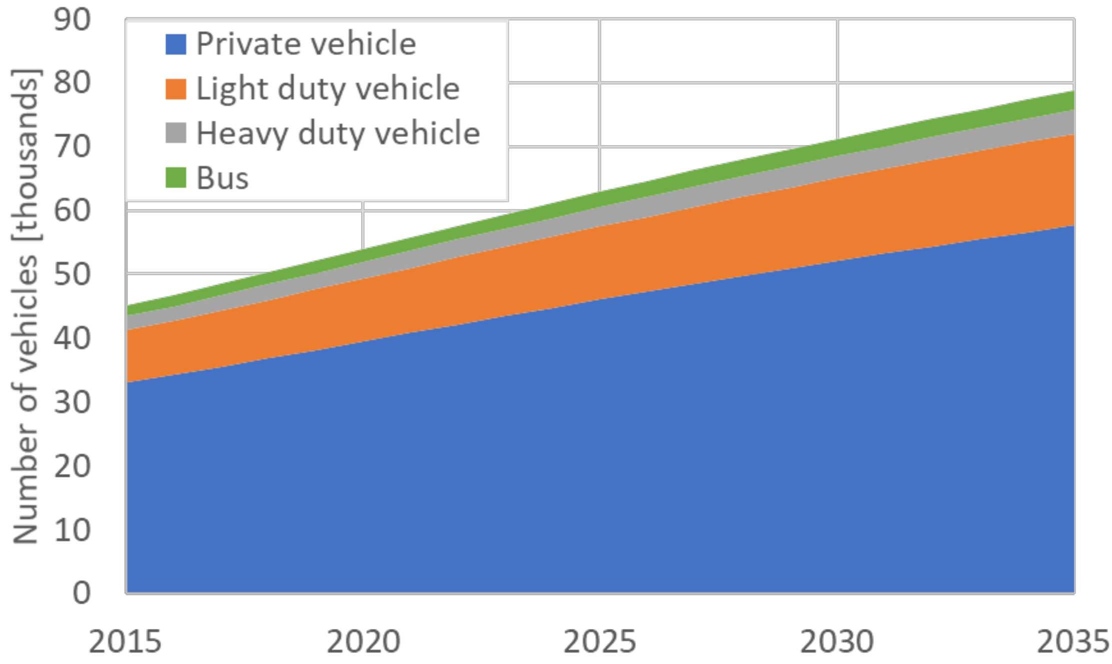


FIGURE 21 - ROAD TRANSPORT FLEET PROJECTIONS TO THE YEAR 2035

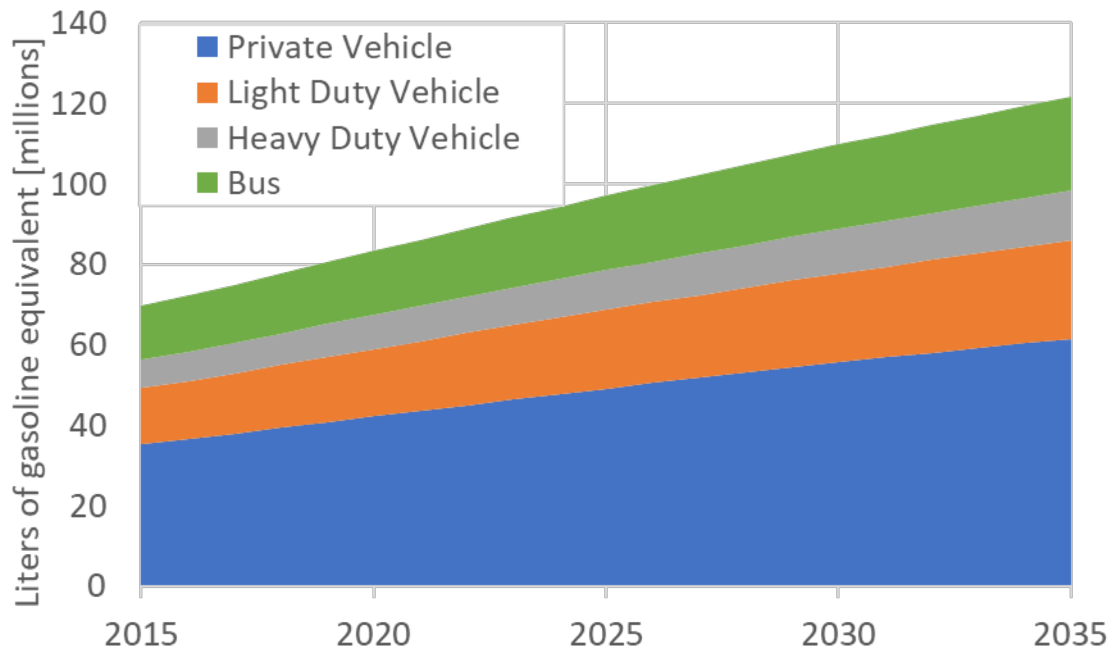


FIGURE 22 - FUEL CONSUMPTION PROJECTION TO THE YEAR 2035

3.3.3 GHG AND TOXIC EMISSIONS BAU FUTURE SCENARIO

*Error! Reference source not found.*Figure 24 andFigure 25 show the BAU projections of both GHG and toxic emissions of the fleet to 2035. As mentioned previously, GHG emissions are directly related to fuel consumption, hence the similarity between tendencies depicted in **Error! Reference source not found.** and **Error! Reference source not found.**. As expected, under BAU conditions, the automotive fleet GHG emissions will more than triple by 2035.

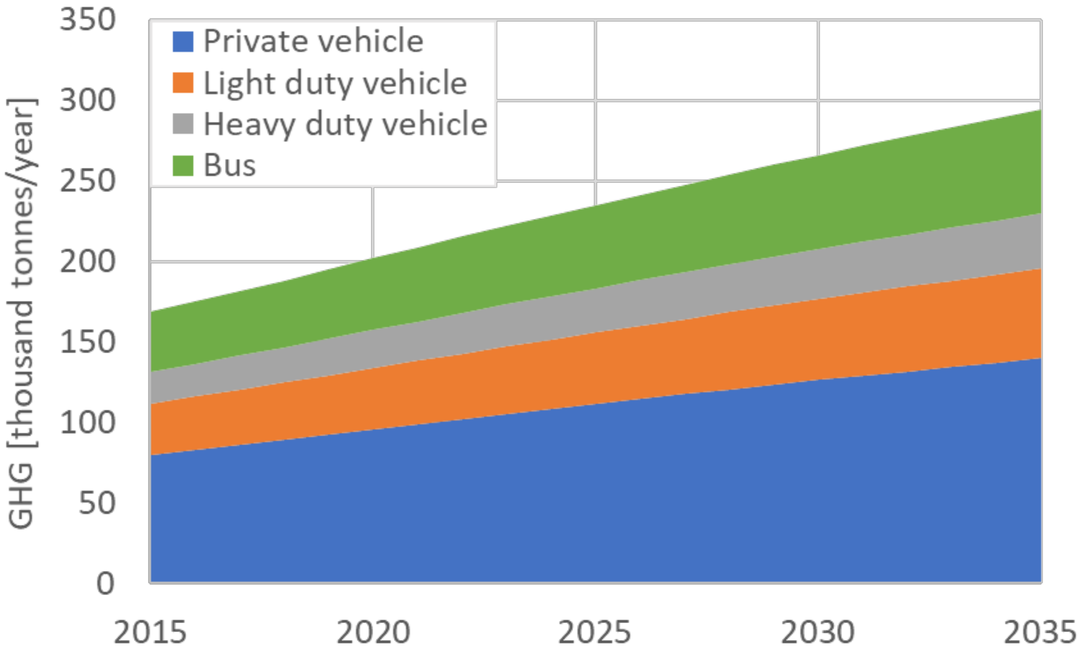


FIGURE 23 - PROJECTIONS OF GREENHOUSE GASES FROM TRANSPORTATION TO THE YEAR 2035

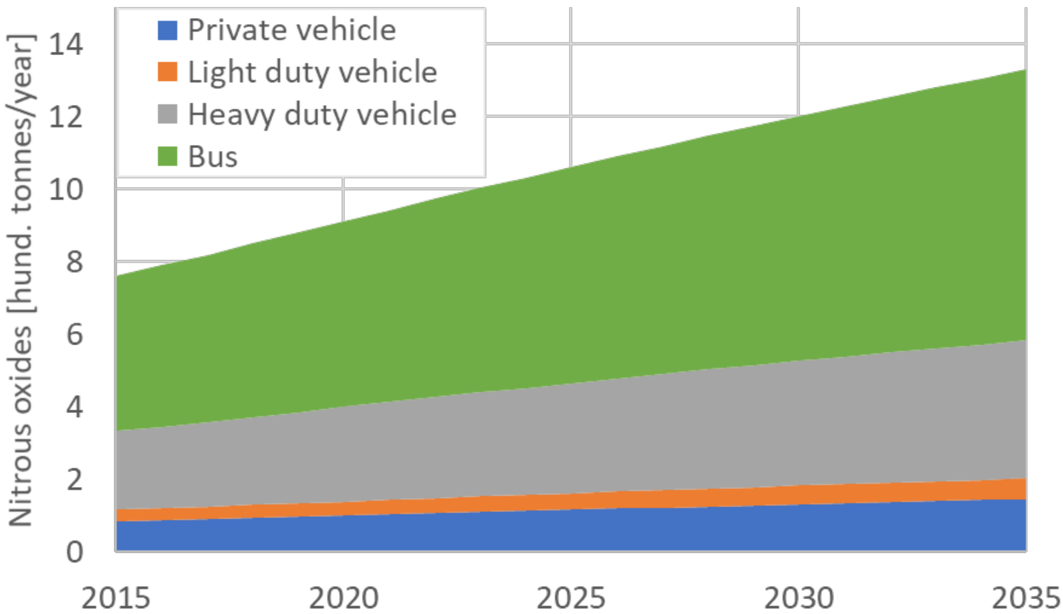


FIGURE 24 - PROJECTIONS OF NITROUS-OXIDES FROM TRANSPORTATION TO THE YEAR 2035

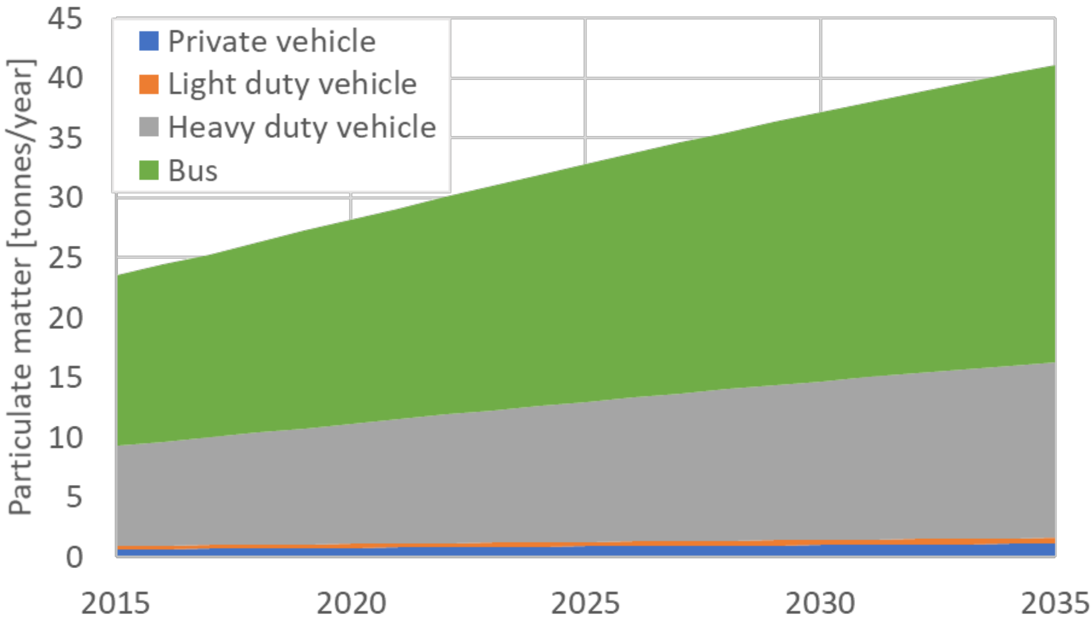


FIGURE 25 - PROJECTIONS OF PARTICULATE MATTER FROM TRANSPORTATION TO THE YEAR 2035

On the other hand, both NOx and PM emissions are strictly related to the growth of the heavy-duty vehicle fleet. This, in addition to the high sulphur content of the fuel currently used in the Isles, the high average age of the fleet, and the inexistence of emission standards, results in an overshoot of future toxic emission, taking the latter to 2 times that of current values.

Table 10 shows a comparison between the current fleet and that expected in year 2035 if BAU conditions are maintained.

TABLE 10. CONTRAST OF THE SIZE, FUEL CONSUMED, AND EMISSIONS GENERATED BY THE RTS FOR THE YEARS 2015 AND 2035 ASSUMING A BUSINESS AS USUAL SCENARIO.

Year	Number of vehicles	Yearly fuel consumed[3]	GHG [Tonnes]	NOx [Tonnes]	PM [Tonnes]
2015	46,000	14.8	145,000	658	20
2035	82,000	26.0	252,000	1150	36
Increase	80%	80%	80%	75%	75%

3.4 CURRENT AND FUTURE ROAD TRANSPORT SECTOR DIAGNOSIS

Based on the above analysis the following conclusions can be reached:

- The current RTS is responsible for almost 30% of the country's GHG emissions. These are strongly related to the use of private cars and LDV.
- Regarding the emission of air pollutants, the use of old buses and old trucks, in addition to the lack of emissions standards and the use of high sulphur content fuels results in high

[3] Value expressed in millions of Gallons Gasoline Equivalent

emission intensities of toxic agents such as PM and NOx. These are highly responsible for the deterioration of air quality in urban areas.

- Based on past trends, the size of the latter is expected to grow considerably in the near future, intensifying all the above.
- Fuel imports required to sustain this growth will put further strain on the countries commercial balance.
- Regarding air pollution, although air quality and its impact on the population's health is generally determined based on the concentration of pollutants at a given point of interest, the growth of toxic emission produced by the RTS will certainly deteriorate air quality in the country [24].

Results suggest that the current path is environmentally and economically unsustainable and is poised to considerably deteriorate the quality of life of residents and visitors.

Based on the above, most developed countries of the world have enforced ambitious goals and measures to reduce both GHG and air pollutant emissions from the transport sector [1]. The enormous challenge of most developing countries is to enable policies and measures that allow them to learn from experiences in other countries, build upon these experiences, and leapfrog into the future and avoid the problems encountered by developed countries in the recent past.

Throughout the following section different emission mitigation measures will be evaluated by establishing their impact on the presented BAU projections. These include:

a. Support the market penetration of electric vehicles,
b. The enforcement of stringent emission standards on the future vehicle fleet,
c. Enabling car-sharing programs and promoting public transport and
d. Banning the import of high sulphur fuels for the road transport applications,
e. Establishing an energy efficiency standard on future vehicle imports,

4. TRANSPORT EMISSION MITIGATION MEASURES

In view of the analysis above, it's clear that there is no one measure that can solve all of Antigua and Barbuda's road transport sector future challenges. Throughout the current section several emission reduction measures will be described, and their impact discussed and analysed. The effectiveness of these will be established by comparing their impact on the BAU projections discussed in the previous section.

The objective of the analysis is to identify measures that will help the authorities put forward an integral cost-effective transport program that enables the country to leapfrog forward towards a more inclusive, efficient and environmentally friendly road transport system and by doing so, meet its Intended National Determined Contributions and improve the quality of living of its citizens. Measures analysed include:

- Promoting the market penetration of electric vehicles (EV);
- Establishing an energy efficiency standard on future vehicle imports (EE);
- Promoting and enabling car sharing programs (CS);
- Promoting public transport; (PT)
- Enforcement of stringent emission standards on the future vehicle fleet (EVI);

- Banning the import of high sulphur fuels for the road transport applications (ULSD);

4.1 PROMOTING THE PENETRATION OF ELECTRIC VEHICLES

As a result of developments in electric drive and battery technologies, the last 10 years have seen growing interest in plug-in electric vehicles as a tool to reduce oil imports and the environmental impact of road transport.

Plug-in electric vehicles (PEV), or simply electric vehicles (EV), have several advantages over conventional vehicles. Among these, they have no tailpipe emissions, they are considerably more energy efficient, and, if not charged with carbon-intensive electricity, their use can result in an overall GHG emission reduction. This will precisely be the challenge in the case of Antigua and Barbuda given that, as shown on Section 2, the country's current electricity grid is almost entirely powered with fuel oil.

On the other hand, factors like upfront battery costs, the need of recharging infrastructure, reduced mileage and the lack of battery end-of-life disposal solutions still need to be addressed for the technology to gain traction in the mainstream market.

However, in applications of high intensity use, such as: taxis, light duty vehicles, garbage trucks and public buses, the lower energy consumption and reduced maintenance costs of electric vehicles could result in a lower total cost of ownership than that of a conventional vehicle. Additionally, performance limitations such as autonomy and battery recharging times, which are crucial in the case of private cars, can be mitigated, given that the operation of commercial systems is more predictable and therefore, risks and limitations can be mitigated with appropriate planning.

Throughout this section the environmental impact of introducing electric vehicles into the different transport fleets will be analysed.

4.1.1 ELECTRIC VEHICLE MARKET PENETRATION SCENARIOS

A sensitivity analysis in undertaken to understand the incremental impact, on the emissions of the different road transport fleets, achieved with the market penetration of electric vehicles. This is done by adopting three scenarios of EV new-vehicle market share by the year 2035, namely pessimistic, moderate and optimistic, under BAU vehicle sales (Table 11).

The proposed scenarios are based on measures adopted by developed countries and cities. For example, the proposed optimistic scenario of achieving an EV market share of 30% over all vehicle imports by 2035, is based on electrification targets proposed by some European cities. London for example has set optimistic targets of 60% [25]. Given the technological redlines of Antigua and Barbuda, a target of such magnitude is considered unrealistic and therefore the optimistic target was set at 50% of that of European cities.

It is noted the current analysis will only contemplate, private cars, light duty vehicles and buses. Although heavy duty vehicles account for 12% of the GHG emissions and almost one third of toxic emissions generated by the RTS, the use of electric heavy-duty vehicles is currently confined to very specific applications, such as refuse trucks, which represent a negligible portion of the segment.

TABLE 11. EV PENETRATION SCENARIOS AS A PERCENTAGE OF MARKET SHARE OF NEW VEHICLES IN 2035

Scenario I Pessimistic	Scenario II Moderate	Scenario III Optimistic
5%	15%	30%

Error! Reference source not found. shows the penetration of electric vehicles into the different transport fleets under the different proposed scenarios. It should be noted that the percentages in **Error! Reference source not found.** represent shares of the entire fleet as electric vehicles penetrate the market, which are different from the percentages in Table 11, which represent shares of the number of vehicles that enter the market each year.

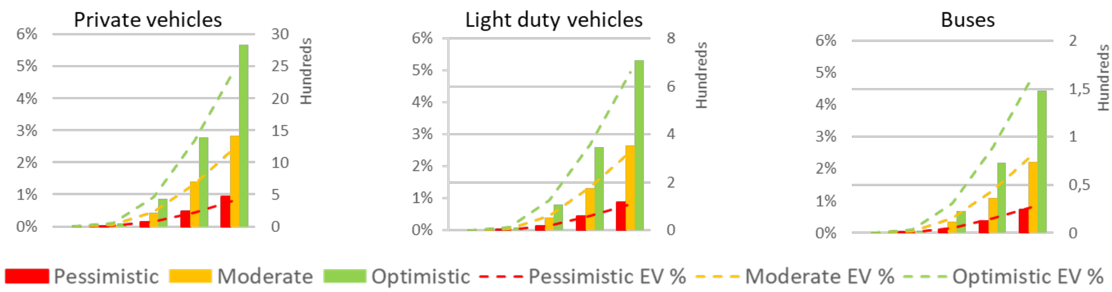


FIGURE 26 - PENETRATION OF ELECTRIC VEHICLES INTO THE DIFFERENT TRANSPORT FLEETS UNDER THE DIFFERENT PENETRATION SCENARIOS.

4.1.2 INCREASED POWER DEMAND ON THE ELECTRIC GRID

To assess the true GHG emission mitigation potential related to the incorporation of electric vehicles into a given fleet, it is crucial to have an estimation of the electric grid carbon intensity. Furthermore, the deployment of large numbers of electric vehicles could present technical challenges and opportunities for the grid regarding: harmonics, system losses, voltage drop and increase of peak power demand among others [26].

Several studies have undertaken this evaluation. First, the additional hourly power consumption induced by a given number of electric vehicles is quantified under different charging scenarios, traffic conditions and tariff systems [27] [28] [29] [30]. These are then overlapped with the statistic grid consumption profile to evaluate the systems capability to supply the additional electricity.

Throughout the current work, the analysis will be limited to evaluating the power generation capacity of the system under the three EV penetration proposed scenarios. The evaluation of the distribution system, frequency control, system reliability, system losses, and other technical and operational aspects of the grid, fall beyond the scope of this work.

To estimate the potential additional power requirements of the system, the following assumptions are made:

- Taking a conservative approach, all vehicles are fully charged during the night when electricity demand is at its minimum (between 1:00 AM and 7:00 AM [11], to date the minimum base load demand is of 30 MW [14];[4]
- No further charging events are required during the day;
- Charging power capacity is discriminated based on fleet category (
- Table 12).

TABLE 12. CHARGING POWER REQUIREMENTS BY RTS SEGMENTS

Private cars	Light duty vehicles	Buses
7 kW	10 kW	55 kW

Based on the above, the power demand required by the electric fleet can be calculated as:

$$PD_i = \sum_k CP_k * Vs_k * CF \qquad (6)$$

WHERE CP_k AND V_k CORRESPOND TO THE CHARGING POWER (

Table 12) and number of vehicles (**Error! Reference source not found.**) of type k and CF is the coincidence factor of the charging events.

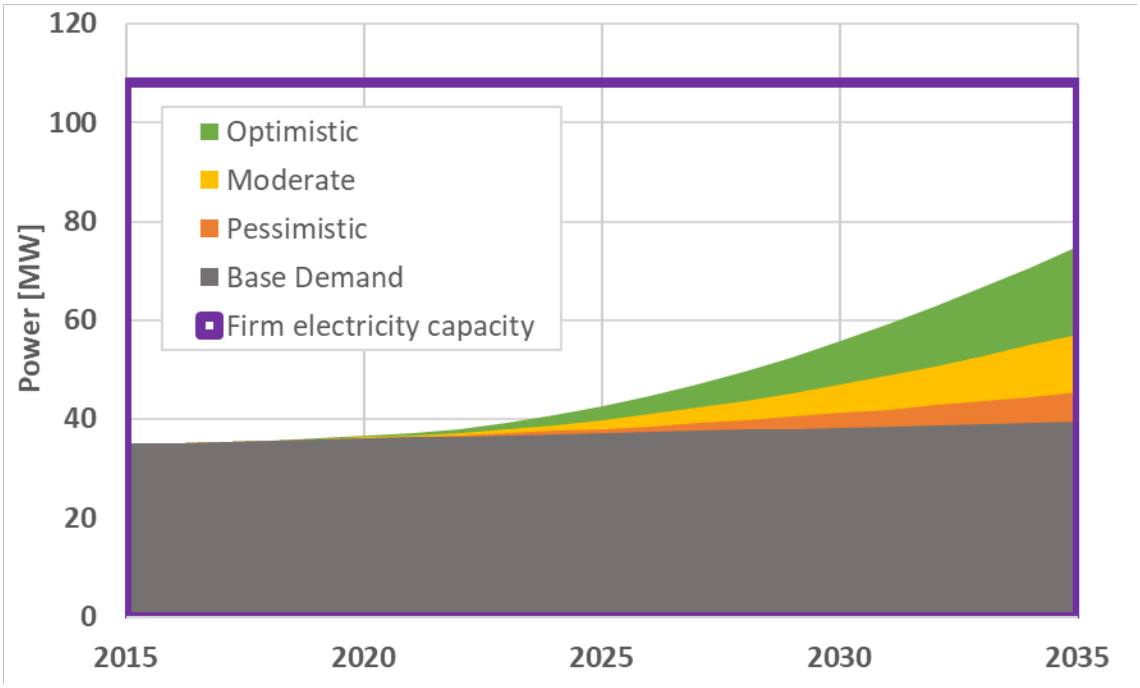


FIGURE 27 - POWER DEMAND FOR THE DIFFERENT EV PENETRATION SCENARIOS, ASSUMING A 100% COINCIDENCE FACTOR

[4] In reality, it is unlikely that many vehicles, particularly private cars, will not start to charge until 1:00 AM.

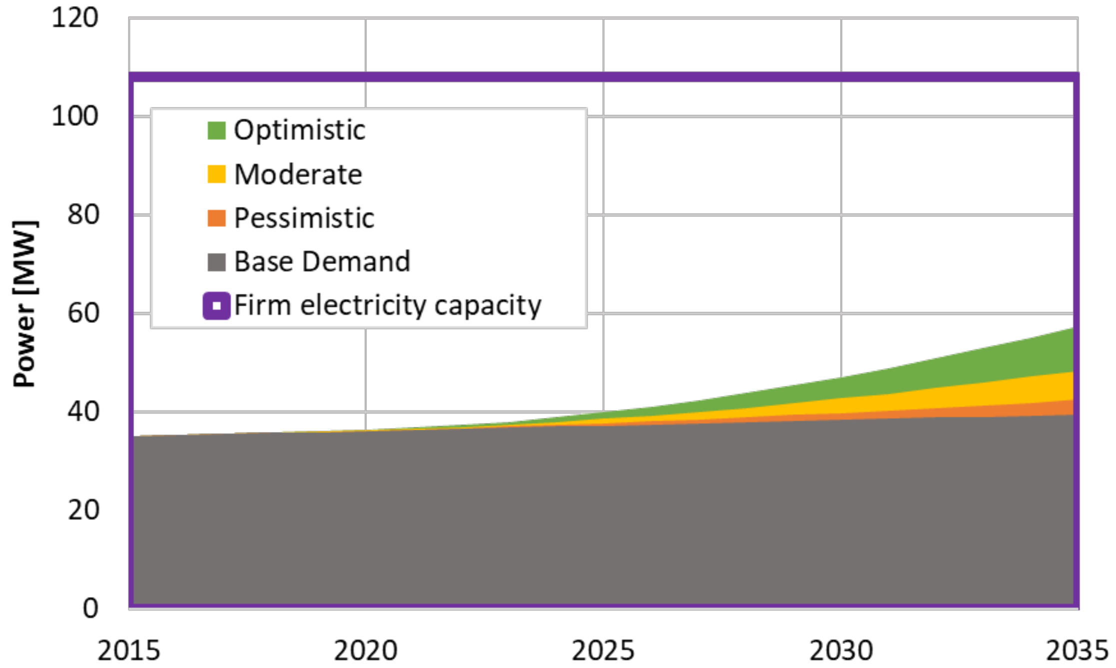


FIGURE 28 - POWER DEMAND FOR THE DIFFERENT EV PENETRATION SCENARIOS, ASSUMING A 50% COINCIDENCE FACTOR.

Figure 27 and Figure 28 show the additional power capacity that would be required to charge the projected EV fleets assuming coincidence factors of 100% and 50% respectively. The first thing that can be noted is that in all scenarios the peak power demand is below 75% of the current installed capacity. Therefore, in a simple power basis analysis, the electric system could support the EV deployments herewith considered. However, note that in the optimistic scenario, assuming 100% coincidence factor (Figure 27) the additional demand due to EV charging in 2035 represents an additional 30% to the expected peak demand (Figure 3). This could compromise grid reliability and could result in an over dimensioning of the distribution system. As expected, Figure 28 shows that reducing the coincidence factor of charging events has a direct impact on the required power capacity of the system. To achieve this, it is imperative to work on power demand strategies for the integration of charging events with the grid´s distribution profile to optimize the utilization of the system. Such strategies would maximize profits for distributors and generators, whilst minimizing the infrastructure requirements and providing the cheapest electricity for the user.

It is noted that based on the average daily mileage and specific energy consumption of both private cars and light duty vehicles, the proposed power capacity of the respective chargers could fully supply the energy consumed during one day in a couple of hours. Therefore, over the 6 hours of minimum demand a lower power capacity could be used. Assuming chargers with lower power rating would constrain the ability of the system to integrate versatile future energy demand management strategies. Charging infrastructure with higher charging power rating (the rating of the on-board chargers for many of the new models entering the market is 7 kW or higher) allows for the charging of EVs to be managed, by adjusting the power used during the charging event. This enables the use of versatile energy demand management strategies, that minimize the impact of charging events on the grid and maximize the return of grid operators and electricity generators. For example, if future investments in solar power were to result in generation surplus, inducing a drop in the price of electricity during period of time, having a system capable of allocating this power would be a valuable asset. Furthermore, an infrastructure that constrains the speed of charging reduces the value proposition of electric vehicles and would likely impact negatively on market adoption. It is preferable to have extra charging capacity and then establish demand strategies to assert user behaviour having in mind that that there will always be people that will rather pay more to make sure that their vehicle is always ready to go, so the system needs to be able to handle this.

The above considerations around charging are to fit within a broader strategy for the integration of renewable generation capacity with electric vehicles moving forward. This requires a holistic system integration which considers not only the grids capability, but also behavioural considerations and system versatility. It is always important to keep in mind that people willingly adopt new technologies when these improve their quality of life.

4.1.3 INCREASED ENERGY DEMAND ON THE ELECTRIC GRID

From an energy point of view, the yearly consumption of the electric vehicle fleets can be estimated based on their intensity of use, in the same manner as that of conventional vehicles, adjusting the specific energy consumption to that of an EV. These are shown on Table 13.

The first thing that is evident when analysing Table 13 is that electric vehicles have a considerably lower "Tank to Wheel" energy consumption than conventional units, with these being in average around 4 times more efficient.

TABLE 13. EV AND CONVENTIONAL SPECIFIC ENERGY CONSUMPTION FOR THE DIFFERENT VEHICLE TYPES [31] [32] [33]

	Energy consumption [kWh/km]		
	Private vehicle	Light duty vehicle	Bus
Conventional ICE vehicle	0.86	1.09	3.12
Electric vehicle	0.20	0.26	0.75
Ratio	4.32	4.27	4.16

Based on the above, the accumulated energy consumed by the EV fleet can be calculated as:

$$E = \sum_i C_i * UI_i \qquad (7)$$

where C_i is the specific electrical consumption [kWh/km] (Table 13) of vehicle type i and UI_i is the usage intensity (**Error! Reference source not found.**) in kilometres travelled per year of the entire fleet of vehicle type i. Note that in this case the electrical vehicles are not affected by the age usage.

Error! Reference source not found. shows the projected electricity demand of the entire electric grid, under the different EV penetration scenarios. To put matters into context, it discriminates the projected electricity demand of the grid without the incorporation of EVs and differentiates between the demand covered by fossil generation and by the expected renewable generation under the countries INDC (section 3).

Projections show that under the optimistic EV penetration scenario, by the year 2035 the use of electric vehicles would result in energy consumption comparable to around 10% of the expected renewable energy supplied to the grid. If it were assumed that electric vehicles are charged during the night, they would not directly use renewable electricity, as solar energy would not be available. However, it could be argued that EV users could pay a premium to attain renewable power.

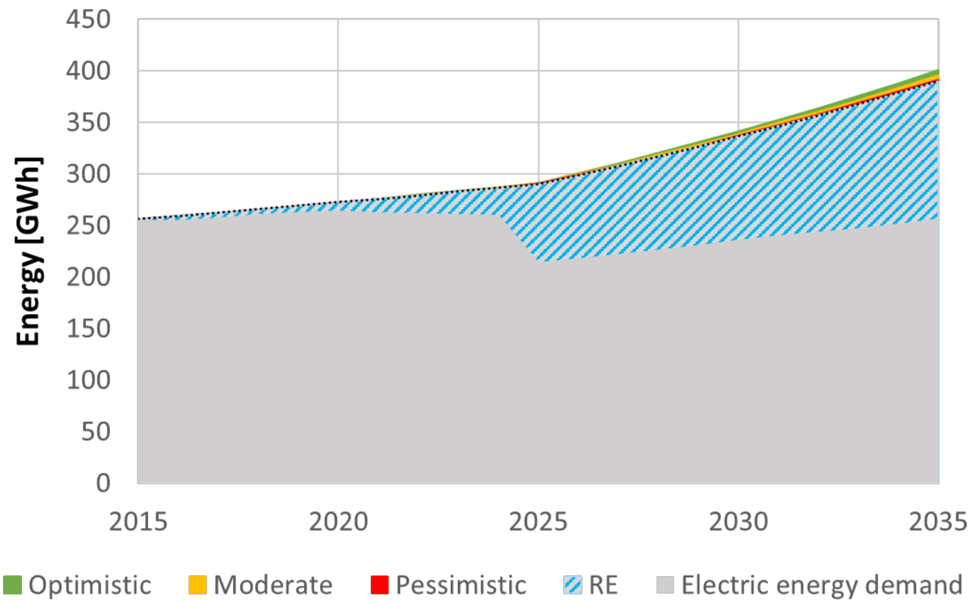


FIGURE 29 - ENERGY GENERATION PROJECTION OF BUSINESS AS USUAL AND RENEWABLE SOURCES COUPLED WITH THE ENERGY CONSUMPTION OF ELECTRIC VEHICLES FOR DIFFERENT SCENARIOS: PESSIMISTIC, MODERATE AND OPTIMISTIC.

Having said this, given that all base load power generation in the isles is produced with diesel gensets, if the produced renewable electricity is absorbed by the EV fleet, additional energy requirements produced by other sectors of the economy will have to be covered with fossil fuel-based electricity, hence, GHG emission reductions will be diminished or even completely trunked. Therefore, estimating the impact of EVs in the overall GHG emissions of the country is not straight forward (i.e. replacing a conventional vehicle for an electric one does not result in a reduction of GHG emissions equivalent to that of the conventional unit displaced).

4.1.4 EMISSION MITIGATION IMPACT - GREENHOUSE GASES

This section builds upon the preceding discussion and evaluates the reduction of the country's overall GHG emission achieved by introducing EVs into the different road transport fleets.

In view of the intended renewable energy capacity that is expected to be installed in the isles' during coming years, and the power demand distribution projected, it is possible to identify the capability of the system to transfer excess renewable generation (if available) to the charging of the introduced electric vehicles.

Error! Reference source not found. shows the progression of installed renewable power capacity and overlaps this with the peak and base power requirements of Antigua and Barbuda over the period of evaluation. The latter do not include the additional power requirements that would be needed to charge electric vehicles.

The first conclusion that can be drawn from the presented results is that during the night, when EVs are supposed to be charged, the accumulated power capacity of both wind and waste to energy systems does not meet the projected base demand of the grid. This means that even during nights when the entire installed wind capacity is producing at its nominal output there will still be the need for fossil-based generation. Furthermore, during the day, when the solar power capacity comes online, current power demand projections also result higher values than the overall projected renewable power capacity. Therefore, it could be assumed that any additional capacity required from the grid, like that needed to charge electric vehicles would have to be supplied by fossil-based generation.

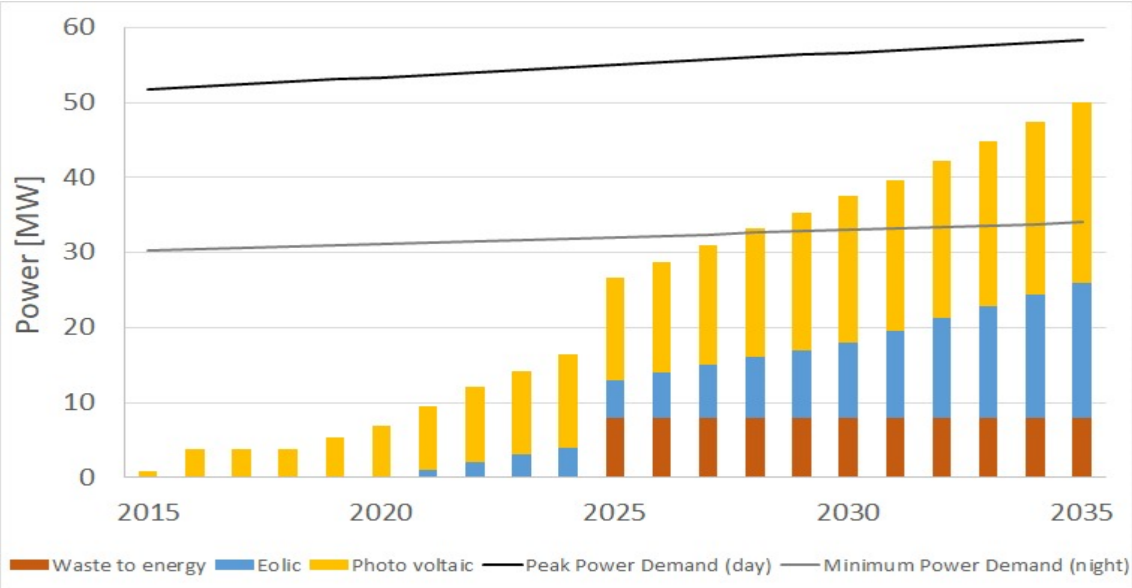


FIGURE 30 - INSTALLED CAPACITY OF RENEWABLE POWER GENERATION AND PEAK AND BASE POWER DEMANDS, WITH NO ELECTRIC VEHICLE PENETRATION, PROJECTED BETWEEN 2015 AND 2035.

As mentioned before, it could be argued that EV owners could purchase renewable electricity from the grid, and therefore run their cars on zero emission power. However, in a system were today almost all its electricity comes from fossil fuels and were in the most favourable conditions by 2035 only 27% of the electricity demand will be supplied by renewable generation, it is almost certain than any additional capacity required, included that of electric vehicles, will come for fossil fuel electricity generation.

The specific GHG emission intensity of the electricity required to charge EVs will be therefore assumed to be that of the "Improved transport and distribution efficiency" projections depicted in **Error! Reference source not found.**. Coupling the latter to the energy consumption of the different categories of EV and comparing the GHG emissions generated to those of a conventional internal combustion unit, it is possible to estimate the GHG emission reduction achieved by displacing a conventional vehicle for an electric one. **Error! Reference source not found.** shows the reduction in GHG emissions achieved by the introduction of an electric vehicle into the different transport fleets over the evaluated period.

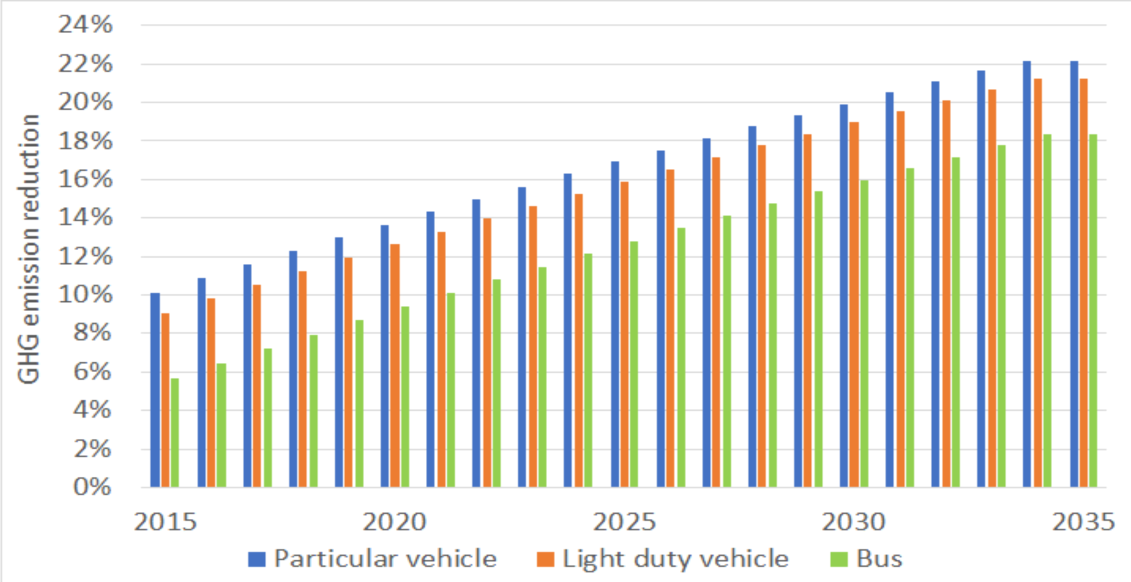


FIGURE 31 - ESTIMATED GHG EMISSIONS MITIGATION OF AN ELECTRIC VEHICLE RELATIVE TO AN EQUIVALENT CONVENTIONAL VEHICLE UNDER THE ASSUMED OPERATING CONDITIONS OF THE DIFFERENT FLEETS IN ANTIGUA AND BARBUDA BETWEEN 2015 AND 2035.

Results show that today, every conventional vehicle that is displaced by an EV results in a GHG emission reduction of around 8%, with this reduction improved into the future as the efficiency of electricity transportation and distribution is improved, amounting to a reduction of almost 20% by 2035.

However, as shown on **Error! Reference source not found.** the overall GHG emission reduction achieved by the inclusion of EVs over the evaluated period results marginal. Overall, the latter amounts to only 1.4% under the most optimistic projections. This is mainly due to the high GHG emission intensity of the electric grid and the relatively low number of EVs compared to the overall fleet.

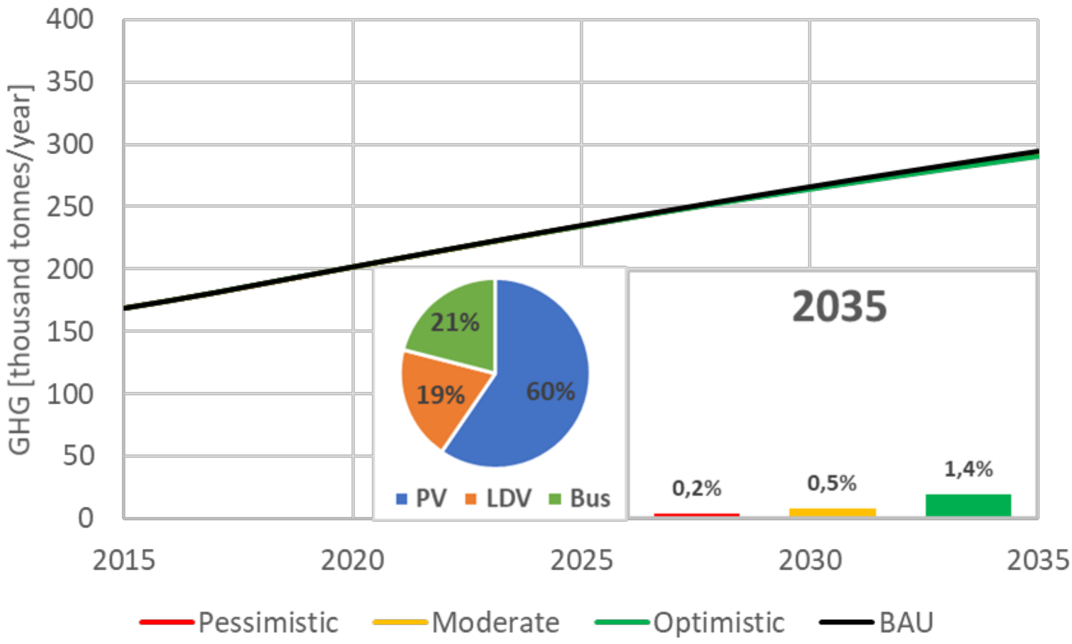


FIGURE 32 - VEHICULAR GHG EMISSIONS PROJECTIONS OF THE IMPLEMENTATION OF PESSIMIST, MODERATE AND OPTIMISTIC ELECTRIC VEHICLE PENETRATION SCENARIOS, FROM 2015 TO 2035, COMPARED TO BUSINESS AS USUAL

4.1.5 Emission mitigation impact - Nitrous oxides & Particulate Matter

Although diesel gensets also generate NOx and PM emissions, these are normally installed away from urban areas and therefore their toxic pollutant emissions should not affect the wellbeing of the population. Under this assumption it will be considered that every EV introduced into the system displaces NOx and PM emissions equivalate to those generated by a conventional unit of the respective category fleet. Therefore, the accumulated NOx and PM emission reductions, Red_i^s, achieved by the introduction of EVs by the year 2035, can be calculated using ***Equation 9*** and ***10,*** respectively:

$$Red_i^s = \frac{NO_x^{BAU-s} - NO_x^{i-s}}{NO_x^{BAU-total}}[\%] \quad (\mathbf{9})$$

where NO_x^{BAU-s} are the NO_x emissions in tonnes of segment s in the BAU scenario, NO_x^{i-s} are the NO_x emissions in tonnes of segment s in the i scenario and $NO_x^{BAU-total}$ are the NO_x emissions in tonnes of all the RTS.

$$Red_i^s = \frac{PM^{BAU-s} - PM^{i-s}}{PM^{BAU-total}}[\%] \quad (\mathbf{10})$$

where PM^{BAU-s} are the PM emissions in tonnes of segment s in the BAU scenario, PM^{i-s} are the PM emissions in tonnes of segment s in the i scenario and $PM^{BAU-total}$ are the PM emissions in tonnes of all the RTS.

Results are shown on *Error! Reference source not found.* and **Error! Reference source not found.** for NOx and PM, respectively. Given that local pollutant emissions of fossil generation is not accounted for, the impact of EVs on local pollutant emissions is considerably higher that on GHG emissions, with these amounting to up to 4% under the optimistic projections. Furthermore, most of the reduction is achieved in the Bus sector, with the latter accounting for 82% and 95% NOx an PM reduction, respectively. This is due to a combination of the high emission intensity factor and high use intensity of conventional buses, compared to cars and LDV.Note that the reductions (in percentage) presented in **Error! Reference source not found.** and **Error! Reference source not found.** are not the accumulated reductions but the reduction in emissions of the different scenarios compared to BAU in year 2035.

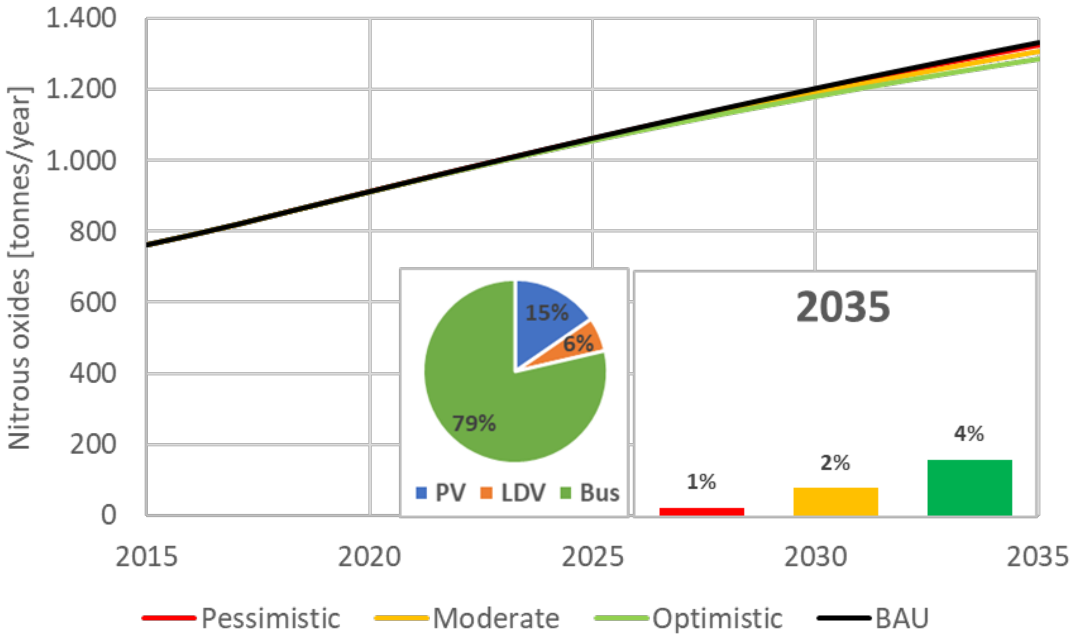


FIGURE 33 - TOTAL NOX EMISSIONS PROJECTION FOR DIFFERENT ELECTRIC VEHICLE PENETRATION SCENARIOS: PESSIMISTIC (I), MODERATED (II) AND PESSIMISTIC (III). FROM 2015 TO 2035.

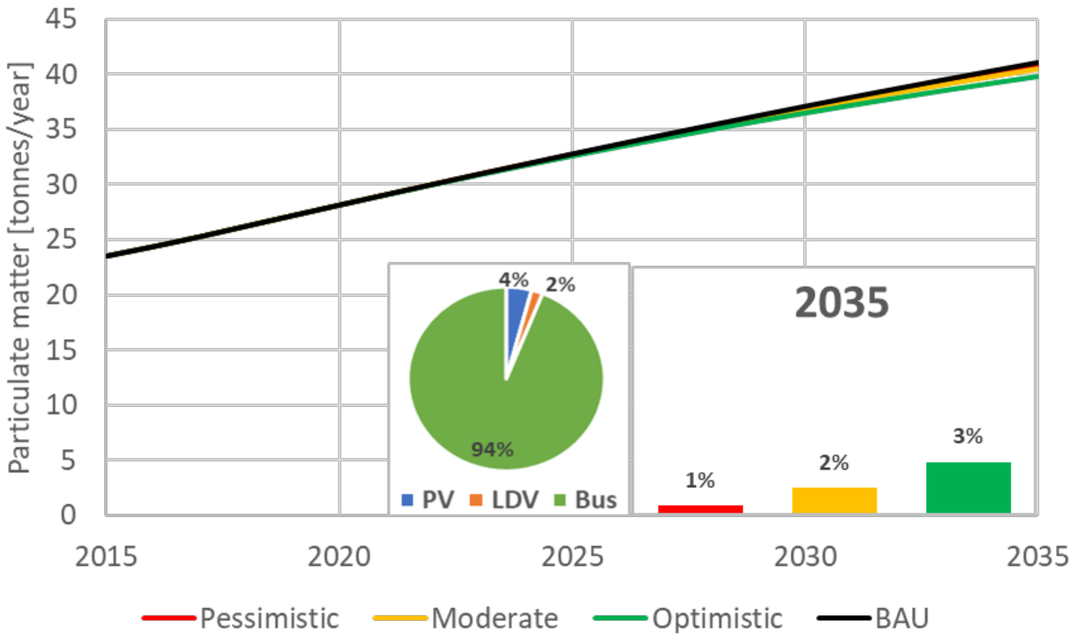


FIGURE 34 - TOTAL PM EMISSIONS PROJECTION FOR DIFFERENT ELECTRIC VEHICLE PENETRATION SCENARIOS: PESSIMISTIC (I), MODERATED (II) AND PESSIMISTIC (III). FROM 2015 TO 2035.

4.2 ENERGY EFFICIENCY STANDARDS

Another way to reduce the GHG emissions of a future automotive fleet is to promote vehicle energy efficiency. This can be done in many ways, however, the more widely used is setting a cap on the average GHG emission per kilometer across all vehicles sold by a given manufacturer during a fiscal year. This means that the average CO_2 emissions per km of the overall fleet sold by a given car brand cannot be above a given threshold. The threshold is tightened over time, which pushes car manufactures to gradually improve the energy efficiency of the cars they sell. If properly structured, this allows manufacturers to develop independent strategies to achieve the established targets in the most cost-effective manner. Setting efficient and realistic standards involves a complex process of technology assessment and collaboration with the manufacturers.

Measures of this kind have already been implemented for light vehicles in most of the world's developed markets. In Mexico, the annual reduction rate is 3.5% [34], in China 4.2% and in the United States 3.8% [35]. In Europe, average fleet targets of 130 gCO_2/km and 95 gCO_2/km were set for 2015 and 2021, respectively [36]. ULEVs are accounted in the average with a multiplication factor that progressively decreases every year.

To understand the impact that a measure of this kind could have on the future GHG emissions of the A&B automotive fleet, three potential scenarios are proposed:

- **Pessimistic:** by 2035 the average emission factor of the fleets is set to 150 gCO_2/km and 160 g/km for private cars and light duty vehicles, respectively.
- **Moderate:** by 2035 the average emission factors of the fleets is set to 130 gCO_2/km and 120 g/km for private cars and light duty vehicles, respectively.
- **Optimistic:** by 2035 the average emission factors of the fleets is set to90 gCO_2/km and 100 g/km for private cars and light duty vehicles, respectively.

To put matters into perspective, in the case of the pessimistic scenario the achieved emission intensities by 2035 are very similar to the average real driving emissions of the current European fleet and therefore could be easily achieved by conventional technologies with little to no effort [17]. The moderate scenario would represent achieving the average real driving emissions of the new European of 2025, whilst the optimistic scenario, would imply leapfrogging and achieving similar real driving emission targets to those established by the EU for their 2035 fleets.

The projected GHG emission reductions over the BAU scenario for the different proposed reductions are shown on **Error! Reference source not found.**.

The proposed measure has a clear impact on the emissions of the overall fleet given that it affects the entire future imports of PC and LDV, which are responsible for most of GHG emissions of the system. The maximum reduction is up to 7%. Even in the pessimistic projections, were by 2035 real driving emissions of new imports are similar to those of Europe's current fleet, overall GHG emission reductions amount to 4%.

This is a considerable improvement over reductions achieved by the incorporation of EVs. However, measures of this kind pave the way for the introduction of hybrid and electric vehicles in the future, given that as the emission cap drops to around 90 gCO_2/km the only way for vehicles to achieve real driving emission intensities of this magnitude is by partial or full electrification of their drive train. Therefore, introducing energy efficiency standards on vehicle imports is a complementary measure to that of promoting the introduction of electric and hybrid vehicles.

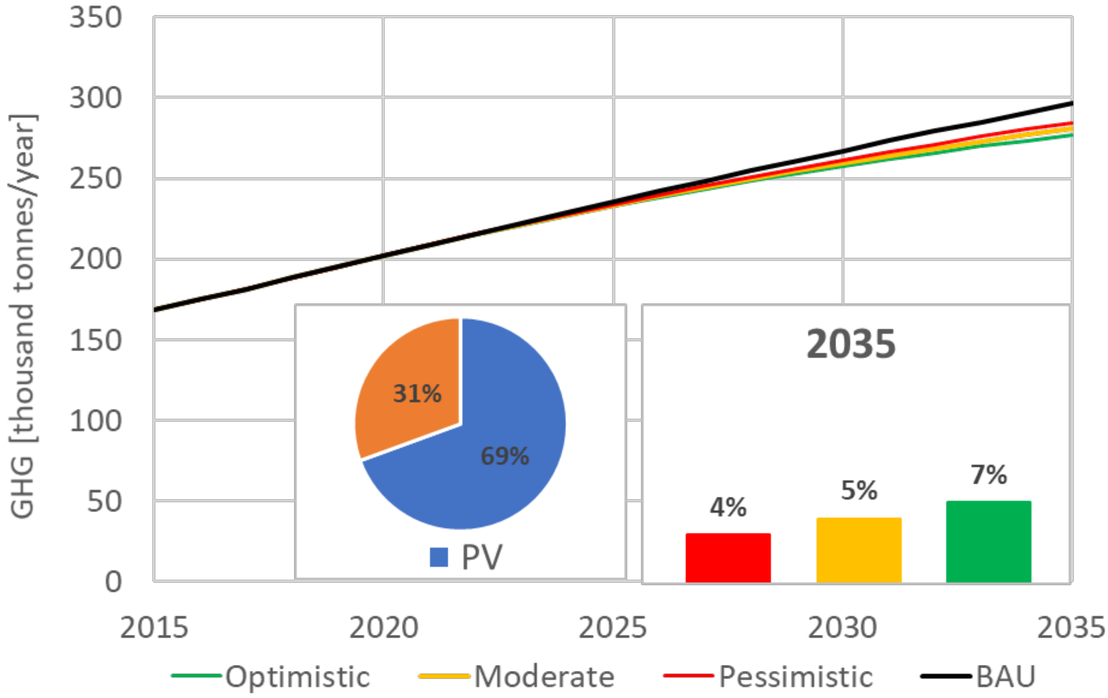


FIGURE 35 - VEHICULAR GHG EMISSIONS PROJECTIONS FOR THE IMPLEMENTATION OF PESSIMIST, MODERATE AND OPTIMISTIC FUTURE FLEET ENERGY EFFICIENCY STANDARDS AS FORM 2020, COMPARED TO BUSINESS AS USUAL SCENARIO.

4.3 MODAL SHIFT - CAR SHARING

Often, we see people traveling in cars alone using a great amount of space and resources that could be used to move two or three more people. Today, the occupancy rate of cars in most cities is of around 1.2 people per car. This means that almost 95% of all private cars have only one person traveling in them. Throughout this section the impact of reducing vehicle idle capacity by promoting connectivity solutions, such as ride-sharing, ride-splitting and car-pooling services will be analysed.

As in the previous section, to understand the sensitivity of the current measure, three scenarios of shared mobility adoption are proposed. These will assume different annual adoption rates of people using shared mobility rather than private cars.

The pessimist, moderate and optimistic scenarios will assume a shared mobility adoption rate of 0,5%, 2% and 4% per annum, respectively. Assuming that the current occupancy rate of cars in Antigua and Barbuda is of 1.4, which is considered conservative, by 2035 the latter should be increased to 1.6, 1.75 and 2, respectively.

Error! Reference source not found. the impact of the proposed scenarios over the BAU GHG emission. The strength behind the proposed measure is that no real investments need to be made. The same as most collaborative business structures, such as UBER or Airbnb, car sharing taps into the idle capacity of the system. Results presented on **Error! Reference source not found.**, show that if 2% of all car user move from using their own to sharing rides with fellow commuters this would generate a GHG emission reduction of the automotive fleet of 16%. This is considerable given that this measure only impacts on the private car fleet.

In addition to the achieved emission reduction, promoting collaborative transport should improve the traffic conditions of the main arteries of the city, which should result in a reduction of travel times required to move within the island and in required infrastructure investments.

The expenses referred to this program should be aimed at promoting collaborative transport by constructing digital platforms that allow connectivity between individuals. Additionally, this sort of initiative should set the ground work for the introduction of autonomous car transport services, given that the latter are to be introduced in collaborative transport schemes.

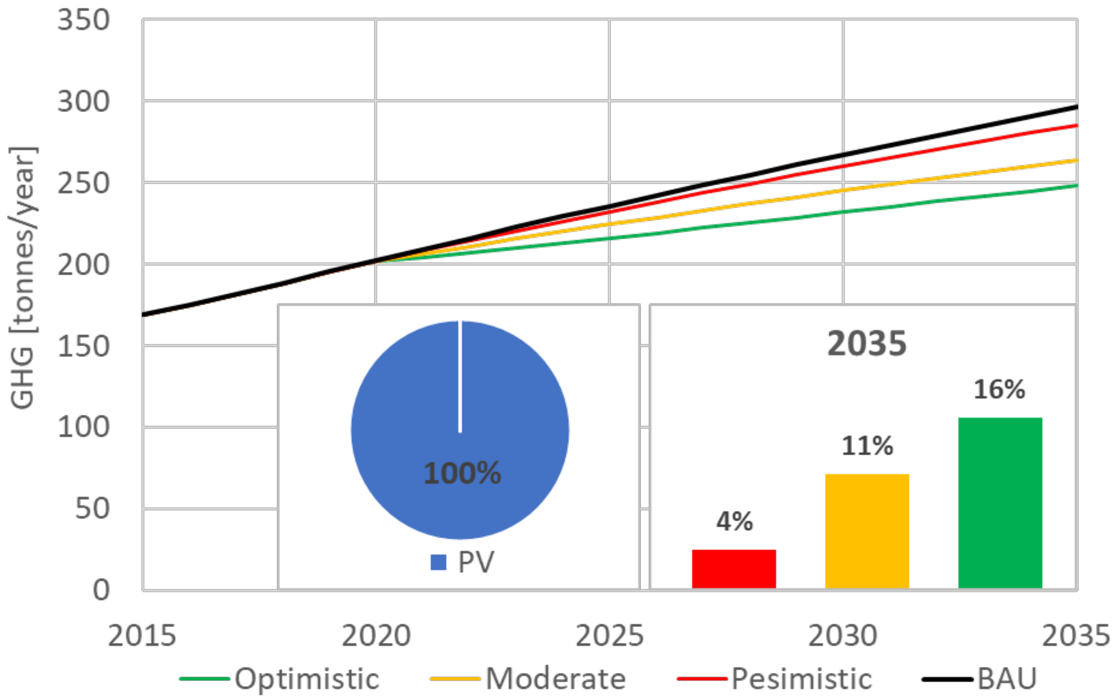


FIGURE 36 - VEHICULAR GHG EMISSIONS PROJECTIONS OF THE IMPLEMENTATION OF PESSIMIST, MODERATE AND OPTIMISTIC CAR SHARING SCENARIOS IN 2020, COMPARED TO BUSINESS AS USUAL SCENARIO.

Given that the proposed measure only affects the private car fleet, which mostly run on petrol, NOx and PM reduction acquired are not significant and therefore not included in the analysis.

4.4 MODAL SHIFT - PUBLIC TRANSPORT

Promoting public transport is at the core of emission reductions achieved by developed countries in recent years. Providing the general public with a safe, reliable, fast, comfortable, and affordable public transport option is what drives people from away from commuting in their own private cars. Aside from walking and riding a bicycle, if well implemented there is no commuting option more efficient than the use of public transport.

To understand the impact of this measure, the pessimistic, moderate and optimistic scenarios will assume that, due to the implementation of an adequate public transport system, the private car fleet growth rate is reduced from the BAU value by 15%, 30% and 60% respectively. Furthermore, , it is assumed that if well managed the bus fleet projected under BAU conditions should be able to allocate all additional commuters. Results for the projected GHG emissions under the 3 presented scenarios are shown on **Error! Reference source not found.**.

As expected, even though the current measure only impacts the emissions of the private car fleet, reductions generated by the proposed modal shift are considerable. This is due to the fact that, as car sharing, promoting a modal shift towards public transportation has a direct impact on the size of the future private car fleet which is responsible for more than 40% of road transport GHG emissions.

As for promoting car sharing, given that most of the costs required to operate a public transport system are already allocated under BAU conditions, the implementation of this measure should not require big additional investments. It is noted that as the number of commuters who use public transport is increased, the fuel consumption of the vehicles will be increased, however the impact of this increase is considered negligible over the overall emissions of the system.

On the other hand, the proposed measure has no impact on the expected growth of local pollutants emissions (NOX and PM). These are mainly produced by the fleet of buses and heavy-duty trucks, which under the presented scenario remain unchanged. In addition to the electrification of buses, which as shown above has an appreciable impact on the overall fleet toxic emissions, other measure adopted by developed countries include the enforcement of stringent vehicle emissions standards and the banning of high sulphur content fuels. The effect of the introduction of such measures on the future fleet toxic emissions will be analysed in the following sections.

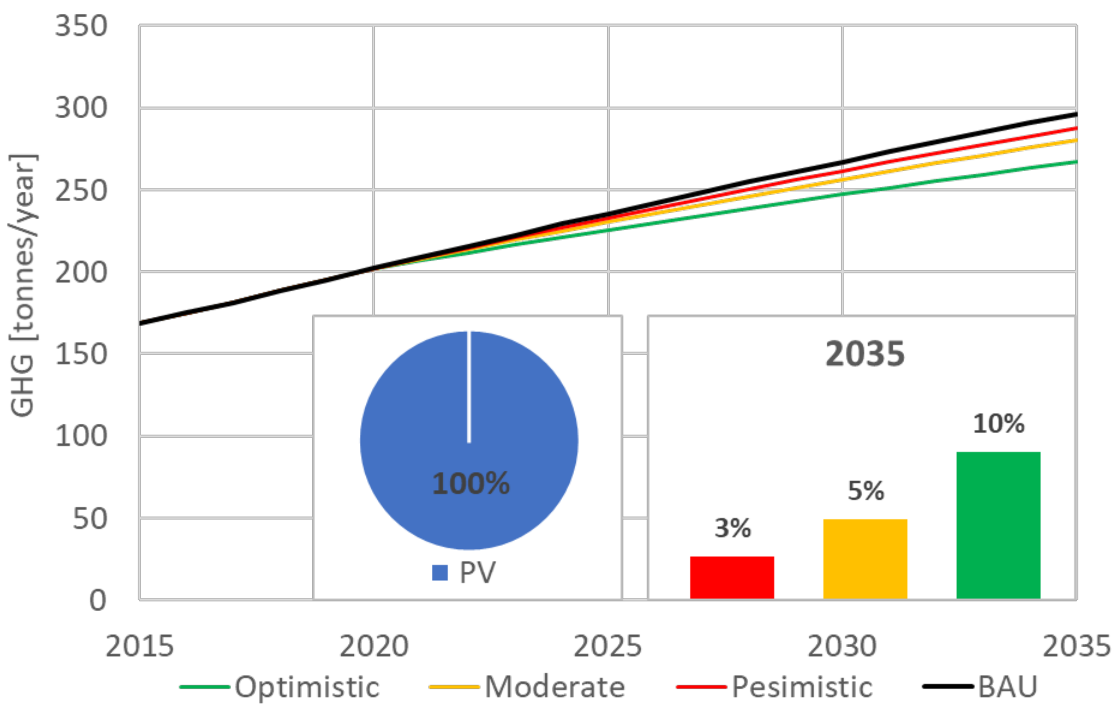


FIGURE 37 - VEHICULAR GHG EMISSIONS REDUCTIONS, FROM 2020 TO 2035, FOR PESSIMIST, MODERATE AND OPTIMISTIC PUBLIC TRANSPORT MODAL SHIFTS SCENARIOS, COMPARED TO BUSINESS AS USUAL PROJECTIONS.

4.5 IMPLEMENTATION OF EURO VI OR EQUIVALENT EMISSION STANDARDS.

As mentioned above, the source of GHG emission in the transport sector is very different to that of toxic emissions. Therefore, applying measures like enforcing standards for vehicle efficiency or promoting commuters' modal shifts, does not imply reducing the emission of toxic agents.

This was made evident by the promotion of diesel cars in Europe over the last 15 years. Whilst, diesel cars are less CO_2 intensive than gasoline vehicles, their NOx and PM emissions are considerably higher. Furthermore, the "tricks" used by car manufactures to pass laboratory-based standards resulted in real driving emission that were more than one order of magnitude higher than the thresholds imposed by emission regulations.

Therefore, due to increasing problems of air quality in highly populated cities, almost every developed country has instated tougher toxic emissions regulations such as Euro VI or equivalent. These were developed to test vehicles under real driving conditions, rather than just standardized laboratory cycles, to guarantee that emission limits where being complied with.

To evaluate the impact of enforcing such a standard on A&B future road transport toxic emissions, the NOx and PM emission profiles of the BAU projection are compared to those attained if all heavy-duty diesel vehicles imported after 2020 complied with EURO VI emission standards. Of course, the implementation of such a measure is not straight forward or easy and expecting Antigua and Barbuda to go from having no emission regulations to enforcing the most stringent regulations in the global market is far reached. However, projecting the impact of such measure on the future fleet toxic emissions helps understudy why it has been implemented by all developed economies and some emerging markets such as China and India. Results of the projected future NOx on PM emissions of the overall fleet under EURO VI regulations are shown on **Error! Reference source not found.** and *Error! Reference source not found.***,** respectively.

As expected, results are clear. The implementation of EURO VI type emission standards, which account for vehicle real driving emissions, are a very effective way to reduce both NOx and PM emissions. Under local conditions, the expected NOx and PM emission reductions are of 14 and 18%, respectively, and have an even impact on the emissions of both the bus and heavy-duty truck fleets.

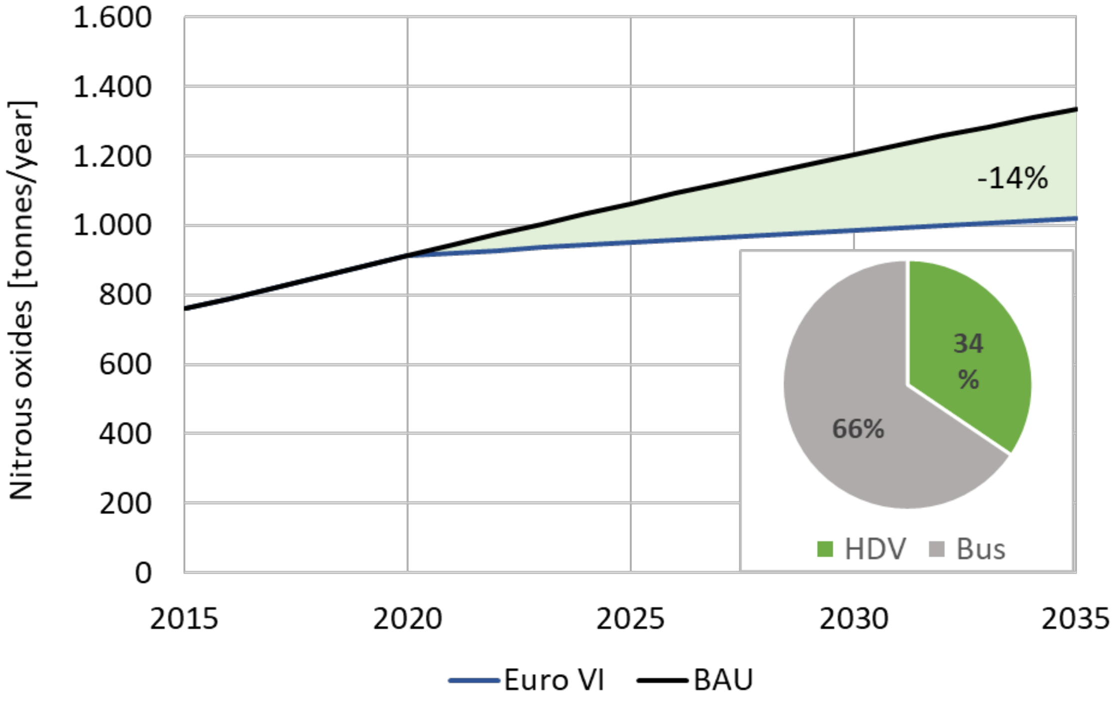


FIGURE 38 - VEHICULAR NOX EMISSIONS REDUCTIONS ACHIEVED BY THE IMPLEMENTATIONS OF EURO VI STANDARDS ON HEAVY DUTY VEHICLES AND BUSES AS FROM 2020, COMPARED TO BUSINESS AS USUAL SCENARIO.

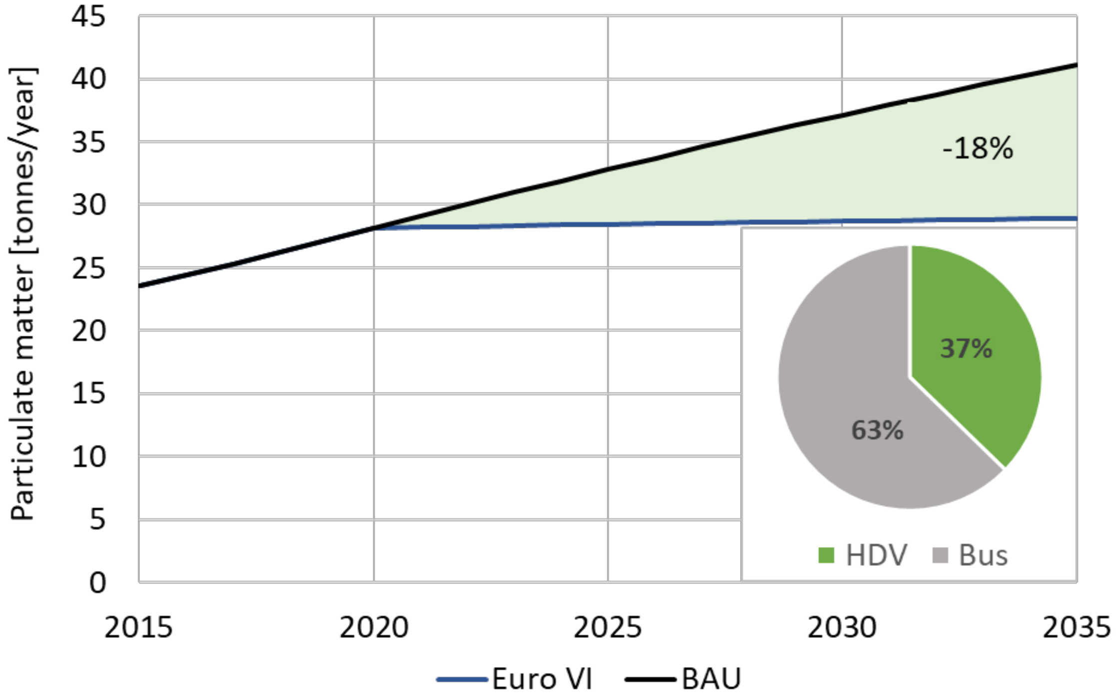


FIGURE 39 - VEHICULAR PM EMISSIONS REDUCTIONS ACHIEVED BY THE IMPLEMENTATIONS OF EURO VI STANDARDS ON HEAVY DUTY VEHICLES AND BUSES AS FROM 2020, COMPARED TO BUSINESS AS USUAL SCENARIO.

The main technical challenge of implementing Euro VI type emission standards, or EURO 4 and EURO 5 standards, is that these vehicles require ultra-low sulphur diesel (ULSD) to operate, which is currently not available in Antigua and Barbuda. Having said this, the use of ULSD not only reduces the emissions of modern diesel vehicles but also has a considerable impact on the toxic emissions of al diesel vehicles. Therefore, the impact of introducing ULSD into the country's energy mix will be analysed in the following section.

4.6 BANNING OF HIGH SULPHUR CONTENT FUELS BY 2020

The use of high sulphur content, especially in diesel vehicles, has strong correlation with the emissions of toxic pollutants. It promotes the formation of PM and nitrogen oxides, as well as sulphur oxides.

Due to the above, developed economies across the glove have banned the use of high sulphur content fuels in means to reduce the environmental and health impacts that these arise, such as: acid rain, lung and other respiratory affections, cardiovascular problems, etc.

As most of the countries which are part of the Petrocaribe trade agreement, Antigua and Barbuda has no restrictions on the content of sulphur for the fuels it imports. Fuels traded in the region are reported to have more than 2000ppm of sulphur [36]. To be conservative BAU projections assumed that the country was currently importing fuels with 2000 ppm of sulphur.

To evaluate the impact that reducing the content of sulphur in imported fuels would have on the toxic emission profile of the fleet, as for other measures three potential scenarios are proposed. The pessimistic scenario assumes the use of fuels with 500 ppm of sulphur by 2020, the moderate scenario introduces 50 ppm sulphur diesel in 2020 and the optimistic scenario assumes the use of 10 ppm ultra-low sulphur diesel by 2020. Results of the projected future NOx on PM emissions under the presented sulphur content fuel scenarios are shown on **Error! Reference source not found.** and *Error! Reference source not found.***,** respectively.

It is worth mentioning that the emission reductions achieved by the proposed measure dose not require the introduction of new vehicles or new infrastructure. These are achieved by fuelling the BAU fleet with lower content sulphur fuels. Therefore, if applied it would have an instant impact on the emissions of the fleet. This is way there is a discreet drop in NOx and PM fleet emissions in the year 2020.

Also, results show that although reducing the content of fuel reduces both NOx and PM emissions in both the bus and heavy-duty truck fleets, its impact on PM emission is considerably higher, achieving emissions of up to 62%, when compared to BAU projections. Furthermore, even under the pessimistic scenario conditions, PM reductions are of almost 51%. This highlights the prompting effect that content of sulphur in fuels has on toxic vehicle emissions.

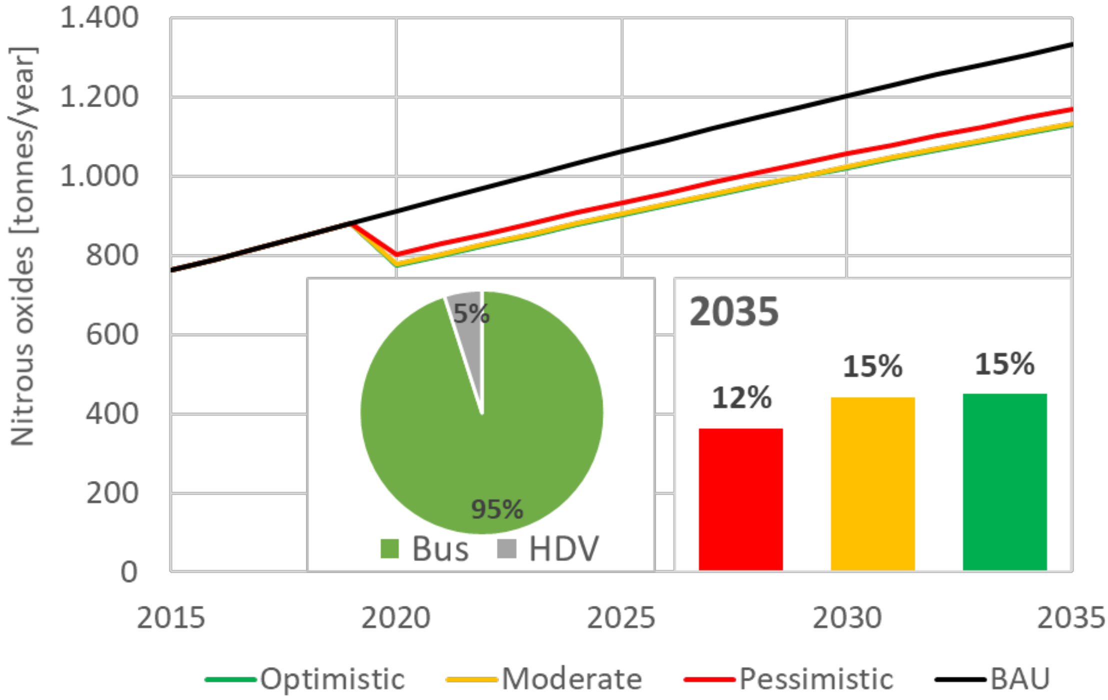


FIGURE 40 - VEHICULAR NOX EMISSIONS PROJECTIONS OF THE IMPLEMENTATIONS OF LOW AND ULTRA LOW SULPHUR DIESEL ON HEAVY DUTY VEHICLES AND BUSES IN 2020 FOR DIFFERENT SULPHUR CONTENT SCENARIOS, COMPARED TO BUSINESS AS USUAL SCENARIO.

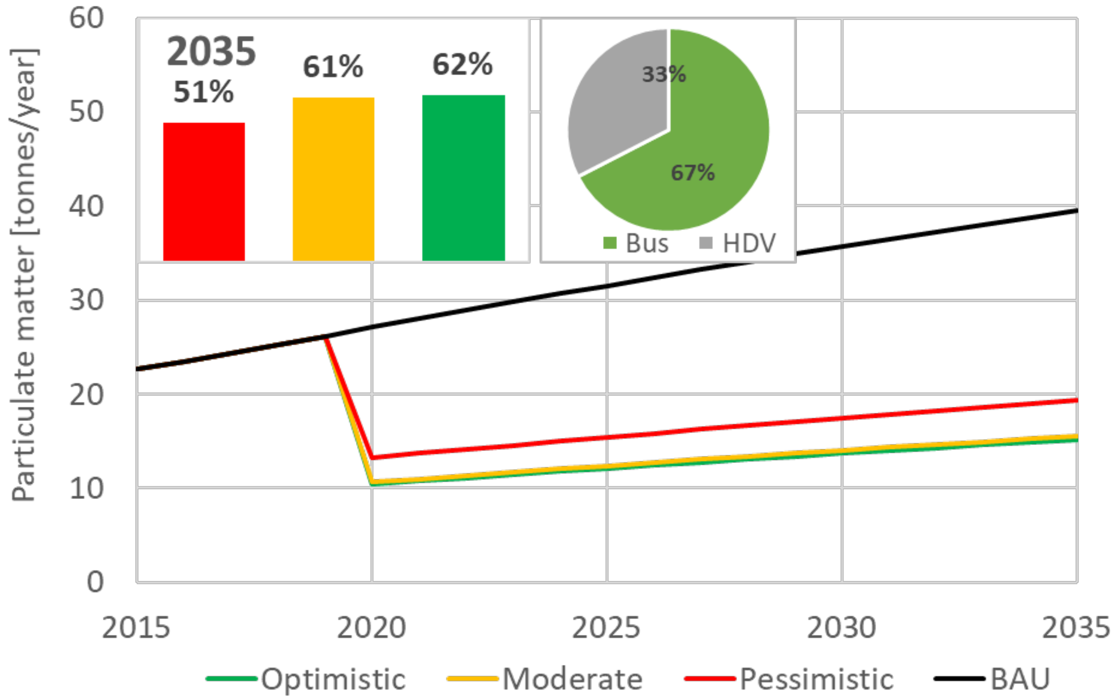


FIGURE 41 - VEHICULAR PM EMISSIONS PROJECTIONS OF THE IMPLEMENTATIONS OF LOW AND ULTRA LOW SULPHUR DIESEL ON HEAVY DUTY VEHICLES AND BUSES IN 2020 FOR DIFFERENT SULPHUR CONTENT SCENARIOS, COMPARED TO BUSINESS AS USUAL SCENARIO.

4.7 OVERVIEW OF THE IMPACT OF PROPOSED MEASURES

To assess the relative impact induced by the propose measure in reducing the different pollutants generated by the transport fleet, **Error! Reference source not found.** condenses the results presented across the entire section.

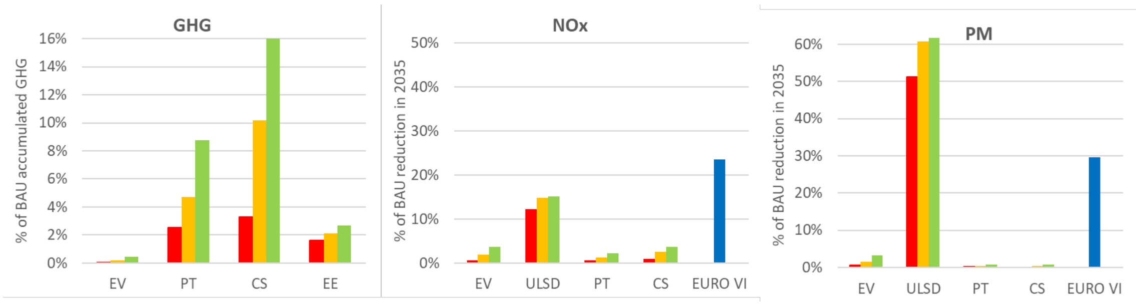
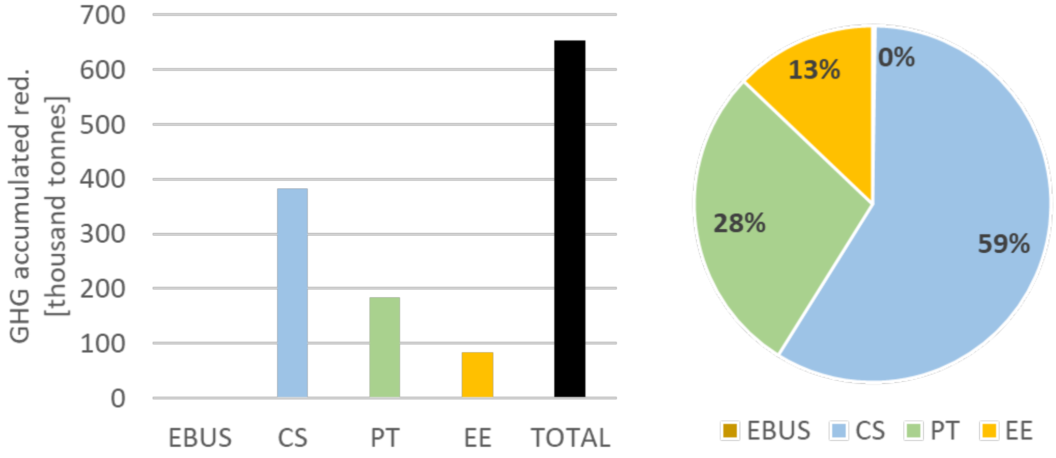


FIGURE 42 - RELATIVE IMPACT OF THE EMISSION MITIGATION MEASURES ON THE DIFFERENT EVALUATED EMISSION UNDER BUSINESS AS USUAL CONDITIONS (EV: ELECTRIC VEHICLES, PT: PUBLIC TRANSPORT, CS: CAR SHARING, EE: ENERGY EFFICIENCY, ULSD: ULTRA-LOW SULPHUR DIESEL)

It is clear that no one measure can effectively reduce both GHG and toxic emissions. Whilst applying standards of vehicle toxic emissions and sulphur fuel content seem to be crucial to mitigate NOx and PM emissions, they have little impact on the GHG emissions of the fleet.

Regarding the latter a coordinate plan needs to be enforce. Promoting the use of public transport and car sharing seems to be the most effective ways to reduce the carbon intensity of the fleet. The incorporation of clean, silent and comfortable electric buses could help traction this modal shift and further reduce the emission of toxic pollutants in city centres. This coupled with energy efficiency standards to push down the GHG emissions of the light vehicle fleet (private cars and light duty vehicles) seems to set the back bone of an effective GHG reduction program.



43a. Breakdown of total GHG accumulated reductions of proposed measures

43b. Incidence of the proposed measures over the total reduction

FIGURE 43 -ACCUMULATED REDUCTION OF PROPOSED MEASURES – MODERATE SCENARIO (EBUS: INTRODUCING ELECTRIC BUSES, CS: CAR SHARING, PT: PROMOTING PUBLIC TRANSPORT, EE: ENERGY EFFICIENCY)

IN

Figure 43 an estimation of the potential reduction of GHG emissions by implementing a combination of measures proposed above (promoting car sharing and public transport by introducing electric buses and implementing emission standards) is presented. Total accumulated GHG reduction is found to be 654,000 tons of GHG which represents a **17%** reduction with respect to BAU accumulated emissions. As it is expected, most of the reduction is due to the promotion of collaborative riding and promoting public transport.

It is important to stress that the proposed measures are by no means the optimum portfolio of interventions. Identifying the optimum measures requires a more thorough analysis which is beyond the scope of this work.

5. CONCLUSIONS

Throughout the present work the environmental impact of the road transport sector of Antigua and Barbuda was assessed in terms of its GHG and toxic pollutant emissions.

First the current fleet was categorized based on vehicle type, after which its GHG and toxic emissions intensity were established, considering the fleet composition, different vehicle operating conditions, age distribution, intensity of use, technological distribution, amongst others. Furthermore, using recent fleet growth rates a BAU projection of the fleet size and its emissions intensity was established to the year 2035. This was used to, not only understand the future implications of the fleet growth rates on the country's environmental targets, but also to set a reference scenario against which different mitigation measures would be evaluated against.

It is important to note that the current fleet growth rates, recoded over recent years in Antigua and Barbuda, are in excess of 8% which is higher than those of most of the LATAM and Caribbean region, which are around of 6.5%. Such rates are not sustainable and typically should start decreasing as the market approaches saturation. If maintained into the future, the vehicle fleet of the country will more than triple by 2035. Furthermore, even under a more conservative fleet growth estimation that takes into account the local GDP and GNI, amongst others, the road transport fleet of the isles still grows considerably into the future, almost doubling the next 17 years. Therefore, it is imperative to put in motion a comprehensive emission reduction plan that places at its core the continued reduction of fleet growth rates, whilst, improving connectivity across the isles' and reducing the specific emission intensity of vehicles.

Based on the above, different emission mitigation measures were analyzed. These included: promoting a technological shift towards electric vehicles; establishing energy efficiency targets for future vehicle imports; promoting a modal shift from private cars to either shared mobility or public transport; the introduction of toxic emission vehicle standards and the reduction of the Sulphur content in fossil fuel imports.

To properly assess the impact on the country's GHG emissions associated to the introduction of electric vehicles, into the different vehicle fleets, a review of the electric grid and generation system was undertaken.

Currently the country's electricity generation is almost entirely done by gensets running on Fuel Oil. In addition to this, transport and distribution losses in the electric grid are of around 30% of all generation, resulting in very high GHG specific emission electricity production. Although the country has in place plans to reduce distribution inefficiencies and has confirmed INDC that establish the introduction of a considerable amount renewable power generation capacity, overall, the continued expected growth of the current electricity demand offsets the projected renewable generation. Meaning that any additional electricity demand, like that required to charge electric vehicles, under current future scenarios, would result in the need of more fossil fuel-based electricity generation. This hinges the potential GHG emission reductions achieved by the introduction of electric vehicles.

On the other hand, the electrification of buses shows promise displacing local pollutant emissions from city centers. This coupled with a safe, reliable, fast and comfortable public transport system, could traction a modal shift from private cars to buses. This has been shown to be the most effective way of reducing GHG emissions and is believed that coupled with a car sharing platform to enable the collaborative transport in areas where public transport cannot operate satisfactorily, could induce a modal shift across the country helping tame the high fleet growth rates currently observed.

Regarding vehicle and fuel standards, the country has fallen considerably behind developed markets. Today Antigua and Barbuda has no standards for vehicle emissions nor does it do for quality of fuel. This has resulted in the import of highly pollutant vehicles. Incorporating these regulations would have a considerable impact on the toxic emission outlook of the overall fleet.

Another regulation that could be introduced, that has shown good results in other countries, is setting energy efficiency standards for future vehicle imports. This would help to gradually reduce the GHG emissions of the fleet, whilst paving the way for the incorporation of hybrid and electric vehicles in the future.

Overall, to effectively reduce GHG and toxic emissions generated by the road transport fleet, a coordinated and comprehensive mitigation plan needs to be enforced. There are no "silver bullets", meaning that no one measure can solve all of the problems associated to the use of road vehicles.

Finally, it is important to note that acquiring the required information to undertake the present study was not simple. In many cases the requested information was incomplete or not existing. Due to this several informed assumptions needed to be made. To introduce and track an effective emission mitigation plan it is imperative to in place data acquisition systems and protocols that help evaluate and asses the effectiveness of the applied measures in an agile and cost-effective manner.

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