The road to independence - A study of reducing fossil fuel import dependency for private land transport on Mauritius

Vegen til sjølvstende - Ei studie om reduksjon av fossil energi import til privat landtransport på Mauritius

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Master Thesis 30 credits 2013

Preface

This thesis concludes my master's degree in Environmental Physics and Renewable Energy at the Norwegian University of Life Sciences (UMB). It is written as part of the project Many Strong Voices (MSV), which connects arctic areas and Small Island Developing States (SIDS) to raise awareness and take action on climate change adaptation and mitigation.

In August 2011 my friend and fellow student, Marie Loe Halvorsen approached me about an opportunity to write a thesis for MSV about energy usage on Mauritius. Through discussions with Ilan Kelman, at CICERO/MSV, and Petter H. Heyerdahl, at the department of mathematical sciences and technology at UMB, the theme of this thesis was developed. Reducing fossil fuel import dependency is an important topic, both in terms of the energy security of Mauritius and in relation to global climate change challenges.

I would like to thank MSV, Norad and Tekna for funding and support, which enabled me to travel to Mauritius and therefore write this thesis.

I give many thanks to Marie, for thinking of me when looking for a travel companion, acting as a sounding board to ideas and making our trip very enjoyable.

To my family, thank you for supporting me and helping me, especially my sister, Marie Lovise, for proofreading the entire thesis.

Last but not least; to my supervisors, Ilan and Petter. Thank you for inspiring me, getting me through the most stressful periods the last few months and pushing me to do better.

Ås, March 13th 2013.

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Abstract

Imported fossil fuels accounted for 83.8% of the primary energy demand on Mauritius in 2011. 36.4% of the fossil fuels imported were used in the transport sector. This thesis examines how Mauritius can reduce their import dependency on fossil fuels for private land transport by use of biofuels and electric vehicles. Nine models for possible fuel consumption in private land transport are used. These models are based on three different fuel intensities and three different average distances travelled each day. It is found that implementing E10 or E20 ethanol blends in gasoline-fuelled cars/dual-purpose vehicles have the potential of reducing fossil fuel imports for private land transport by 1.4% to 5.6% or 2.8% to 11.2% depending on the consumption model. The required ethanol for such blends can be produced from by-products of the existing sugar industry on the island.

Four scenarios for electricity generation to fuel electric vehicles were also considered; Scenarios A and B models an electricity generation source mix consistent with the 2010 mix and a government target mix for 2025, scenario C models electricity generation exclusively from coal and scenario D models electricity generation only from renewable energy resources. All scenarios result in a decrease of required fossil fuels import for private land transport when replacing conventional vehicles with electric vehicles, with scenario C showing the least and scenario D showing the largest decrease. However an all-electric car fleet can more than double the electricity demand if the charging coincides with the peak electricity demand. As a consequence, measures must be put in place to mitigate this risk. Some measures to this effect, such as a vehicle-to-grid system, will enable electric vehicle batteries to act as extra energy and power capacity for the electric grid and thus facilitate a higher share of renewable energy in the general electricity generation on Mauritius. An electric vehicle fleet fuelled with electricity generated from renewable energy sources should therefore be the long-term goal for private land transport on Mauritius.

Samandrag

På Mauritius var 83,8% av det primære energibehovet dekka av importert fossil energi i 2011. 36,4% av dette vart brukt i transport sektoren. Denne oppgåva tek for seg korleis Mauritius kan redusere import av fossil energi til privat landtransport ved å bruke biodrivstoff og elektriske bilar. For å kartleggje drivstoff forbruk i privat landtransport er ni modellar for drivstoff forbruk foreslått. Forbruksmodellane er basert på tre verdiar for drivstoff intensitet og tre verdiar for gjennomsnittleg køyreavstand per dag. Ved å innføre E10 eller E20 i bensindrivne bilar kan Mauritius redusere sin import av fossil energi til privat land transport med 1,4% til 5,6% eller 2,8% til 11,2% avhengig av forbruks modell. Biprodukt frå eksisterande sukkerindustri på øya kan brukast til å produsere tilstrekkelig etanol til å dekke forbruket til både E10 og E20.

Vidare er fire scenario vurdert i oppgåva; Scenario A og B ser på elektrisitet generert med lik fordeling av energikjelder som i 2010 og Mauritius sit mål for fordeling av energikjelder i 2025, Scenario C ser på elektrisitet generert berre frå kol og scenario D ser på elektrisitet generert berre frå fornybare energikjelder. Ved overgang frå tradisjonelle bilar til elektriske bilar viser alle scenario ein nedgang i fossil energi import for privat landtransport. Scenario C fører til minst nedgang medan scenario D gir mest nedgang. Ei utfordring med ein flåte med berre elektriske bilar er at så mange bilar vil meir enn doble behovet for elektrisitet dersom dei blir lada samtidig med maksimal bruk av elektrisitet. For å forhindre dette kan diverse tiltak nyttast. Tiltak som "vehicle-to-grid" vil ikkje berre løyse denne utfordringa, men også leggje til rette for høgare del av elektrisitet generert frå fornybare energikjelder ved å bruke bilbatteri som ekstra kapasitet for energi og effekt til elektrisitetsnettet. Langsiktig mål for å minimere fossil energi import til landtransport bør difor være ei flåte av elektriske bilar som brukar elektrisitet generert frå fornybare energikjelder.

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c	0.278 (kWh/MJ) conversion factor between kWh and MJ
C	Total import cost per year (Rs/year)
C_{fuel}	Unit import cost of given fuel (Rs/toe)
d	365 (days/year)
D_{av}	Average distance travelled by a vehicle (km/day)
E_{in}	Energy input to the power plants for the given fuel (toe)
E_{infuel}	Required input of a given fuel for the given electricity production mix (toe/year)
E_{intot}	Total fossil fuel input to power electric vehicles for a given electricity production mix (toe/year)
E_{out}	Energy output of the power plants for the given fuel (GWh)
F_{av}	Average fuel consumption for a vehicle (l/day)
F_{el}	Daily fuel consumption of electric vehicles (MWh/day)
F_{eltot}	Additional electricity generation required to fuel electric vehicles (MWh/day)
F_{tot}	Total fuel consumption (l/year)
g	Gasoline equivalent factor (lge/l)
g_e	Gasoline equivalent factor for ethanol (lge/l)
g_{eg}	Ethanol blend gasoline equivalent factor (lge/l)
I	Fuel intensity (l/km)
I_{el}	Average fuel intensity for an electric vehicle (kWh/km)
I_{lge}	Gasoline equivalent fuel intensity (lge/km)
k	Required fuel input per kWh for a given fuel (MJ/kWh)
K_{tot}	Total required fuel input per kWh for given electricity production mix (MJ/kWh)
l	Share of loss in grid
N	Number of vehicles
S_e	Share of ethanol in blend
S_{el}	Share of total electricity production for each fuel
S_f	Share for given fuel of total fossil fuel in electricity production mix
S_{ff}	Total share of fossil fuels in electricity production mix
S_g	Share of gasoline in blend
η	Efficiency of power plants for a given fuel (%)

Abbreviations

BEV	Battery electric vehicle
CEB	Central Electricity Board (Mauritius)
CSO	Central Statistics Office (Mauritius)
EU	European Union
GDP	Gross Domestic Product
ICE	Internal combustion engine
IEA	International Energy Agency
IPPs	Independent Power Producers
lge	Litre gasoline equivalent
LPG	Liquid Petroleum Gas
LRT	Light rail transit
MID	Maurice Ile Durable
NTA	National Transport Authority (Mauritius)
PHEV	Plug-in electric hybrid vehicle
PV	Photovoltaic
SIDS	Small Island Developing States
Toe	Tons of oil equivalent
V2G	Vehicle-to-grid

1. Introduction

1.1 Mauritius, a vulnerable small island

Small island developing states (SIDS) are defined by their size and vulnerabilities. A consequence of being a small island is very limited resources, both natural and human, and therefore few possibilities for a wider range of industries. As a result they are heavily dependent on import of goods. Due to their small size and isolated locations imported goods to SIDS will generally be more expensive than for other countries[1].

Like other SIDS, Mauritius is heavily dependent on imports for both energy as well as food. In 2008 they were only considered self-sufficient in poultry and eggs[2]. Though even the poultry industry was 80% reliant on imported feed. All energy required for the transport sector is imported and 83.8% of the total primary energy requirement for Mauritius is from imported fossil fuels[3]. 20% of the world primary energy demand arises from the transport sector[4]. In Mauritius, the transport sector accounts for 36.4% of the total imported fossil fuels and about 30% of the primary energy demand[3]. Mauritius has no oil reserves and is dependent on import of fossil fuels both for the transport sector, but also for electricity generation[5]. This makes Mauritius particularly vulnerable to changes in oil and coal prices.

CO2 emissions and climate change has been a much discussed topic in recent years. There are therefore quite a few studies and reports on how to change society and the current energy systems to get a low-emission society and thus reduce consumption of fossil fuels. Andaloro et al. offers an analysis of the possibilities of renewable energy on a small island in southern Italy[6]. Réunion Island is a French island in the same area as Mauritius. A study by Praene et al. shows the possibility of having a net-zero energy island[7]. Other studies and reports have cities and city planning as focus areas to reduce emissions and therefore fossil fuel use[8, 9]. From a technological perspective, they conclude that renewable energy on islands can greatly reduce the dependency of imports. However the economical and political challenges involved in implementing renewable energy are more difficult to overcome. As many renewable energy power plants require large upfront investments in terms of costs, it is difficult for governments that depend on getting re-elected to prioritize renewable energy in already strained budgets.

Mauritius, as a small isolated island, has the potential to turn the dependency problem around by implementing an alternative transport system on the island. Being isolated, there is no interconnection with land transport of other countries; therefore it could be easier to restructure the transport sector.

Historically the sugar refining has been the main industry on the island, today the sugar industry has lost some of its influence as it contributed only 1.6% of the gross domestic product (GDP) in 2011 [10, 11]. In comparison, the tourism sector on Mauritius has a much greater influence as it accounts for 8.4% of the GDP in 2011[11]. However as part of their operations the main sugar factories generates their own electricity using bagasse, a bi-product from sugar refining, and coal. In addition surplus electricity is also exported to the electricity grid. In fact the sugar industry generates almost 60% of the electricity on Mauritius[3]. Ethanol can be produced from molasses, another bi-product from sugar refining, and used as fuel in vehicles.

In 2008 the concept The Maurice Ile Durable ("Sustainable Mauritius") was first envisioned by the Prime Minister of Mauritius, Dr Navinchandra Ramgoolam[12]. Maurice Ile Durable (MID) is an on-going process where the entire nation has had the opportunity to be involved in discussing the future goals for the country, through Internet forums as well as professional working groups. The goal of the project is to steer the development on Mauritius in a sustainable way. In order to achieve this, sustainability goals have been developed in five key areas: energy, environment, education, employment and equity. The aim of the project is to develop concrete policies and action plans for a sustainable island. A transport system that relies on existing island resources, such as renewable energy or biofuels is in line with the goals of the MID.

1.2 Thesis problem

This thesis will examine if Mauritius can reduce their import dependency of fossil fuels in the private land transport by use of biofuels and electric vehicles. Although other alternatives to reduce fossil fuel dependency will be mentioned, the main focus will be on switching to electric vehicles and using ethanol blends in conventional vehicles, and the challenges and advantages associated with those.

1.3 Structure of the thesis

This thesis will examine the possibilities of reducing fossil fuels dependency in the private transport sector in Mauritius. This introduction gives a background of Mauritius and the importance of the thesis. Chapter two will detail the methods used to gather and process data. Chapter three gives a background on different modes of private transport and both conventional and alternative fuels for these. Chapter four outlines the current infrastructure and private transport use. Chapter five will then explore the immediate plans the government of Mauritius has for both private and public transport, which may impact fossil fuel imports.

In chapter six the possibilities of reducing fossil fuels consumption by reducing transport needs, using biofuels and other alternative fuels will be examined. Chapter seven will then look at the possibilities of using electric vehicles on Mauritius. The impact of using an electric vehicle fleet instead of the current car/dual purpose vehicle fleet is considered. Chapter eight use the results from the previous chapters to compare the imports of fossil fuels due to conventional fuel, ethanol blends and different scenarios for electricity production. Chapter nine will summarize the main conclusions of the thesis.

2. Methodology

This chapter details the data sources and methods for collecting and processing data used in this thesis.

2.1 Data sources

The main source of data from Mauritius for this thesis is the Central Statistics Office (CSO) in Mauritius. The CSO collects statistics on a range of topics; those most used in this thesis are statistics related to energy and transport. Data not available from the CSO has been collected from government reports, interviews with government officials and private company workers or estimated based on earlier studies. A list of all persons interviewed can be found in Appendix B.

2.2 Data collection

As part of the preparations for this thesis a fieldtrip to Mauritius was undertaken. The stay lasted for one month, from August 21st to September 20th 2012. During the visit data was collected by personal observations, interviews conducted and by finding data from the CSO not available online. Visits were also made to the Champagne hydropower plant and La Baraque sugar factory and power plant. Personal observations from the stay on Mauritius have been used to validate statements from interviews and estimates based on literature from other places than Mauritius.

2.3 Limitation of data

Available data of fuel consumption on Mauritius is general for all land transport; this includes private, public and consumption for transport for industry. Due to this limitation, a range of fuel intensities and average distance travelled are used to model possible fuel consumption in private transport. Three different fuel intensities and three different average distances are considered, giving nine different models for the fuel consumption in private transport. In addition, details on the share of vehicle fuelled by different fuels where only found for 2010. As a consequence of this, 2010 is used as a reference year and a basis for analysis throughout the thesis.

2.4 Limitation of scope

The scope of this thesis has been limited only to include fuel used for private land transport on Mauritius. This includes privately owned cars and dual-purpose vehicles in addition to motorcycles and autocycles. Dual purpose vehicles are defined by the CSO as vehicles under two tons that are used for transporting both passengers and goods[13]. Autocycles are defined as cycles with both pedals and a motor[13]. Buses and trucks used in industry and public transit are not considered. Electric vehicles are assumed to be able to substitute for cars and dual-purpose vehicles, but electric motorcycles or autocycles are not considered in detail here.

2.5 Assumptions

There is an underlying assumption throughout the thesis that the fuel consumption for a vehicle is between 0,07 and 0,13 litre gasoline equivalent per km. Litres of gasoline equivalent (lge) are the amount energy in an alternative fuel that equals a litre of gasoline. Also assumed throughout the thesis is an average distance travelled by a car of between 10 and 30km/day. Nine models are used to determine the fuel use of vehicles using fuel intensity of 0.07, 0.10 and 0.13 lge/km and average distances travelled of 10, 20 or 30km/day. An overview of the different models can be found in Appendix C. Similarly electric vehicles as modelled in this thesis are assumed to have an average consumption from the grid of 0.15kWh/km.

When comparing different scenarios for fuel consumption in chapter 8, the number of vehicles is assumed to be constant at the same number as in 2010 and the vehicles are distributed by type of fuel by the same share as in 2010. It is also assumed that electric vehicles in the following order replace conventional vehicles: LPG fuelled vehicles; gasoline fuelled vehicles and in the end diesel fuelled vehicles.

2.6 Data processing /formulae

The average fuel consumption of a given fuel for a vehicle is given by:

$$(4.1) \quad F_{av} = \frac{F_{tot}}{d * N}$$

Where:

F_{av} = Average fuel consumption for a vehicle (l/day)
F_{tot} = Total fuel consumption (l/year)
N = Number of vehicles
d = 365 (days/year)

The fuel intensity of a given fuel is found from the gasoline equivalent fuel intensity by:

$$(4.2) \quad I = \frac{I_{lge}}{g}$$

Where:

I = Fuel intensity (l/km)
I_{lge} = Gasoline equivalent fuel intensity (lge/km)
g = Gasoline equivalent factor (lge/l)

Average distance travelled by a vehicle can then be found:

$$(4.3) \quad D_{av} = \frac{F_{av}}{I}$$

Where

D_{av} = Average distance travelled by a vehicle (km/day)

Total fuel consumption of a given fuel for a year is found by rearranging the above equations:

$$(4.4) \quad F_{tot} = D_{av} * I * N * d$$

The above equations are used in chapter 4 to model consumption in private land transport.

Equation 6.1 gives the gasoline equivalent factor for an ethanol blend.

$$(6.1) \quad g_{eg} = S_g + g_e * S_e$$

Where

g_{eg} = Ethanol blend gasoline equivalent factor (lge/l)

S_g = Share of gasoline in blend

S_e = Share of ethanol in blend

g_e = Gasoline equivalent factor for ethanol (lge/l)

Assuming that the car needs the same amount of energy when running on gasoline or ethanol, the total fuel consumption can be calculated as:

$$(6.2) \quad F_{ee} = F_g * \frac{1}{g_e} * S_e$$

$$(6.3) \quad F_{eg} = F_g * \frac{1}{g_e} * S_g$$

The daily, required electricity for an all-electric car fleet is:

$$(7.1) \quad F_{el} = \frac{I_{el}}{1000\text{kWh/MWh}} * D_{av} * N$$

Where

F_{el} = Daily fuel consumption of electric vehicles (MWh/day)

I_{el} = Average fuel intensity for an electric vehicle (kWh/km)

Taking into account loss in the grid; the additional daily electricity required is:

$$(7.2) \quad F_{eltot} = F_{el} * (1 + l)$$

Where

F_{eltot} = Additional electricity required to fuel electric vehicles (MWh/day)

l = Share of loss in grid

To determine the actual energy used to generate electricity and therefore fuel the electric vehicles the yield of the different power plants on Mauritius is found.

$$(7.3) \quad \eta = \frac{E_{out} * 86\text{toe/GWh}}{E_{in}} * 100$$

Where:

η = Efficiency of power plants for a given fuel (%)

E_{in} = Energy input to the power plants for the given fuel (toe)

E_{out} = Energy output of the power plants for the given fuel (GWh)

86 toe/GWh is the conversion factor used by the CSO and is also used by the IEA[3, 14].

The total input fossil fuel to generate the required electricity is found from the following equations.

The required input to generate 1 kWh for a given fuel:

$$(8.1) \quad k = \frac{1}{\eta * c}$$

Where

k = Required fuel input per kWh for a given fuel (MJ/kWh)

c = 0.278 (kWh/MJ) conversion factor between kWh and MJ

Average required input to generate 1 kWh for a given electricity production mix.

$$(8.2) \quad K = \sum S_{el} * k$$

Where

S_{el} = Share of total electricity production for each fuel

Taking losses in the grid into account we get a total required fuel input per kWh of:

$$(8.3) \quad K_{tot} = K * (1 + l)$$

Where

K_{tot} = Total required fuel input per kWh for given electricity production mix (MJ/kWh)

It is then possible to calculate the total fossil fuel input to power electric vehicles:

(8.4) $E_{intot} = \frac{D_{av} * I_{el} * d * N * K_{tot}}{41840 MJ/toe}$

Where
E_{intot} = Total fossil fuel input to power electric vehicles for a given electricity production mix (toe/year)

41840 MJ/toe is the conversion factor as given by the CSO[3]. The IEA has a slightly different number for this conversion factor; they use 41868 MJ/toe[14]. However since most data in this thesis come from the CSO, the conversion factor used in this thesis is the one used by the CSO.

The required input of a given fuel is found by taking:

(8.5) $S_f = \frac{S_{el}}{S_{ff}}$

Where
S_f = Share for given fuel of total fossil fuel in electricity production mix
S_{ff} = Total share of fossil fuels in electricity production mix

(8.6) $E_{infuel} = S_f * E_{intot}$

Where
E_{infuel} = Required input of a given fuel for the given electricity production mix (toe/year)

The cost of import for the different scenarios can then be found:

(8.7) $C = \sum E_{infuel} * C_{fuel}$

Where:
C = Total import costs per year (Rs/year)
C_{fuel} = Unit import cost of given fuel (Rs/toe)

3. Background on vehicles and fuels

This chapter gives a short description of conventional vehicles and alternative vehicles. In addition it gives a description of possible fuels used; petroleum fuels and biofuels as well as electricity.

3.1 Private vehicles

Cars or automobiles are designed for passenger transportation and are most commonly powered by an internal-combustion engine (ICE)[15, 16]. An internal-combustion engine is either an engine where the fuel ignites by being compressed, as is the case of diesel, or where a spark, in the case of gasoline, ignites the fuel. Figure 3.1.a shows the major functional components of a conventional automobile, such as the motor and battery.

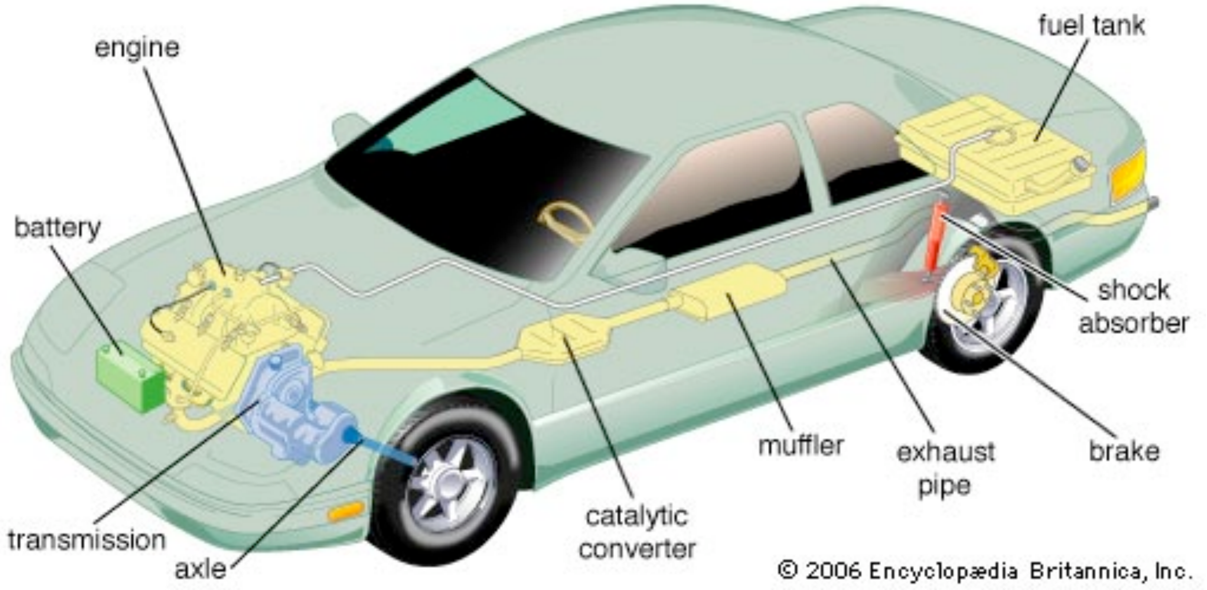


Figure 3.1.a: Major functional components of an automobile. [15] © 2006 Encyclopædia Britannica, Inc.

In an electric vehicle, electricity is used to power the motor. Electricity has a very high efficiency in an engine, as there is less waste to heat production and noise. The greatest challenge in running electric vehicles is the capacity of the batteries used. The capacity of the battery determines the range of the vehicle. The specific energy and power of the batteries limits the range of the vehicle. For batteries the specific energy can be in the range of 20 Wh/kg for lead acid batteries to 160 Wh/kg for the high-energy lithium-ion batteries. Lithium-ion batteries seem to be the most promising technology, in terms of capacity, and are the type of batteries that is considered in this thesis[17, 18]. An overview of specific energy and power for different types of batteries can be found in Appendix D. As a comparison; the IEA defines 1 toe as equal to 11.63MWh, or the specific energy of crude oil as 11.63 kWh/kg[14]. Therefore the added weight associated with the batteries for electric vehicles is significant. As a consequence of this and the high price associated with batteries today, electric vehicles are limited to a much shorter range than that of conventional vehicles. In addition the charging of the batteries takes several hours, where as for conventional vehicles it takes minutes to refuel.

In hybrid-electric vehicles batteries and ICEs work in combination in order to extend the range of a battery and to obtain higher fuel efficiency for the vehicle. The battery can be charged when using the breaks and therefore exploit energy that would otherwise be lost.

3.2 Petroleum fuels

Petroleum refers to the liquid, gaseous and solid forms of complex hydrocarbons found in the earth[19]. Although the term technically includes natural gas as well as some solids, here it will refer to the liquid forms, commonly called crude oil. Through distillation at different temperatures, the mixture of hydrocarbons can be separated into components such as gasoline, kerosene, gas oil and other hydrocarbon compounds[19]. Gasoline and diesel are readily used to fuel cars, while hydrocarbons such as kerosene, diesel, fuel oil and gas oil can be used to generate electricity.

There are several reasons why petroleum fuels are so widely used in the transport sector today. Petroleum fuels have a high energy density and are easy to transport and store. As the main fuel for the transport sector for decades, there is a well-established infrastructure for distribution. Petroleum fuels are also in high demand, as they power most of the world's vehicle fleet. The technology is well developed and there is a wealth of knowledge and experience to draw from[16].

There are, however, also a few disadvantages. The main ones are that petroleum fuels have high CO2 emissions, there is a limited supply and prices are variable and unpredictable. This has led to increased support from both governmental and private organisations to find alternatives to conventional vehicles and petroleum fuel[16]. For many countries, Mauritius amongst them, there are significant dependencies on other regions and countries connected to the limited supply of petroleum fuels[16]. Without its own extraction of oil, Mauritius is heavily dependent on import of fuels.

3.3 Biofuels

Biofuels are fuels produced from biomass. Liquid biofuels, such as ethanol, oil from plant seeds and biodiesel can easily be integrated in the current distribution system. Because little amendments have to be made to the current distribution system, biofuels have an advantage over other alternative fuels.

3.3.1 Ethanol

Ethanol, or ethyl alcohol, is an alcohol with molecular formula: C_2H_5OH. Other than its use as a transport fuel with gasoline, ethanol is important in the chemical industry as a solvent and to synthesize other organic compounds[20]. The discussion in this thesis is solely about ethanol for use in the transport sector.

3.3.1.1 Production process

Ethanol is produced by fermenting sugar by adding yeast or bacteria to the sugar. The following equation illustrates the reaction[21]:

$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$

The reaction only occurs until ethanol is about 10% - 12% of the blend[21, 22]. At this point excess water must be removed. Therefore the mixture is distilled until an acceptable percentage of ethanol is achieved.

Other than directly from sugar, ethanol can be produced from starch or cellulose, with the added step of hydrolysis[21]. Since sugar cane is the only source of ethanol considered in this thesis, this additional step will not be discussed.

3.3.1.2 Ethanol as a fuel for vehicles

To use ethanol as a fuel it needs to have a concentration of 95-99.8 %[22]. Ethanol used directly, in warmer climates such as on Mauritius, can contain small amounts of water. However, ethanol used in gasoline blends must have less than 1% water, as the water can cause problems with the fuel[22]. Although the energy content of ethanol is only about 2/3 of what exists in gasoline, the fuel consumption of an ethanol blend remains about the same as that of regular gasoline[22]. This is because ethanol has a high octane number and therefore reduces the overall knocking[21, 22]. Knocking occurs when the fuel ignites prematurely, and therefore does not contribute to powering the car. Blending ethanol with gasoline will reduce the number of times that knocking occurs, and more fuel will be used efficiently.

3.3.2 Other biofuels

Oil from some plant seeds, such as rape and palm can be used directly in diesel engines, or alternatively mixed with diesel. Many plant oils however must be converted into biodiesel, to be a viable fuel. Biodiesel is produced by combining the plant oil with an alcohol to produce an alkyl ester of fatty acid that is comparable with diesel[22]. As a fuel, biodiesel has a fuel efficiency approximately at the same level as diesel, even though the energy content is somewhat lower[22].

3.4 Electricity

Electricity is an energy carrier. As such it is not a source of energy but a carrier of energy.

3.4.1 Supply/demand

Electricity cannot be stored; the only option is to convert the energy into other forms such as chemical energy stored in batteries and potential energy such as water in a dam. Therefore most electricity systems are dependent on being able to generate electricity in the instant that it is needed, or if there is storage available, the energy must be converted when it is needed. As a consequence the generation of electricity is dependent on and in many cases equal to the system demand.

Different systems have different demand profiles. System demand varies by time of day, day of week and season. Warm climates will generally have a higher demand during summer due to cooling while colder climates generally have higher demands during winter, for heating. Because of variations the energy demand is generally divided into base load, intermediate load and peak load. Base load is the minimum power demand of the system, and is the amount of energy that must be produced at all times. The peak load however is the maximum power demand of the system, which generally lasts for only 15% of the time. In between these two is the intermediate load[23]. Different power plants are suited for the different loads, as their characteristics will tell.

3.4.2 Electricity generated from renewable energy

Generating electricity from renewable energy can be achieved by burning biomass in a thermal power plant. Electricity can be generated by using the mechanical force of water running from a higher-lying dam to a lower-lying power station. It can also be generated by using the mechanical force from wind or waves, or by using sunlight to create chemical potential in a photovoltaic cell. The downside to many renewable energy sources, with the exception of hydropower and biomass are that they are variable and not fully predictable. Wind, solar and wave power are dependent on weather, season and time of day. It is not possible to generate electricity from wind power when there is no wind. Also to fully exploit the potential of the power station, the system must be able to accept the power generated when the wind is blowing. The same can be said for wave power and to some extent solar power. Hydropower can also be somewhat dependent on the season, as dams need to be filled up by rain. However hydropower and electricity generated from biomass are controlled and can be generated when needed as opposed to when it is available. Hydropower is also very well suited for generating electricity for the peak load, as the time from low load to high load for a hydropower plant is quite small.

3.4.3 Fossil fuels in electricity generation

Fossil fuels can be used in thermal power plants to generate electricity. Here, they are burned in high-pressure boilers, gas turbines or reciprocating engines. Coal and bagasse on Mauritius are burned in high-pressure boilers to produce pressurized steam. The steam then rotates a turbine, which in turn is connected to a generator. Gas turbines and reciprocating engines are both internal combustion engines. Here the product gases from the combustion are used to rotate a turbine, in the case of gas turbines, or to move pistons back and forth, in the case of reciprocating engines[17]. On Mauritius gas turbines are used for electricity generation from kerosene, while reciprocating engines are used to burn diesel and fuel oil. Due to costs of operation and the time it takes to adjust the loads of the power plants, coal and bagasse power plants are used for base load and diesel and fuel oil power plants are used for intermediate load. The gas turbines are only used for emergency situations and breakdowns[24].

4. Transport development on Mauritius

This chapter will focus on the actual fuel consumption in the transport sector in Mauritius. First a description of the development of number of vehicles and infrastructure will be made. Then the total fuel consumption in the transport sector will be discussed. At the end of the chapter, the actual fuel consumption in private land transport will be modelled for the year 2010.

4.1 Development in number of vehicles

The number of registered vehicles in Mauritius has dramatically increased in recent years, as shown in figure 4.1.a. From 2009 to 2010 the amount of registered vehicles increased by 4.8 %. Out of these, the increase in cars and dual purpose vehicles was 6.4%, motor cycles and auto cycles increased by 4.2% while the rest of the fleet increased by 1.2%[25]. The estimated population increase was 0.44% for the same period, meaning that in absolute terms, vehicles per capita increased[26].

In 2011 there were 151 cars and 134 motorcycles and auto cycles per 1000 inhabitants on Mauritius. In 1990 there were 45 cars and 54 motorcycles and auto cycles per 1000 inhabitants[27-29]. In 21 years, the personal vehicle per 1000 persons increased by 190%.

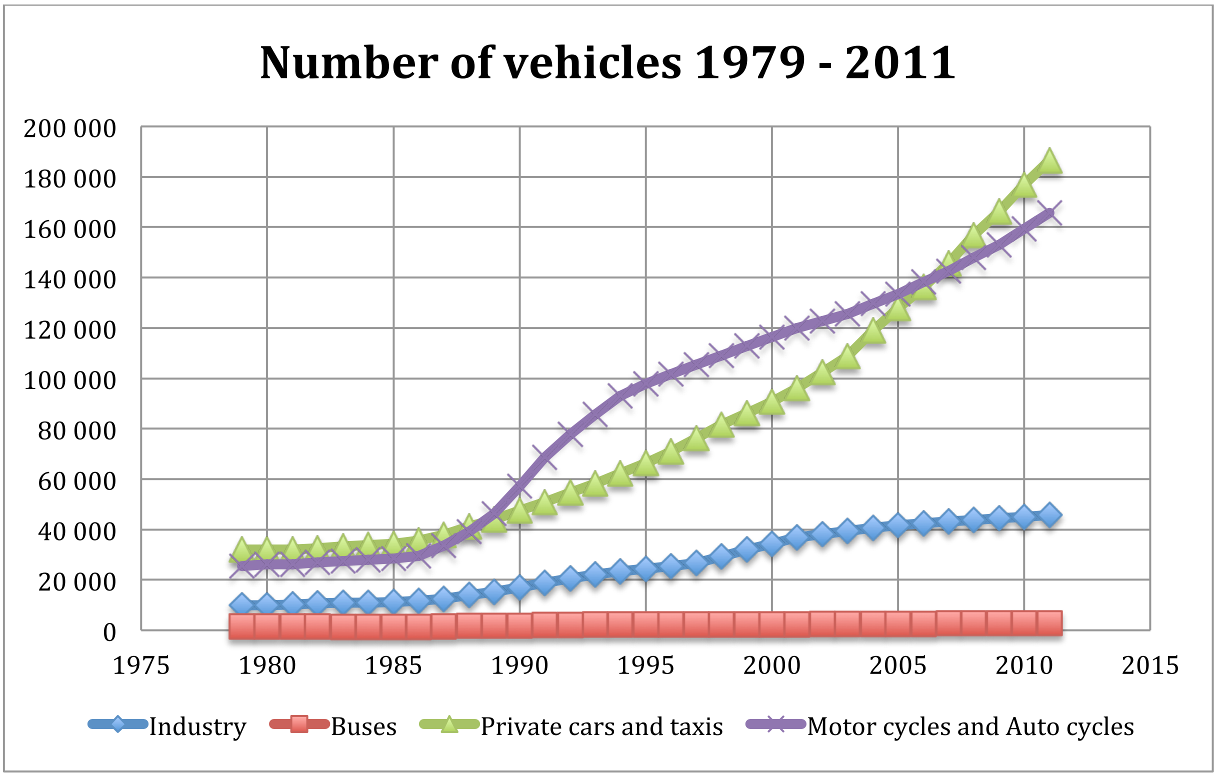


Figure 4.1.a: Development of number of vehicles on Mauritius 1979 – 2011[29].

There are three main reasons for the large increase in private vehicles. The gross domestic product (GDP) is defined by Britannica as "total market value of the goods and services produced by a nation's economy during a specific period of time"[30]. The GDP per capita in Mauritius has risen steadily the last 20 years[11], which means that more people have the means to own a private vehicle. Having your own car signifies social status in Mauritius. At the moment, there are no trains on Mauritius; therefore the only alternative to a private vehicle is the bus service or taxis. The existing bus service covers most of the island, with more than 2900 buses operating almost 260 separate routes[31, 32]. The scheduled frequency varies, usually there are from 1-4 buses per hour. However, bus services are perceived as "unreliable, hot and crowded" according to Mr Ramooah, the Transport Planner at the National Transport Authority[32]. Although the policy is to take buses out of service when they are 18 years old, there are still a number of old buses in operation, and breakdowns are "not uncommon"[32]. In addition there is no dedicated bus lane in the roads in and into Port Louis, which means that buses have no real advantage over other vehicles on the roads in terms of time it takes to travel a given journey. As a result, private vehicles are faster and are a more comfortable alternative, causing increasing congestion on the roads in Mauritius.

4.2 Infrastructure development

As the number of cars on the roads goes up, there is an increasing requirement for new roads and for maintenance on existing roads. From figure 4.2.a and 4.2.b we can see that the length of roads on Mauritius have increased after the amount of cars have increased. However although the number of cars/dual-purpose vehicles has increased by about 500%, the length of roads have only increased by about 16% the last 25 years.

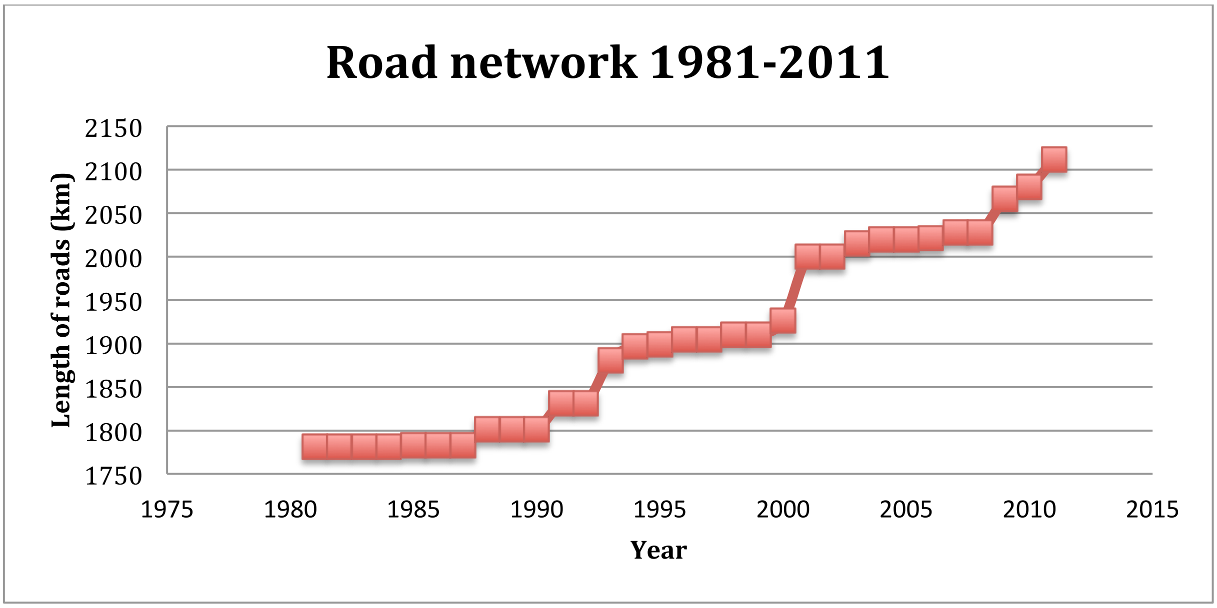


Figure 4.2.a: Development of road network 1981 – 2011. [33]

Figure 4.2.b shows the existing road network on Mauritius. About half of the total lengths of roads are main roads. The only motorway was 82km in 2011 and goes from Mahebourg in the south to a bit north of Port Louis. As Mauritius is a small island, there is a limit to how many new roads can be built. Since the number of vehicles on the roads has kept increasing, there is also an increasing problem of traffic congestion. Both the motorway

and two main roads go through the centre of Port Louis. The main work force is employed in the capital and the area from Curepipe to Port Louis is heavily populated. There is therefore typically large traffic congestion in the centre and in the immediate area of Port Louis during rush hours. Various measures are proposed by different departments of the government of Mauritius to solve the increasing traffic congestion around Port Louis, these will be discussed in detail in chapter 5; the immediate future of Mauritian transport.

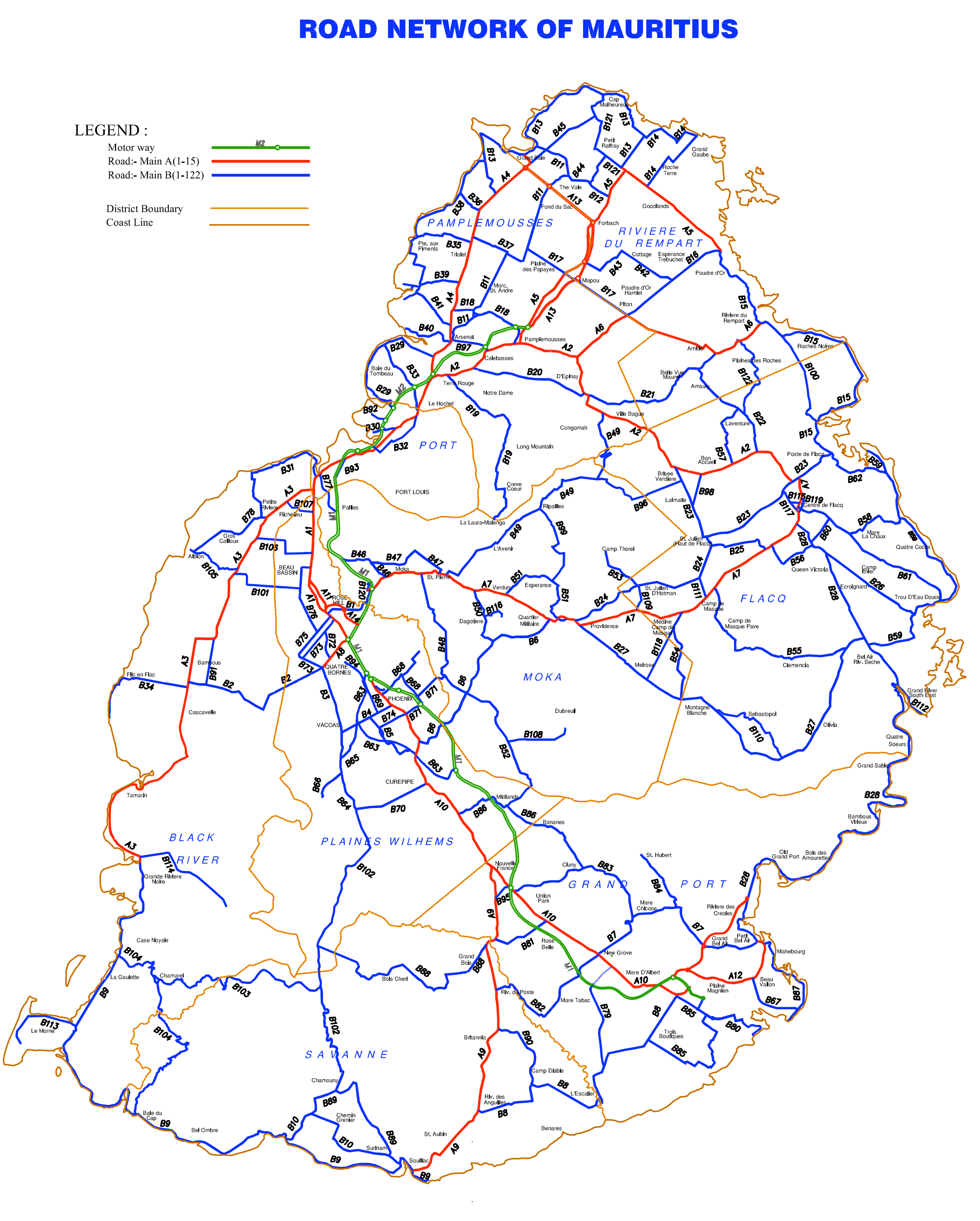


Figure 4.2.b: Overview of existing roads on Mauritius. [34]

4.3 Fuel use in the transport sector

As a consequence of a larger number of personal vehicles and the use of these, the consumption of fossil fuels in the transport sector has increased, although improvements in overall fuel intensity might lessen the impact some. Figure 4.3.a shows the consumption of gasoline, diesel and LPG in the transport sector from 1990 until 2011. These numbers are for the total transport sector however, and include all trucks used for industry as well as buses used in public transport. There are two graphs for each fuel type. The graphs with the addition – land gives data for the land transport only, this distinction was made from 2000 onwards. The other graphs include gasoline and diesel used in sea transport as well as land transport, and have data from 1990. As we see from the figure, the amount of diesel and gasoline used in sea transport is relatively small, it also shows little variation from year to year, which indicate that the use of such transport has been almost constant from 2000-2011[3]. We can therefore conclude that most of the increase in consumption of fossil fuels in the transport sector comes from the fuel used in land transport.

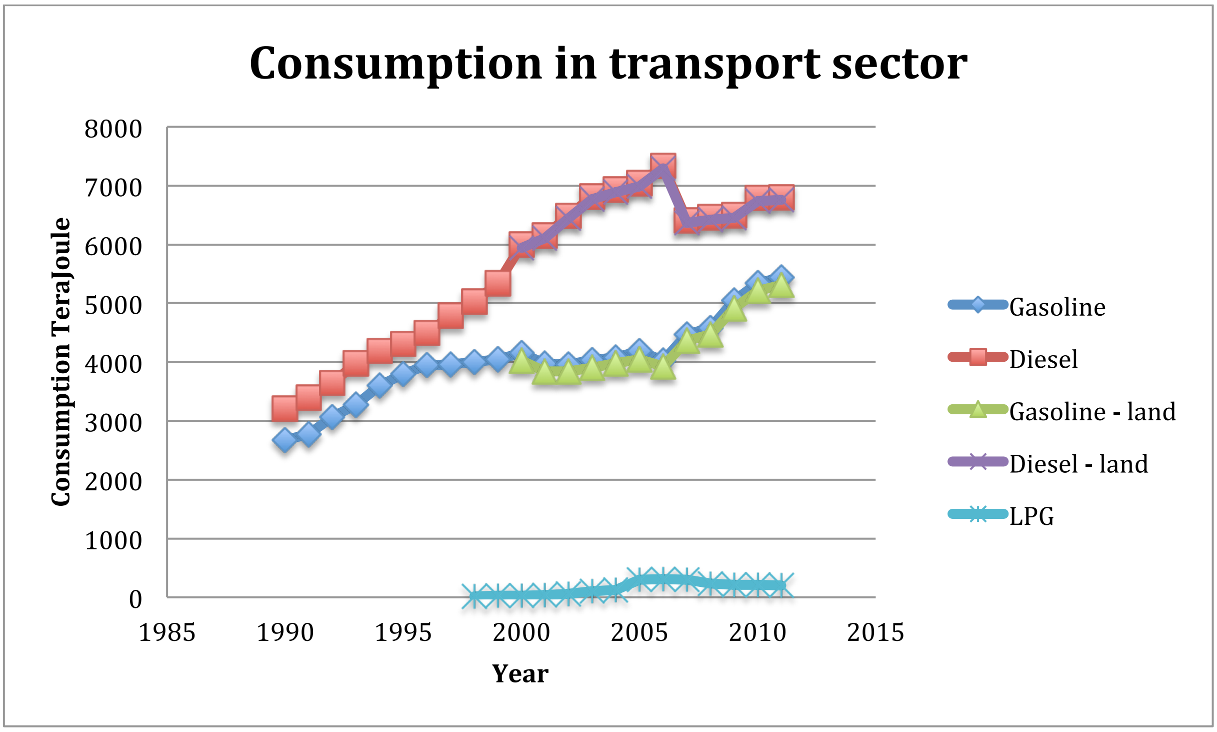


Figure 4.3.a: Gasoline, LPG and diesel consumption in transport sector TJ.[3, 35-39]

4.4 Fuel intensity

To model the use of fuel in private land transport, we first require a measure of the fuel intensity. Fuel intensity is here defined as fuel use per km travelled of a vehicle. There is an important distinction to be made between on-road fuel intensity and test values of fuel intensity. The test values of fuel intensity are obtained by driving vehicles in a series of test-cycles. The on-road fuel intensity of the vehicle fleet is much more interesting than test values from manufacturers, as it is a measure of the actual fuel intensity of the vehicle fleet. However it is also very difficult to obtain data for on-road fuel intensity. In order to get an accurate picture of on-road fuel intensity, extensive surveys of the distance driven and the fuel used must be taken[40].

Tested fuel intensities, ranging from 0.055 to 0.10 lge/km, for selected countries in 2005 and 2008 as part of an IEA analysis can be found in Figure 4.4.a in the appendix[41]. The on-road fuel intensity however is generally higher than the tested fuel intensity[17]. The on-road fuel intensity of the entire car fleets for selected developed countries is shown in figure 4.4.b in the appendix. That study shows that the fuel intensity for the fleets have been between 0.07 lge/ km to 0.13 lge/km the last 20 years[40]. Diesel cars use less fuel than similar gasoline cars, however because of, amongst other reasons, the relative size of new diesel cars compared to new gasoline cars, there is only a slightly lower fuel intensity of diesel cars[40]. A survey-based Chinese study of on-road fuel intensity showed 0.102, 0.086 and 0.090 l/km as the on-road fuel intensity for city, highway and composite driving respectively[42]. A similar Chinese study showed a real world average of 0.1138 l/km[43].

Mauritius is not amongst the countries surveyed in the studies mentioned here, however there is reason to believe that the fuel intensity of the vehicle fleet in Mauritius will be comparable to these studies. The import origin of cars in Mauritius is shown in Appendix E, with more than 80% of imports in 2010 coming from Japan and Asia. Although on-road fuel intensity differs from tested fuel intensity, we can use the studies mentioned above as an indicator for what the fuel intensity in Mauritius would be. For the purposes of this thesis it is therefore assumed that the fuel intensity in 2010 has been in the range of 0.07 lge/km to 0.13 lge/km.

Motorcycles and auto cycles will as a consequence of their smaller size and weight have much smaller fuel intensities than cars. Fuel intensity for motorcycles are not as widely analysed as that of the car fleet. A study of carbon emissions from America shows that the gasoline consumption per passenger of motorcycles are at about half that of the car fleet[44]. This would mean that the fuel consumption per vehicle is less again for motorcycles compared to cars as cars have a larger number of passengers. A small study from Taiwan have found the fuel intensity for motorcycles at around 40 km/l or 0.025 l/km for metropolitan Taipei[45], and an analysis of the fuel consumption in China show a fuel intensity for motorcycles as around 0.04 l/km [46]. For the purposes of this thesis, we will assume that the fuel intensity of motorcycles and auto cycles is 0.04 l/km.

4.5 Fuel consumption for private transport

Total fuel consumption of a vehicle is a function of the km driven by a vehicle and the fuel intensity of vehicles. According to a salesman at Nissan Mauritius, the average car on Mauritius drives about 15-20km/day[47]. The daily travel of each vehicle has a saturation level. There is a limit to how much car travel per day that is acceptable for people, and for some countries the travel per day has actually decreased in recent years[16]. At what actual distance the saturation level is found at varies between different countries. Survey-based data for selected developed countries gives an average saturation distance of 25 km/day (Japan) to 53 km/day (USA)[16]. 15-20 km/day therefore seems like a reasonable guess, as we would expect Mauritius to have a saturation distance closer to Japan than to USA because of the smaller size of the country. Also Mauritius, as a developing country, might not have reached the saturation distance yet, it is therefore reasonable to believe that the distance travelled is less than that of Japan.

Table 4.5-a: Number of vehicles registered in 2010 distributed on fuel type[48]

Total vehicles registered	**100%**	**380 000**
Gasoline fuelled vehicles	67.33%	260 000
Diesel oil fuelled vehicles	30.13%	110 000
Hybrid fuelled vehicles	0.04%	0
Electric fuelled vehicles	0.00%	0
Others	2.51%	10 000

In 2010 there were 160 000 registered motorcycles and auto cycles[29]. It can be assumed that all of these have a gasoline-fuelled engine. Another reasonable assumption is that all vehicles used in industry and heavy cars are diesel-fuelled. Therefore, based on table 4.5.a, the number of cars and dual-purpose vehicles was about 100 000 gasoline powered, 62 000 diesel powered and 10 000 LPG powered in 2010.

Drivers of the 10 000 LPG vehicles had a total fuel consumption of 8,6 million litres in 2010 which equals a vehicle average of 2.4 l/day by equation 4.1[39]. Table 4.5.b shows the corresponding distances for fuel intensities discussed above using equations 4.2 and 4.3. Calculations are made with a gasoline equivalent factor of 0.74 litres of gasoline /litre of LPG[49].

Table 4.5-b: Distances travelled by LPG vehicles based on fuel intensity, 2010*[39, 49]*

Fuel intensity (lge/ 100 km)	**Fuel intensity (l/km)**	**Average distance (km/day)**
7	0.09	25
10	0.14	18
13	0.18	14

The average travel distance estimate of 15-20 km/day seems consistent with the findings from table 4.5.b. However LPG cars only make up 2.5% of the total vehicle fleet of 2010, and we cannot base the whole population on these numbers. As a consequence the calculations in table 4.5.c and 4.5.d are based on three different average travel distances; 30, 20 and 10 km/day in addition to three different fuel intensities; 7, 10 and 13 litre gasoline equivalent/100km. The different combinations are defined as models 1-9 in the two tables. The gasoline equivalent factor of diesel is 1.12 litre of gasoline/litre of diesel[40].

Table 4.5-c: Total fuel consumption by diesel cars/dual-purpose vehicles for selected distances and fuel intensities 2010[39]

Model number	No. vehicles	Fuel intensity (lge/100 km)	Fuel intensity (l/km)	Average distance (km/day)	Total diesel (million l)	Total diesel (kton)
1	62000	7	0.06	30	42	36
2	62000	7	0.06	20	28	24
3	62000	7	0.06	10	14	12
4	62000	10	0.09	30	61	52
5	62000	10	0.09	20	40	34
6	62000	10	0.09	10	20	17
7	62000	13	0.12	30	79	67
8	62000	13	0.12	20	53	45
9	62000	13	0.12	10	26	22

Table 4.5-d: Total fuel consumption by gasoline cars/dual-purpose vehicles for selected distances and fuel intensities 2010 and corresponding motorcycle use[39]

Model number	No. vehicles	Fuel intensity (l/km)	Average distance (km/day)	Total gasoline (million l)	total gasoline (kton)	Rest gasoline (kton)	l/motor cycle	(km/day) motorcycle
1	100000	0.07	30	77	56	59	500	34
2	100000	0.07	20	51	38	78	700	45
3	100000	0.07	10	26	19	96	800	56
4	100000	0.10	30	110	81	35	300	20
5	100000	0.10	20	73	54	61	500	36
6	100000	0.10	10	37	27	88	700	51
7	100000	0.13	30	142	105	10	100	6
8	100000	0.13	20	95	70	45	400	26
9	100000	0.13	10	47	35	80	700	47

Table 4.5.c shows nine possibilities for the total consumption of diesel for cars/dual purpose vehicles in 2010. All of the possible total consumption values are less than the actual total consumption of diesel for all land transport in Mauritius. As there are no

readily available data on distances travelled and fuel intensity of diesel for buses, lorries and trucks on Mauritius, it is not feasible to attempt to validate this data any further.

Table 4.5.d is similar to table 4.5.c, but with results for gasoline-fuelled cars /dual-purpose vehicles. In addition the corresponding distances travelled per day for motorcycles/auto cycles has been calculated, with the assumption that the motorcycles has a fuel intensity of 0.04 l/km. As we have no further data for the utilisation of motorcycles, the results cannot accurately be validated any further than that all different models are possible.

5. The immediate future of Mauritian transport

The Mauritian government has developed several proposals for the future of the transport sector in Mauritius. This section looks at three specific plans; upgrading the road net, developing a bus-way/light railway and introducing a congestion charge. The suggestions discussed here are developed for the purpose of solving the increasing problem of traffic congestion around Port Louis.

5.1 Upgrading the road net

As a consequence of the increasing number of vehicles on the roads and the traffic congestion around Port Louis, the road network needs upgrading. Work has commenced to increase the capacity of the motorway M1 by transforming it from two lanes to three lanes of traffic[32, 50]. In addition, a ring road around Port Louis is being developed with the purpose of diverting traffic and therefore decreasing congestion during rush hours[32]. Both these measures will decrease traffic congestion in the short term. For the long term however, unless the growth of vehicle ownership decreases, a one-off expansion of the road net have little impact on reducing traffic congestion[51].

5.2 Bus-way or Light Rail Transit (LRT)

In the 1980s the government started planning for alternative means of transportation. The solutions have mainly focussed on two alternatives; a light rail transit or a separate bus-way. The separate bus-way is comparable with a light rail transit as it operates separately from the road net and is not accessible by cars or other traffic. Both of these alternatives are designed to range from Curepipe to Port Louis along the path of the old railway[32]. The main differences between these two alternatives are the fuel used and the passenger capacity. Both options are proposed to have shuttle buses and parking spaces in connection with the stations.

A study Halcrow Fox and MDS Transmodal conducted for the government of Mauritius in 2001 examines and compares these two alternatives[52]. According to this study, for the bus-way to be a viable alternative, the buses in service needs to be modernised from those in operation today[52]. The main reason for this is that the alternative to a private vehicle must be attractive to customers. The old buses are not attractive because they are uncomfortable and unreliable, as discussed in chapter 4.1. In addition, the buses would have to take about 150 passengers or more, travelling in groups of three, to function as a comparable alternative to the light rail transit in terms of passenger flow[52]. Typical buses in use on Mauritius today can be seen in figure 5.2.

Figure 5.2: Bus station in Mahebourg. (Photo: Paulen/Halvorsen)

Although the option of a bus-way, both a kerb-guided bus-way and an unguided bus-way, is cheaper; both in regards to operation as well as the initial investment costs; the social aspect as well as the environmental impact has made the LRT the preferred choice to develop[52, 53]. However, the study did not consider electric buses. Cost and reliability are two main concerns raised regarding building the LRT. Although more expensive than conventional buses, electric buses may prove less costly and more reliable than the LRT. Electric buses such as the Chinese firm BYDs K9 bus, have a driving range of up to 250km on a single charge, and will take from three to six hours to recharge[54, 55]. These buses would therefore be able to run the 25 km long trip from Curepipe to Port Louis ten times or five return trips on one charge. If there were to be difficulties either with the electricity supply, the signals or the tracks, the LRT has no option but to stop operation. A bus is able to divert to other roads. The decision to build a LRT has already been made, thus further studies to evaluate an electric bus service compared to the LRT is of little use. The LRT is at the planning stage; currently a Singaporean consultancy group has been appointed to develop an action plan regarding the construction of such a railway. This work was underway in September 2012[56].

In terms of reducing the fossil fuel dependency, the LRT will be fuelled by electricity, and will likely also replace some private vehicle consumption. However, to reduce the traffic congestion there must be supporting policies such as road pricing[53]. This would further encourage use of the LRT over private vehicles. At the moment there are no available projections of how much electricity that will be required to operate the LRT. The impact of this added electricity consumption could be compared to the impacts of added electricity consumption due to electric vehicles in chapter 7. The main difference here is that LRT does not use batteries, but will draw electricity from the grid at the time of use and therefore increase overall demand of electricity during operating hours.

5.3 Congestion pricing in Port Louis

Traffic congestion in Port Louis is so bad that police officers are stationed at roundabouts and intersections to control traffic. An example of this is shown in figure 5.3. Congestion pricing in Port Louis has the purpose of encouraging use of public transportation, or to divert private transport to other times of day. The proposed pricing scheme is to charge a fee on entering the city during rush hours[57]. Together with an improved public transport system, congestion pricing has the potential to reduce both fossil fuel consumption and traffic congestion significantly[53].

Figure 5.3: Rush hour in Port Louis. (Photo: Paulen/Halvorsen)

6. Alternative solutions for land transport on Mauritius

This chapter will focus on reduction of transport needs as well as a more detailed discussion of the proposed use of ethanol blends and other biofuels. The use of electric vehicles, and some other technology will be discussed in chapter 7.

6.1 Reducing transport needs

Technological new thinking plays an important part of reducing the fossil fuels dependency on Mauritius. However it is important to take into account that the most effective solution is to reduce the energy consumption, or in the case of the transport sector; reduce the use of private transportation. To reduce the overall demand for private transportation, there are two important behaviours that need to be stimulated: firstly, measures are needed to shift the use of private transportation to public transportation. These include introducing attractive and efficient public transportation such as the LRT or bus-way and introducing congestion pricing. Secondly, measures to make it more attractive to use non-motorized mobility such as walking and cycling should be considered. These include planning cities and communities in such a way that the length and frequency of necessary motorized travel is reduced and pedestrian and bicycling facilities is prioritized in the infrastructure[58]. Currently exhaust, absence of pedestrian facilities and a general warm and humid climate are factors that make walking and cycling on Mauritius less attractive than motorized transportation. An alternative to walking and cycling can therefore be electric bicycles or electric autocycles. Or use of electric tuk-tuks as an alternative to taxis and small delivery services. Figure 6.1 shows pedestrians at the afternoon rush hour in Port Louis, presumably to or from their cars, bus stops or shops.

Figure 6.1: Walking during afternoon rush hour in Port Louis. (Photo: Paulen/Halvorsen)

6.2 Biofuels

This section focuses on how biofuels can be used for transport on Mauritius in order to reduce reliance on fossil fuels. Mauritius has produced ethanol in the past and currently use bagasse for producing electricity, but there is no use of biofuels in the transport sector today. This section examines the potential production and consumption of bio-ethanol and also considers other possible sources of biofuels on Mauritius.

6.2.1 Production potential of ethanol from molasses

Due to the end of the Sugar Protocol in 2009, where the EU guaranteed a certain price for sugar from Mauritius and other countries, the sugar industry in Mauritius suffered a loss of 36% of its income[59, 60]. The sugar industry has long recognized that changes must be made for them to remain competitive. The centralization of the industry to four main factories and the export of electricity from the coal/bagasse cogeneration plants are measures that all the sugar factories have completed in order to become more profitable. Omnicane, the company owning the main sugar factory in the south of Mauritius, has also taken further measures to become more profitable. Examples of how Omnicane plans to utilize all parts of the sugar cane and the different products leftover from refining sugar are shown in figure 5.2. These measures include producing bio-ethanol and fertilizers from molasses and generating electricity from wind and hydro power plants. The production of bio-ethanol on Mauritius is based in the sugar industry. Molasses; a by-product from the process of refining sugar, is fermented and then distilled to fuel grade ethanol.

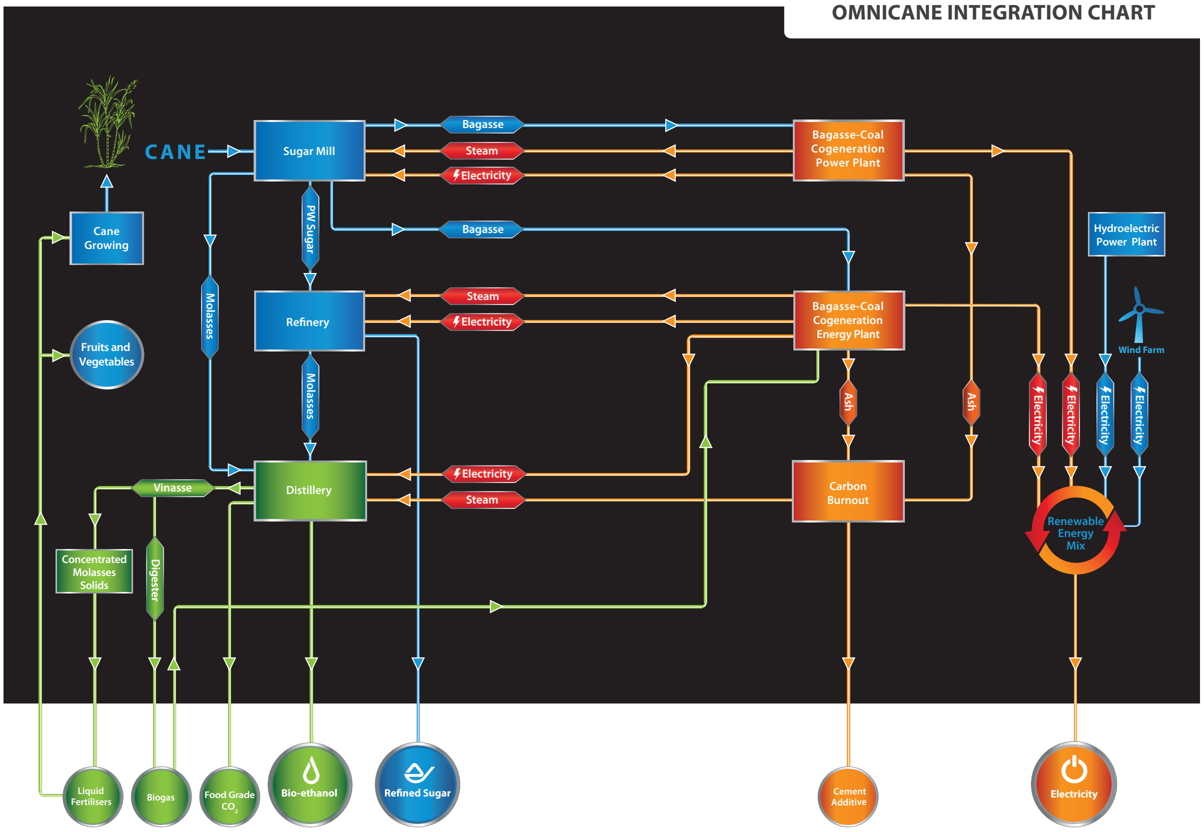


Figure 6.2.: Example of production of bio-ethanol as part of the sugar processing.[61] © Omnicane

The example of the integrated production plan from Omnicane in figure 6.2 is still not fully realised, as they are still waiting for authorization from the government. Nevertheless, it shows the possibility of taking advantage of all by-products of sugar production. The distillery part of the above scheme is planned to be operational by August 2013[61].

Omnicane estimates a production of about 17 l of ethanol per ton of sugar cane processed[59]. Every year they process about 1.5 million tonnes of sugar cane at their factory. The capacity of their distillery will be about 23 million litres/year, using 1.3 million tonnes of sugar cane. They also assume a harvest of 425 tonnes cane per hectare[59]. Using these numbers there is an expected yield of about 7200 l of ethanol per hectare. According to the IEA the global average yield of ethanol per hectare in 2010 was 5200 l/ha, with the assumption that 1 l ethanol equals 0,65 litres gasoline equivalent (lge) and that the world average yield is 3400lge [4, 62]. This means that Mauritius has a relatively high potential yield of ethanol according to Omnicane. About 60 000 hectares are used for production of sugar cane on Mauritius[61]. With 7200l/hectare, the total production potential of ethanol is 432 million litres. Using the more conservative world average potential the production of ethanol could reach 312 million litres. This is still a considerable amount that can be used for fuel.

6.2.2 Estimated consumption of ethanol

To achieve the goals of the MID project, a series of tests has been conducted to examine the potential of using ethanol blends in gasoline vehicles[32]. The planned introduction of E10, an ethanol blend with 10% ethanol by volume, has not yet been realised as of 2012. Depending on the success of this fuel blend, the government plans to increase the ethanol content to 20%, E20. The final goal is to have E20 as a mandatory fuel blend for gasoline vehicles[63].

Although ethanol can be mixed with diesel; the mixture is volatile and requires extra additives[22]. Therefore, in this thesis we only consider ethanol mixed with gasoline. Further the ethanol blends that will be considered are as proposed by the government of Mauritius; E10 and E20. As ethanol has lower energy content than gasoline, a vehicle using the same amount of energy will use slightly more ethanol blend than plain gasoline.

For the two proposed ethanol blends the gasoline equivalent according to equation 6.1 is 0.965 lge and 0.93 lge for E10 and E20 respectively. Corresponding ethanol and gasoline consumption for using ethanol blends in cars and dual-purpose vehicles can be found in Appendix F. For ethanol blends with the same fuel intensity as that of gasoline, the ethanol would displace 6.4% gasoline and 14.4% gasoline for E10 and E20 respectively.

In practice, the ethanol blend will displace more gasoline than that calculated above. The actual displacement will approach 10 and 20% because ethanol has a higher value of octane than gasoline and will therefore reduce the occurrences of knockback in the engine. Therefore, the actual fuel intensity will be higher for ethanol blends than for regular gasoline[22]. For the purpose of the comparison in chapter eight, vehicles fuelled by ethanol blends are assumed to use the same amount of fuel as that of vehicles fuelled by normal gasoline. As a result, the reduction of required fossil fuels import for private transport will be 1.4% to 5.6% for E10 and 2.8% to 11.2% for E20.

The production potential of ethanol that Omnicane predicts, will more than cover the ethanol consumption of using E10 for all gasoline-powered cars and dual-purpose vehicles. For E10, the ethanol required for the fuel ranges from 2.6 to 14.2 million litres depending on the consumption model. If all gasoline used in land transport in 2010 had been replaced with the E10 ethanol blend, the amount of ethanol needed would be 15.7 million litres.

For E20 the ethanol required for the fuel ranges from 5.2 to 28.4 million litres. As Omnicane forecasts a production of 23 million litres of ethanol per year, the planned production will not cover all consumption models for E20. Model 7 (0.13lge/km, 30km/day) has a total ethanol consumption that exceeds the planned production. Likewise, exchanging all gasoline for land transport with E20 will require 31.4 million litres, which exceeds the planned ethanol production by 8.4 million litres. This means that to supply E20 for all gasoline-fuelled land transport on Mauritius, an additional distillery is required. The production potential for ethanol from molasses on Mauritius is more than large enough to have ten additional distilleries. Therefore, one extra distillery to cover ethanol use on the island is reasonable. Any surplus ethanol produced can be exported to for example Europe.

6.2.3 Other sources of biofuels

Ethanol is the most readily available biofuel in Mauritius. A common criticism is that first generation biofuels can often do more harm than good. A recognized disadvantage in the production of biofuels elsewhere is that it takes agricultural land away from food production. As mentioned earlier, the country does not produce more than a small fraction of its own food requirements. Available land should therefore rather be used for food production than for biofuels. This is not the case with ethanol production as discussed in section 6.2.1. Here, the ethanol is a bi-product of the sugar production meaning the production fully exploits its potential, as long as sugar cane is prioritized ahead of other food production.

In addition to the scarcity of land for agricultural use, one must consider the use of phosphorus for transport energy. Phosphorus is an essential element for the growth of plants that cannot be substituted with anything else or manufactured[64]. The easily accessible reserves of phosphorus, namely phosphate rock, are expected to reach its peak production in this century[64-66]. Hence progress must be made to use the extracted phosphorus more efficiently as well as using more expensive methods to extract phosphorus from other sources. As scarcity of phosphorus will limit the growth of food, using phosphorus solely for the production of biofuels for transport, is not sustainable as long as other alternatives for fuel exists.

Micro-algae are well suited for biodiesel production as they have potential to produce large amounts of oil[17, 22]. The estimated yield of oil from algae is 7-31 times larger than that of palm oil which has the next best yield of oil[67]. Micro-algae can be grown in the ocean and therefore does not need to occupy land that could be used for food production. At the moment though, the technology for cultivating micro-algae for biodiesel is too expensive compared to conventional diesel or other sources of biodiesel[67]. In the future however, biodiesel from micro-algae might be the best alternative for fuelling Mauritian buses and trucks.

6.3 Compressed air vehicles and hydrogen vehicles

Motor Development International has together with Tata Motors developed a concept of a car fuelled by compressed air. The cars are small, light and can be run in urban areas on only compressed air. Also under development are compressed air vehicles that can run on both conventional fuel and compressed air, obtaining a fuel intensities as low as 0.02 for these hybrids[68]. Peugeot Citroen is also developing a hybrid that use compressed air in sync with conventional fuel. Here is a system where energy is passed back and forth between the compressed air and the motor of the vehicle used. The energy stored is only enough to accelerate to 50km/h, however according to tests the resulting fuel intensity for the vehicle is 0.029l/km[69].

Hydrogen vehicles use hydrogen to fuel the vehicle in one of two ways, either in an electrochemical reaction in a fuel cell or by burning hydrogen in an ICE. Use of hydrogen in a fuel cell is a very promising technology that causes no local pollution. Both technologies gives water as exhaust. Implementation of hydrogen vehicles requires large investments in the form of filling stations and hydrogen production plants. Because of lacking infrastructure, hydrogen vehicles make up a very small part of the global vehicle market. As a consequence, the vehicles are still quite expensive as there is no large-scale production. In addition, the fuel cells require some platinum materials, which are both rare and expensive[17, 70].

Although both compressed air vehicles and hydrogen vehicles are promising technologies that would reduce the fossil fuel imports for land transport, they are not ready for implementation on Mauritius. For hydrogen vehicles, the cost of an entirely new infrastructure is too much for the limited resources of Mauritius. While compressed air vehicles are still at the testing stages.

7. Electric vehicles on Mauritius

This chapter examines the advantages and disadvantages of replacing parts or all of the car/dual purpose vehicle fleet with electric vehicles. First an analysis of the energy sources for electricity will be made.

7.1 Electrical grid

The most conventional source of energy for electric vehicles is the national grid. The electricity grid on Mauritius is a completely isolated system[71]. This means that there is no exchange of electricity with other systems. A consequence of this together with the lack of natural resources is that all fuels for electricity generation, except for electricity generated from bagasse and renewable energy sources, must be imported in liquid or solid form, commonly as fossil fuels.

7.1.1 The current situation

The demand and therefore the generation of electricity vary during the day. In Mauritius there is generally a peak power demand in the morning and the early afternoon. This can be clearly seen in figure 7.1.a, which shows the generation of the various power stations for 18. February 2009. The figure shows that there is a high demand for electricity during working hours (09.00 – 16.00) and an additional peak in the evening (19.00- 22.00), when people get home from work. February is in the summer in Mauritius and for 2009 this date was the highest peak[72]. The Central Electricity Board is a company under the Mauritian government that is responsible for generation and distribution of electricity in Mauritius[71, 72].

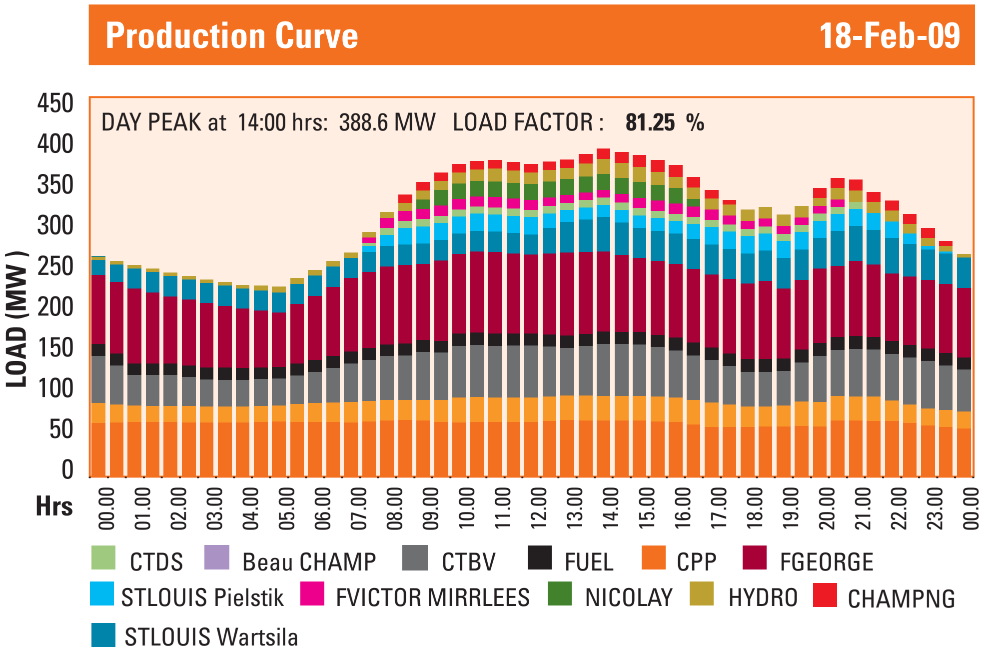
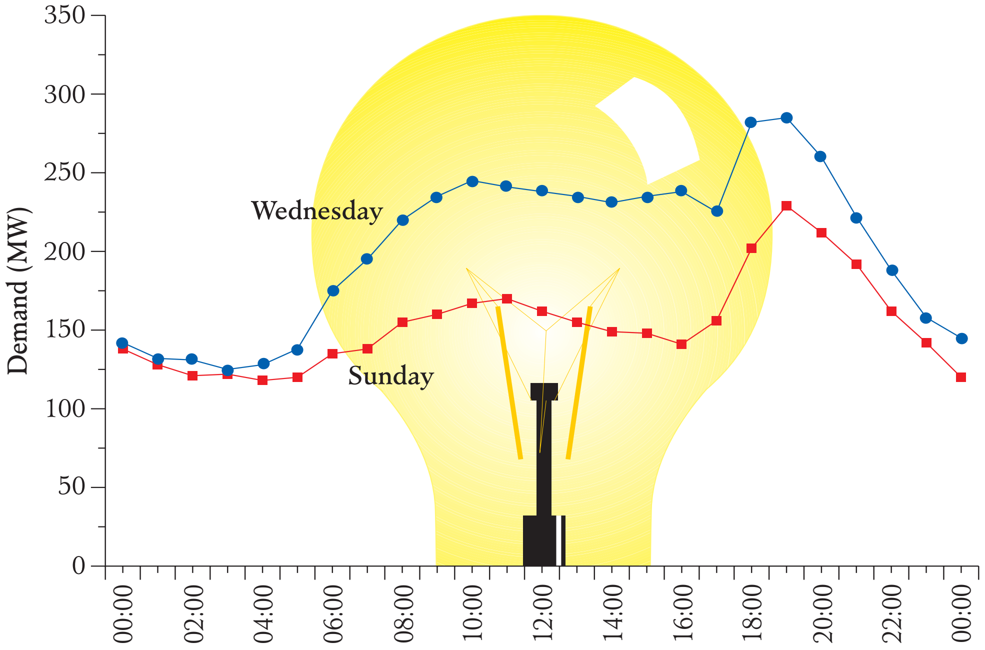


Figure 7.1.a: Electricity generation curve, Island of Mauritius 18. February 2009. [72] © CEB

Figure 7.1.b shows the variations between workdays and weekends for a summer week and winter week in 2003. Although the actual data presented in this figure may be out-

dated, the demand profile has kept approximately the same shape according to the Central Electricity Board (CEB)[71]; it is therefore a useful indication for our analysis. Electricity demand during the summer months is generally higher due to a higher need of power for cooling such as ventilation, air conditioning and refrigeration. The difference in demand during the morning/mid day peak in figure 7.1.b shows this quite clearly. The peak power demand has continued to increase since 2009. In 2011 the peak demand was 412.5 MW and in 2010 it was 404.1MW on the Island of Mauritius[3]. This is the level of electricity generation that the CEB must be able to cover.



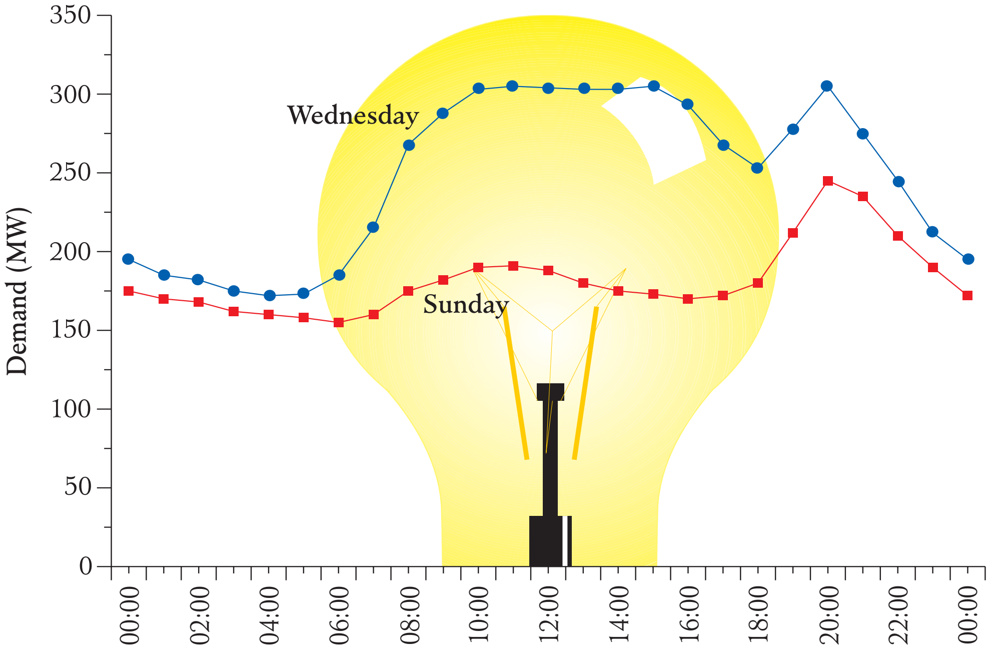


Figure 7.1.b: winter demand profile (top) and summer demand profile (bottom) 2003.[73] © CEB

Although CEB is responsible for generation of electricity, there are also a number of Independent Power Producers (IPPs). Today all generation from coal and bagasse are provided by IPPs. The sugar factories in Mauritius use a coal/bagasse cogeneration to provide their own power and also export any surplus electricity to the CEB. Through its contracts with the IPPs the CEB has committed to buy any surplus electricity that the IPPs generate(*62*). The IPPs, which in table 7.1.a are generating all energy relating to the following sources: Landfill gas, coal and bagasse, supply almost 60% of the total electricity consumption on Mauritius[3].

Table 7.1-a: Electricity generation by source of energy, 2010 - 2011*[3]*

Source of energy	**2010 (GWh)**	**2010 (%)**	**2011 (GWh)**	**2011 (%)**
Hydro	100.7	3.7	56.5	2.1
Wind	2.5	0.1	2.8	0.1
Landfill gas	-	-	3.1	0.1
Gas turbine (kerosene)	18.9	0.7	11.6	0.4
Diesel and fuel oil	976.6	36.3	1058.7	38.8
Coal	1039.5	38.7	1108.2	40.6
Bagasse	550.4	20.5	489.5	17.9

In October 2011 the Sotravic Group, a Mauritian company, started operating an electricity power plant fuelled by landfill gas. The plant is expected to generate a total of 110GWh the next 5 years, or an average of about 22GWh per year[74]. From table 7.1.a we can see that the plant produced 3.1GWh from it opened in October till the end of 2011. The generation of electricity of the landfill was projected to reach its peak generation potential in 2012, and therefore the yearly generation will decrease in following years, according to Surroop and Mohee[75].

It is important to take into account the current electricity system when considering an electric car fleet and the impact it will have on the system. With a good understanding of the situation today it is easier to avoid problems and take advantage of possibilities connected to implementing electric vehicles. This is discussed more in chapter 7.2 and 7.3.

7.1.2 Future electricity demands and generation plans

The CEB's main responsibility is that there at any given time is enough electricity produced to meet the demand. As the peak demand for a year rises, the CEB must be able to produce that amount of power. The IPPs have priority over the CEB in the generation of electricity on Mauritius[71, 76]. As a consequence, CEBs power plants are not fully exploited, and often run at a less than ideal load, as they must still be able to meet the peak demand. The effective capacity of the existing power plants were 655.2 MW for 2010 and 659.2 MW for 2011 in the Island of Mauritius[3]. The capacity of each plant for 2011 can be found in Appendix G. There is a good buffer at the moment with a 265.8 MW difference between total effective capacity and the peak power demand. This buffer is needed in the event that power plants are unable to deliver power due to scheduled maintenance or due to breakdowns.

Meeting peak demand is the main challenge for the CEB. The government has targets for which mix of energy sources that should be achieved. These are set out in table 7.1.b. Although these targets have a higher share of renewable energy in the production mix, the CEB must be able to meet the peak demand in the case that renewable sources such as solar and wind does not generate the required amount. This can be achieved by having the capacity to cover the peak demand with power plants, which can be regulated, such as those operating on fossil fuels, bagasse, waste and hydro. Another alternative is to employ storage of electricity that can make up the difference during peaks.

Table 7.1-b: Government targets for the energy mix up to 2025. *[5]*

Year	Coal	Kerosene	Fuel oil	Solar	Wind	Hydro	Bagasse	Waste
2007	42%	1.2%	36.8%	0%	0%	5%	15%	0%
2020	46%	1%	20%	5%	5%	3%	15%	5%
2025	35.5%	1%	20%	10%	10%	2.5%	15%	6%

Several new power plants are planned, a 10MW PV power plant, a wind power plant of about 29MW and a new coal power plant[71]. Due to its nature, PV power plants are ideal to cover the midday peak demand, as that is the time the PV power plants produce electricity. In addition, as different means of cooling is a major power draw, it follows that the days the sun is giving the most heat and power, there is also a greater need for that energy for cooling. PV power plants cannot produce any power during the evening peak, as this occurs after the sun has set. Wind power is less predictable and also has seasonal variations, and is therefore even more difficult to incorporate into a small system. The planned new coal power plant on Mauritius will use pulverized coal technology and have a capacity of 110MW[77]. Pulverized coal power plants have full load efficiencies ranging from less than 30% to more than 40% depending on the operating temperature and pressure[17]. For the purpose of this thesis is it assumed that the planned coal power plant will operate with an efficiency of 30%.

Although government targets calls for more renewable energy in the production mix, the incorporation of such sources are difficult to manage in a small system such as Mauritius. The use of fossil fuels in the electricity generation is not only because of economic factors, but also due to the practicality of being able to regulate the production.

7.2 Available electric vehicles

Today there are no electric vehicles in use on the island, Nissan has imported five Nissan Leaf, but are waiting for the government to provide incentives to facilitate battery electric vehicles (BEVs)[47]. The current policy from the government of Mauritius however does not include extra incentives for the procurement of BEVs at this time[32].

Hybrid vehicles have the potential for much better fuel intensity than conventional vehicles. However manufacturers to date often use the extra power available to enhance performance, for example acceleration, rather than fuel intensity[17]. A study by the American Energy department gives tested fuel intensities as between 0.129 to 0.052 l/km for selected hybrid electric vehicles [78]. The best hybrid electric vehicles have better fuel intensities than conventional vehicles, however this varies with the model. The Toyota Prius, which was one of the models with better fuel intensity in the study above, is one of the hybrids available on Mauritius.

Mauritius is a small island; it should therefore be possible to take most trips with a BEV on one charge, unless you want to view the entire coastline of 177km in one trip. As BEV already have a long enough range to cover most driving needs on the island, Plug-in electric hybrids (PHEVs) are not considered in this thesis as most PHEVs are alternatives to BEVs that extend the range for the vehicle.

There are a number of electric vehicles available with different types of batteries, costs and driving ranges. Ranges of a BEV can be from 30km (Buddy Electric) to 500km (Tesla Motors) per charge[79]. For the purpose of this thesis, the Nissan Leaf will be used to model the consequences of substituting the conventional car/dual purpose fleet with electric vehicles. The Nissan Leaf available on Mauritius today has laminated lithium-ion batteries with a total energy capacity of 24kWh and a total voltage of 360V. The standard charging equipment needs about eight hours to completely charge the batteries, suggesting that the capacity of the power outlet is 3kW. There is also a quick charging connector that charges 80% of the battery in 30minutes. This equates to a capacity of the power outlet of about 38kW. The battery itself has a power of over 90kW. The specified range of one charge is 160km[47, 80].

With a range of 160km on a 24kWh battery, the expected energy use/km from the grid is 0.15kWh/km. Assuming that electric vehicles would be used for the same purposes as conventional vehicles, table 7.2.a indicates the electricity used if all cars/dual purpose vehicles in 2010 had been electric vehicles with the same average distance travelled (km/day) as that used in the calculations of fuel use in chapter 4. The number of cars used here is 172 000, the total number of gasoline-, diesel- and LPG-powered vehicles used in the calculations in chapter 4. Also calculated is the additional production of electricity necessary when using electric vehicles considering a 10% loss in the grid.

Table 7.2-a: Electricity consumption of an all-electric fleet of cars/dual-purpose vehicles of the same siza as the car/dual-purpose vehicle fleet on Mauritius 2010. Based on specifications for Nissan Leaf.

Average distance travelled km/day	Energy efficiency kWh/km	Electricity used (MWh/day)	Loss in grid (%)	Additional electricity produced (MWh/day)	Additional el produced (GWh/year)
10	0.15	258	10	287	105
20	0.15	516	10	573	209
30	0.15	774	10	860	314

The total generation of electricity in 2010 was 2689GWh. Electrification of the car/dual purpose vehicle fleet in 2010 would have increased the required electricity production by 4-12%.

7.2.1 Efficiency of converting fossil fuels to electricity

For electric vehicles to be a viable alternative for reducing carbon emissions and fossil fuel dependency, the electricity grid needs to be more ”green” and less dependent on fossil fuels [81]. This section examines how efficient the power plants on Mauritius convert energy from the input of fossil fuels to the output electricity. As the majority of the electricity generation is based on coal and fuel oil, it is necessary to measure the consumption of these fuels used in the electricity generation in order to estimate how much fossil fuels electric vehicles charged by the grid would consume.

The average efficiency of coal/bagasse cogeneration plants is calculated here:

Coal/bagasse cogeneration plants[82]:

Total coal input:	399000 toe
Total bagasse input:	182000 toe
Total energy input:	581000 toe
Electricity output:	137000 toe

$$\frac{137000toe}{581000toe} = 0.236$$

The average efficiency of electricity generation from the coal/bagasse cogeneration plant was 23.6% in 2010. Table 7.2.b show this calculation for all the energy sources listed, including separated coal and bagasse. The coal and bagasse however is only used in coal/bagasse cogeneration plants to date.

Table 7.2-b: Average efficiency (%) of electricity generation processes in Mauritius for different fuels 2008-2011. *[3, 36]*

	2008	2009	2010	2011	Average 2008-2011
Kerosene	26	25.7	26.0	26.2	26.0
Diesel and fuel oil	43.7	43.4	44.0	43.9	43.7
Coal	25.7	24.5	24.1	24.9	24.8
Bagasse	20.1	23.0	22.3	23.5	22.2

The most efficient of these power plants are the diesel and fuel oil power plants with an average efficiency of almost 44%. However the coal/bagasse generation plants do not only generate electricity, but also produce steam. This is an important element used in the process of refining sugar from sugarcanes. The production of steam and generation of electricity to use in the sugar factories are the primary objective of the coal/bagasse cogeneration plants. Therefore, even though the efficiency of these power plants is not as high as for example that of the diesel and fuel oil power plants, they are an integral part of the sugar industry. This is an economic factor that must be considered for the island as well as purely looking at the efficiency of the plants. Chapter 8 explores the impacts on the fossil fuels dependency of Mauritius caused by fossil fuels based electricity generation for use in BEVs compared to that caused by fossil fuels consumption in ICEs.

7.3 Challenges of using electric vehicles

The challenges of using electric vehicles as an alternative to ICE vehicles lies in both the energy supply and the distribution of energy for the batteries.

7.3.1 Production and grid capacity

Consider the all-electric cars/dual purpose vehicle fleet discussed above, where all cars/dual-purpose vehicles are replaced by electric vehicles. In the event that all the electric cars are charged at the same time, 516MW would be drawn from the grid. Although it is unlikely that all vehicles would be charged at once, there is still a possibility of it occurring. It is possible that electric vehicle owners returning from work immediately would plug in their BEV for charging, coinciding with the evening peak electricity demand. If 75% of the BEV started charging at that time, the extra draw from the grid would amount to 387MW. This would almost double the peak demand for the evening, and consequently require much more installed capacity for electricity production as well as an upgrade of the distribution grid.

The same would also hold true for charging of BEVs during the mid-day peak, especially during summer. The planned 110MW coal plant could generate sufficient power to charge 20% of the BEVs during peak hours, if none of the old power plants are phased out. The purpose of the new coal plant is to secure the increasing electricity demand on Mauritius; it is not to facilitate electrification of the car fleet. Therefore, in order to ensure sufficient capacity to allow BEVs to be charged during peak demand, the total reliable capacity would have to increase. To achieve this, more fossil fuel based power plants needs to be installed in the case of charging during the evening peak. Or alternatively, if the charging occurs during the mid-day peak, PV power plants could be used.

7.3.2 Expenses of electric vehicles vs. internal combustion engine vehicles

Although the cost of fuel via electricity is lower than the conventional fuels for cars, the investment costs of electric vehicles cannot yet compete with that of the conventional vehicles.

Figure 7.3.a shows the yearly fuel costs of different types of fuels for the 9 models for consumption discussed in chapter 4. The prices used in the figure to determine fuel costs are average retail prices of fuel and average price of electricity for 2010[39]. As this figure clearly shows, the electric vehicle is much cheaper to run for the private consumer. The cost of the electricity compared to fossil fuels ranges from 36% to 14% of the cost of fossil fuels depending on the fuel intensity and the length travelled. The fuel intensity and length travelled corresponding to the models one to nine can be found in Appendix C and also correspond to the data in table 4.5.d and 4.5.e.

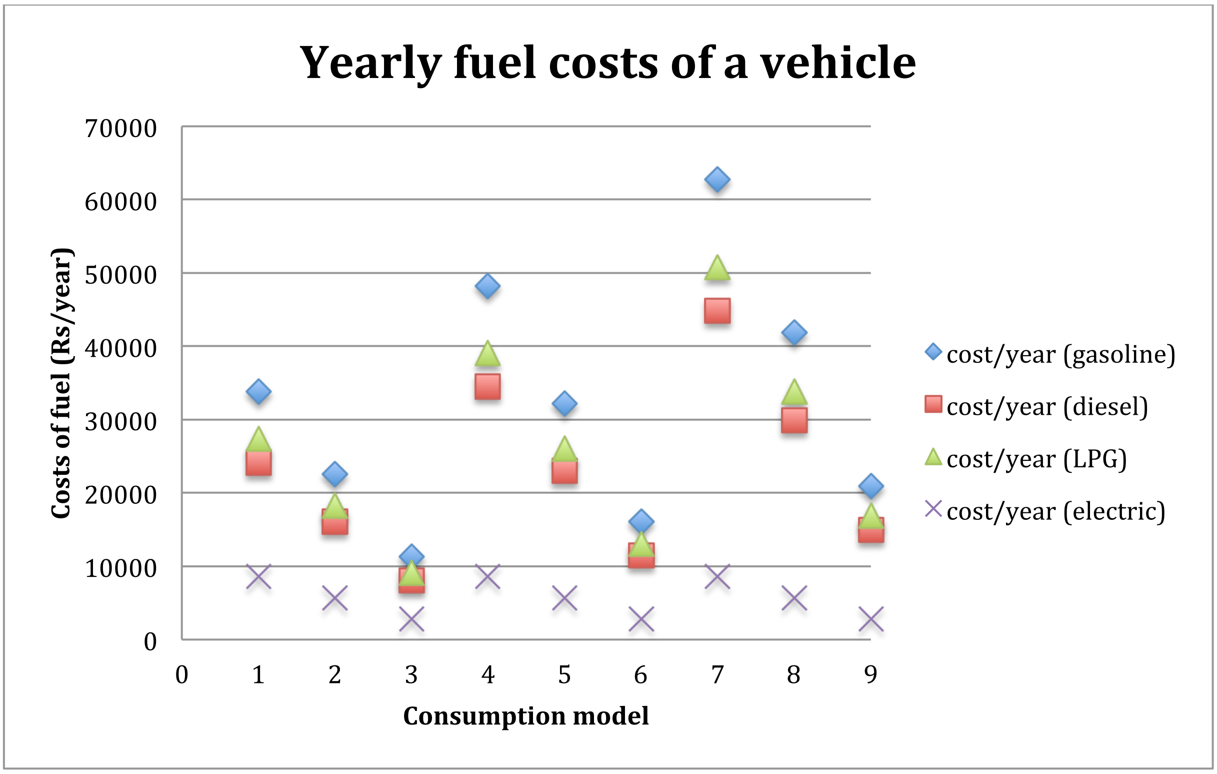


Figure 7.3.a: Yearly fuel costs of a vehicle for the consumer. [3]

The electric vehicles have a much higher initial investment cost than conventional vehicles due to the cost of the battery. The costs of batteries are expected to decline as more efficient batteries are developed, and as electric vehicles are produced in greater numbers[17]. At the moment the Nissan Leaf has a price of about 1.5 million rupees, while the conventional vehicles has prices ranging from about 600 000 rupees to 1.24 million rupees[83], making conventional vehicles the cheaper option. Unless the government incentivises the purchase and use of electric vehicles through tax reliefs or other measures, it is unlikely that electric vehicles provide a viable option for consumers. This may change in the future if battery costs decline or oil prices rise sufficiently so the benefits of a lower electricity price outweighs the additional initial costs of the battery[16, 17]. Setting speculation of future costs of batteries or oil aside, the success of electric vehicles will be driven by government intervention measures.

7.4 Advantages of using electric vehicles

There are many advantages to using electric vehicles on Mauritius. It can improve storage of electricity for the grid, the local environment would benefit from cleaner air and the global environment could also benefit. These advantages are discussed below.

7.4.1 Night time charging

As mentioned earlier in this chapter, the unregulated charging of electric vehicles could lead to a dramatic increase in peak demand for Mauritius in aggregate. Night time charging means that all electric vehicles are charged at night. It could be facilitated by connecting a timer to the charger allowing charging between 23.00 and 07.00. Thus night time charging would diminish the problem of increasing demand for power at peak times.

Night time charging could also give additional benefits to the power generation system. Increasing the base load to a level where the power plants that supply the base load are allowed to operate with higher loads, will increase the average efficiency of the power plants[17]. The IPP thermal power plants have an effective capacity of 240.5 MW while Fort George, a diesel power plant operated by the CEB, has an effective capacity of 137MW[39]. Hydro power plants are best used as a reserve for rapid changes in the demand, and the other thermal power plants are either too expensive to operate except in emergencies, or are supposed to be phased out by now[71]. Therefore, for the purpose of this thesis we assume a total effective capacity for base load to be 377.5MW.

Based on the base load in figure 7.1.a we can assume base load at around 250MW in 2010. With a total efficient capacity for base load of 377.5MW, the available capacity for night time charging would be around 130MW. This would be sufficient to charge 25% of the total all-electric vehicle fleet at the same time. Assuming that each BEV is driven 10km/day, the vehicle would require charging every 16 days, or if each BEV is driven 30km/day, the vehicle would need to be charged every five days. For both these scenarios, implementing night time charging is a sufficient measure to ensure that the total all-electric fleet could be implemented within the existing capacity. Measures to prevent that more than 25% of the fleet were charging at the same time should be implemented.

7.4.2 Electric vehicle batteries as storage for the grid

Having a fleet of electric vehicles can translate to having a fleet of batteries. For the electric grid, it would be an advantage to be able to utilize these batteries as energy storage and power capacity for the grid. In the long term, with an intelligent charging system, the electric vehicles can be programmed to charge when there is generated a surplus of electricity. This will enable the power companies to incorporate more variable energy sources such as solar, wind and wave power. With a vehicle-to-grid (V2G) system, electric vehicle batteries could supply electricity to the grid when the demand is high. Simulations of a V2G system for Denmark estimates that even during rush hour, more than 80% of vehicles are parked[84]. The evening peak demand of about 100MW more than base load, lasting for about 4 hours, requires about 400MWh. If all this were to be covered by electric vehicle batteries, it would require the full battery of about 17 000 Nissan Leaf. More realistically if 25% of the battery are made available for the grid, a total of about 68 000 vehicles connected to the grid would cover peak demand. If 80% of the vehicles were parked and 50% of the parked vehicles were connected to the grid, an all-electric vehicle fleet, equivalent to that of 2010, would have 68800 vehicles connected to the grid. This would be sufficient to cover peak demand during the evening using 25% of the total battery capacity. The actual integration of such a system would require communication and real time control systems. In addition, the success of such a system requires charging stations at each parking space. This results in high implementation costs for this option.

Another alternative to use electric vehicle batteries, as storage for the grid is to switch batteries with fully charged ones. The company “Better Place” that operates in Denmark, Israel and several other countries uses this concept[85]. The concept involves battery switching stations and charging many batteries together. Compared to the V2G concept it is a less complex system, as there is no need to keep track of the charging requirements for each individual vehicle. Instead the batteries that require charging can be treated as one unit. However there is a need of an extra amount of batteries in order to have available batteries fully charged at switching stations.

7.4.3 Solar power charged BEVs

Directly charging electric vehicles from solar power is an alternative to charging with power from the grid. Using solar power directly circumvents some of the problems with grid capacity. However the grid must be able to accept and use the electricity generated from the PV power plants when it is not used for charging the vehicles. Thus it must be possible to regulate other power plants to generate less electricity. In addition the fuel for electric vehicles would be from a completely renewable source. BEVs charged with solar power would therefore remove the fossil fuels dependency of those vehicles completely.

There is a great potential for solar power on Mauritius. There is 2000-2250 hours of sunshine per year. Average radiation is 5.4kWh/m^2 each day[86]. With a practical efficiency of 10 – 30%, the average daily electricity generation would be 0.54 – 1.62

kWh/m^2 for photovoltaic cells[21]. A car driving 30km/day would require 4.5kWh/day, this is equivalent to between 2.8 and 8.3 m^2 of photovoltaic cells.

One of the main challenges of using photovoltaic cells to power electric vehicles is the placement of the solar panels. To use the photovoltaic cells for electric vehicles, the vehicles need to be connected to the charger during the day when the sun is up. Although 8m^2 per vehicle is not a lot to put on the roof of a private house, the electric vehicles are most likely not parked at home during the day. Charging at work would require photovoltaic installations at the workplace as well as a charging network for multiple vehicles. The rooftop space would be less per charging vehicle than that of private houses, and would restrict the number of vehicles that can be charged this way. However with charging stations and PV panels connected to the grid, this restriction will disappear.

An alternative is to have rooftop photovoltaic cells connected to the grid and charging stations for electric vehicles at the workspace. However this would add to the midday peak demand, as this peak fits well with the solar radiation of a day, and may require an upgrade in the grid capacity. In the event that solar power is not available, the added demand from daytime charging of electric vehicles would have to be provided by other power plants. Photovoltaic cells might be more suitable for covering the midday peak demand than charging electric vehicles through the grid.

7.4.4 Local and global environment

Electric vehicles have no tail-pipe emissions. A shift from conventional vehicles to electric vehicles would therefore greatly improve local environment in terms of air quality and pollution. In addition the general traffic noise would decrease with use of electric vehicles. On a national and global level, environmental impacts depend on the source of energy supply. Fossil fuel power plants emit pollutants in the air and contribute to increasing carbon dioxide in the atmosphere, thereby contributing to global warming. Electric vehicles running on electricity from renewable energy, would account for no air pollution, however there are various other factors to consider for the environment. Examples are production and disposal of photovoltaic cells, ecological impacts of establishing hydro power plants and visual and noise impacts of wind turbines.

8. Comparative analysis of scenarios for private transport

This section will compare the fossil fuel consumption of conventional vehicles running on diesel and gasoline or ethanol blends with gasoline to that of electric vehicles. Four different scenarios are considered. The first scenario considers electricity generated by the same energy mix as that of 2010. Here the share of the different energy sources remains the same as that which was generated in 2010. The second scenario considers electricity generated by the energy mix that is the government target for 2025. The third scenario considers electricity generated from coal only. The fourth and last scenario is one where all electricity used to fuel the electric vehicles is generated from renewable energy sources.

The comparison will only consider using electricity and bioethanol as fuel for cars and dual-purpose vehicles; the fuel for autocycles and motorcycles will remain gasoline. In addition in the scenarios considered here it is assumed that the first vehicles to be replaced by electric vehicles are the LPG fuelled vehicles, then the gasoline fuelled vehicles and in the end the diesel fuelled vehicles. The reason is that smaller vehicles, generally gasoline and LPG fuelled vehicles, is closer in size and performance of electric vehicles, and would therefore be replaced first. The baseline for the comparison is the 2010 distribution of cars and the models for fuel consumption discussed in chapter 4. The models 1-9 are based on the three different fuel intensities (0.07, 0.10 and 0.13 lge/km) and three different average distances travelled (10, 20 and 30 km/day). An overview of these models can be found in Appendix C.

None of the scenarios discussed in this chapter take into account the growth in number of vehicles; the purpose of the scenarios discussed here is to find the consequences of using bioethanol and electric vehicles compared to conventional vehicles. It is also assumed that the average electricity consumption from the grid for electric vehicles is 0.15 kWh/km. The consumption of fossil fuels for electricity generation is based on the average efficiency 2008-2011 found in table 7.2.b in chapter 7. In addition, for the coal based and the 2025 energy mix it is assumed that the pulverized coal power plant will have an average efficiency of 30%. The methods used to find the total consumption for the different consumption models and fuels are discussed in chapter 2.

8.1 Scenario A: Electricity generated from 2010 production mix

The first scenario considered is one in which the electricity production mix is identical to that of 2010, described in chapter 7, see table 7.1.a.

8.1.1 From conventional fuel to electricity

Model 7 gives the greatest impact of switching from conventional fuels to electricity, with a reduction of required fossil fuels of 62% for an all-electric car/dual-purpose vehicle fleet. This is also where the largest fuel consumption is, as model 7 is where the average distance travelled is 30 km/day and the fuel intensity is 0.13lge/km. At the other end of the spectrum, model 3 represents an average distance travelled of 10 km/day and a fuel intensity of 0.07lge/km. Model 3 gives a much smaller impact on the imported fossil fuels, with the reduced fossil fuels requirement for the all-electric fleet of 11%. However, for all the models however it is a clear trend that electric vehicles fuelled by electricity with the same energy mix as that for 2010 will reduce the amount of fossil fuels that must be imported. The required fossil fuels import with a 100% share of electric vehicles in the car fleet represents the required fossil fuel for generating the electricity needed to run the cars and the gasoline to fuel the motorcycles and autocycles. Figure 8.1.a shows what impact switching from conventional to electric vehicles would have on the amount of fossil fuels that must be imported for use in private land transport.

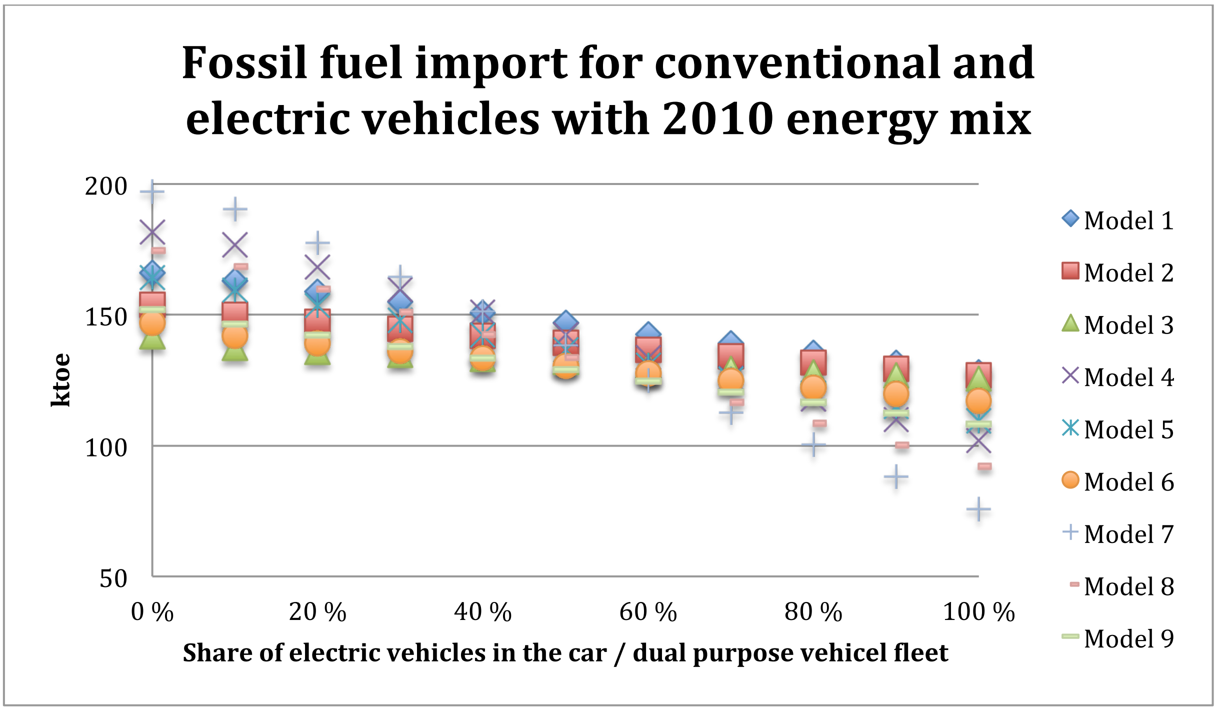


Figure 8.1.a: Import of fossil fuels for private transport for 0-100% electric car fleet with 2010 energy mix.

8.1.2 From E10 to electricity

The reduction of required fossil fuel import ranges from 10 to 59% with an all-electric car/dual purpose vehicle fleet compared to a conventional fleet with E10 for gasoline-fuelled vehicles. The results here are very similar to those in the previous section, with only a reduction in fuel use for the conventional vehicles fuelled by gasoline. As the gasoline-fuelled vehicles are assumed to be the second to be replaced after LPG fuelled vehicles, the difference between the two figures is the required import of fossil fuels up to a 60% share of electric vehicles. As it is assumed that the gasoline displaced by the ethanol in the E10 fuel is 10% of the total consumption for cars/dual purpose vehicles, this is the difference between the required import of fossil fuels for conventional fuel and E10. Figure 8.1.b shows the impact that switching from conventional vehicles to electric vehicles would have when all gasoline-fuelled cars use the E10 ethanol blend.

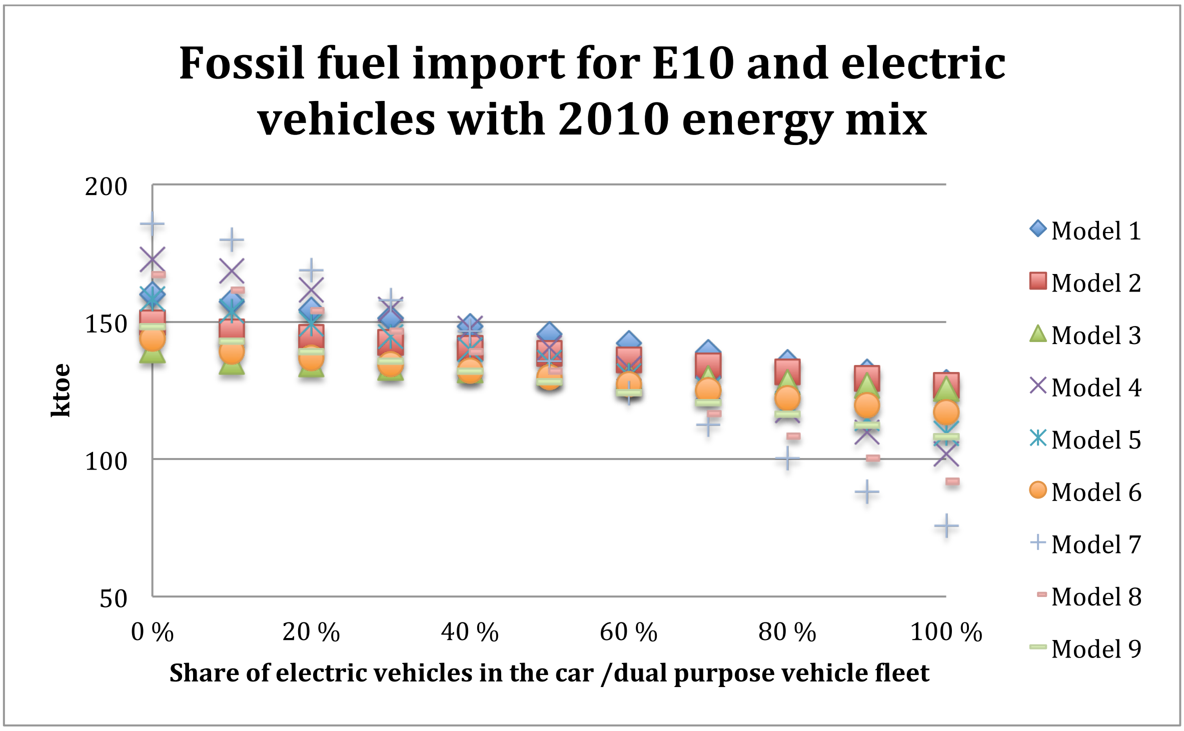


Figure 8.1.b: Import of fossil fuels for private transport for 0-100% electric car fleet with 2010 energy mix and E10 fuel for gasoline fuelled cars/dual purpose vehicles.

8.1.3 From E20 to electricity

The reduction of required fossil fuel import ranges from 9 to 57% with an all-electric car/dual purpose vehicle fleet compared to a conventional fleet with E20 for gasoline-fuelled vehicles. As with the results in the previous section, the only difference between these results and those in the last two sections is a decrease in the required fossil fuel import for a 0 – 60% share of electric vehicles in the fleet. This is due to the gasoline consumption being reduced by 20% due to the ethanol content in the fuel. It is therefore clear that with the 2010 energy mix, use of electric vehicles would reduce the consumption of fossil fuels. The efficiency of conventional vehicles is significantly less than the combined efficiency for the electricity generated, although the generation of electricity from other sources than fossil fuels, such as hydro and bagasse may be the main reason for this. Figure 8.1.c shows what the impact of switching from conventional vehicles to electric vehicles would be when all gasoline-fuelled cars use the E20 ethanol blend.

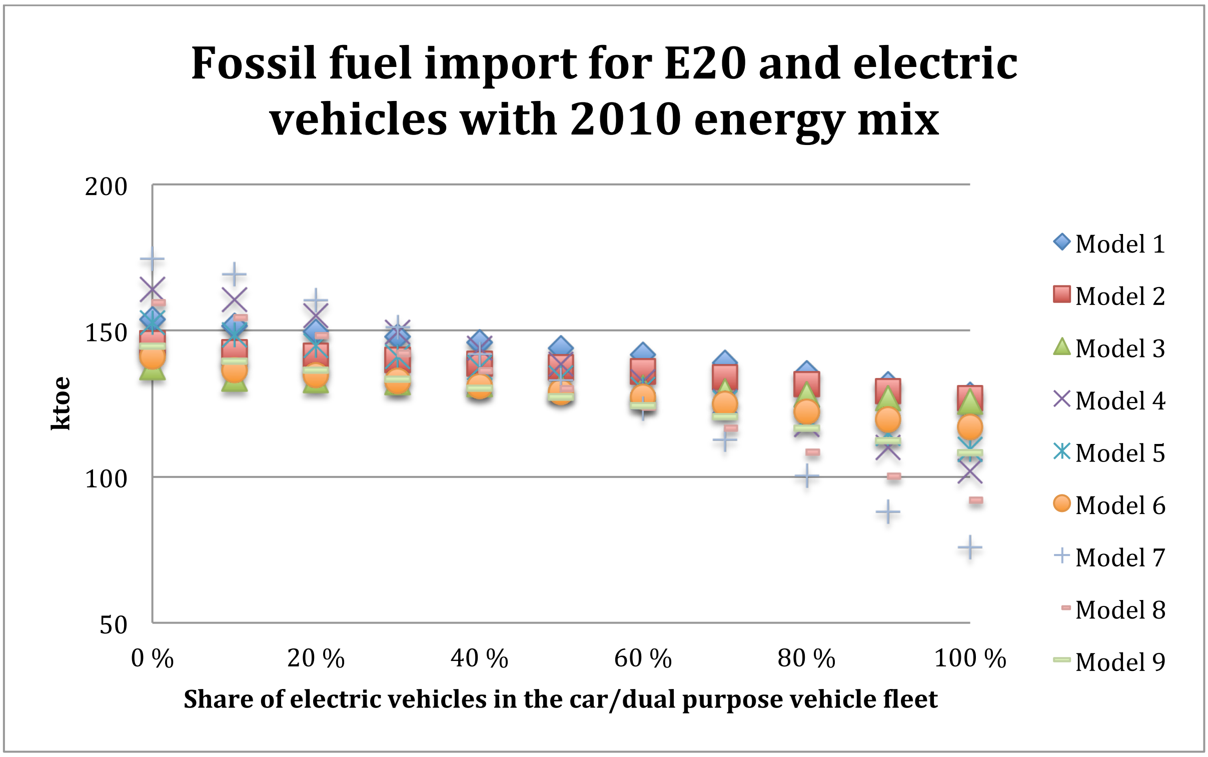


Figure 8.1.c: Import of fossil fuels for private transport for 0-100% electric car fleet with 2010 energy mix and E20 fuel for gasoline fuelled cars / dual purpose vehicles.

8.2 Scenario B: Electricity generated with the target 2025 energy mix

The second scenario considered is one where electric vehicles are charged from the grid with electricity generation distributed by different sources as described for 2025 in table 7.1.b in chapter 7. Compared to the 2010 energy mix, the 2025 energy mix has a much larger share of renewable energy with 43.5% of the total produced electricity compared to 24% in 2010. Therefore the fossil fuel based electricity generation is a smaller share of the total. In the figures below, it is assumed that 25% of the total electricity generation is from coal in coal/bagasse cogeneration plants and the remaining coal based electricity generation, 10.5 % of the total, is from coal in a pulverized coal plant.

8.2.1 From conventional fuel to electricity

For all the models it is a clear trend that electric vehicles fuelled by electricity with the target 2025 energy mix will reduce the amount of fossil fuels that must be imported. The required fossil fuels import with a 100% share of electric vehicles in the car fleet represents the required fossil fuel for producing the electricity needed to run the cars in addition to the gasoline to power the motorcycles and autocycles. The reduction of required fossil fuel import ranges from 15 to 69% with an all-electric car/dual purpose vehicle fleet compared to a conventional fleet. The increased amount of renewable energy sources in the mix can be observed, as the slopes for each model in figure 8.2.a are steeper than that of the corresponding slopes in figure 8.1.a. Also contributing to this is the slightly better efficiency of the pulverized coal plant compared to the cogeneration plant. Figure 8.2.a shows what impact switching from conventional to electric vehicles would have on the amount of fossil fuels that must be imported for use in private land transport.

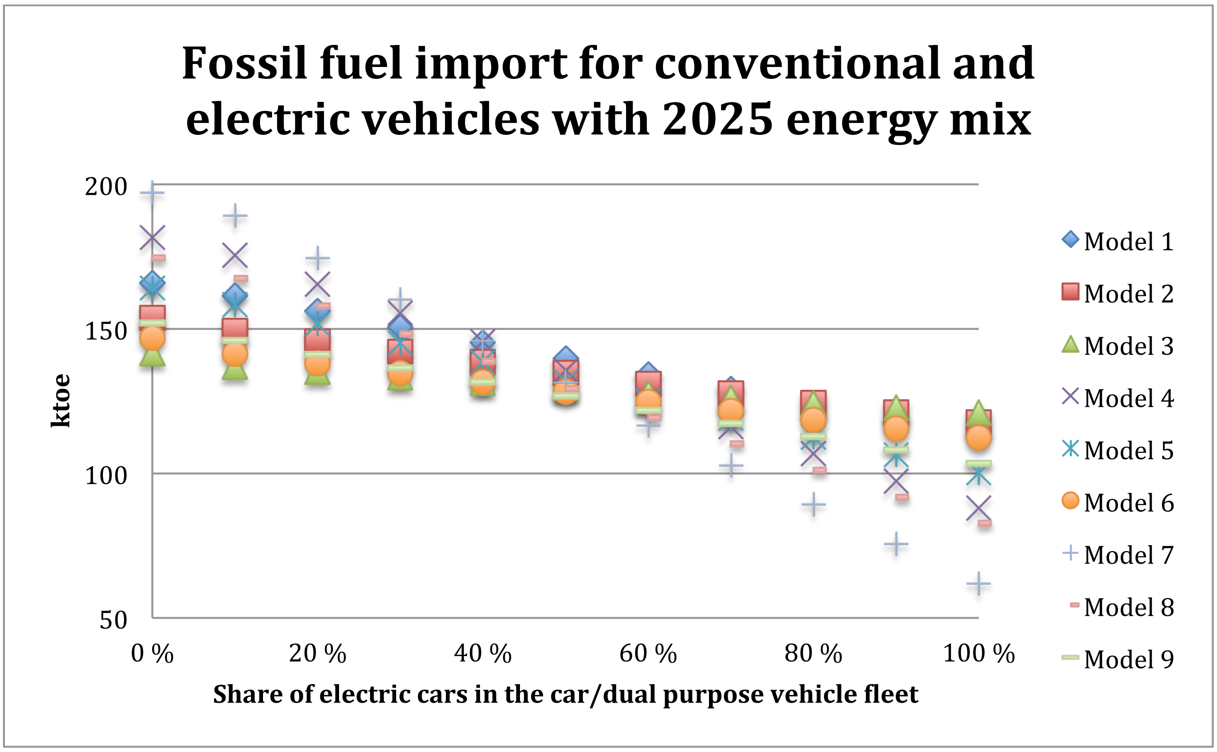


Figure 8.2.a: Import of fossil fuels for private transport for 0-100% electric car fleet with 2025 energy mix.

8.2.2 From E10 to electricity

The reduction of required fossil fuel import ranges from 13 to 67% with an all-electric car/dual purpose vehicle fleet compared to a conventional fleet with E10 for gasoline-fuelled vehicles. Figure 8.2.b shows the impact switching from conventional vehicles to electric vehicles would have when all gasoline-fuelled cars use the E10 ethanol blend. The introduction of E10 has a similar effect on the consumption as that of E10 in the previous scenario.

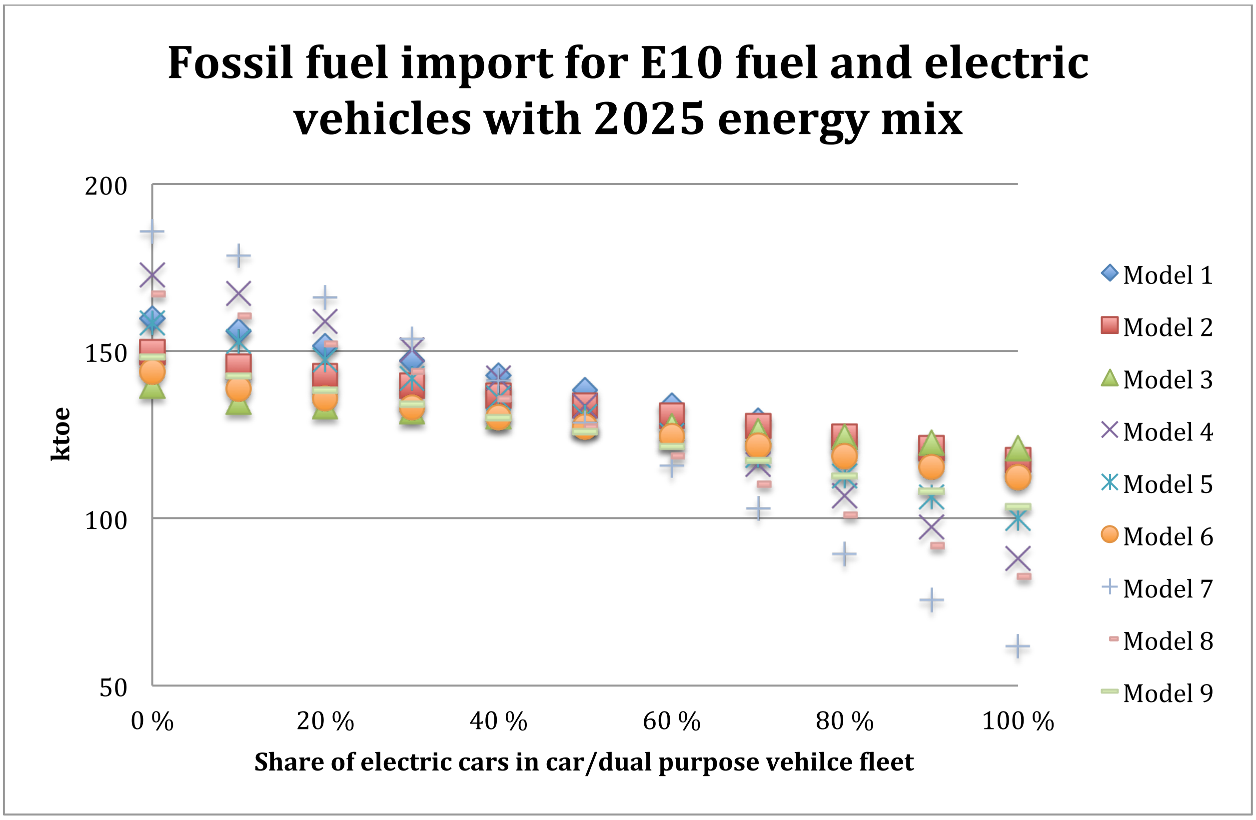


Figure 8.2.b: Import of fossil fuels for private transport for 0-100% electric car fleet with 2025 energy mix and E10 for gasoline-fuelled cars/dual purpose vehicles.

8.2.3 From E20 to electricity

The reduction of required fossil fuel import ranges from 12 to 65% with an all-electric car/dual purpose vehicle fleet compared to a conventional fleet with E20 for gasoline-fuelled vehicles. Figure 8.2.c shows the impact switching from conventional vehicles to electric vehicles would have when all gasoline-fuelled cars use the E20 ethanol blend. The introduction of E20 has a similar effect on the fossil fuel import as it did in the previous scenario.

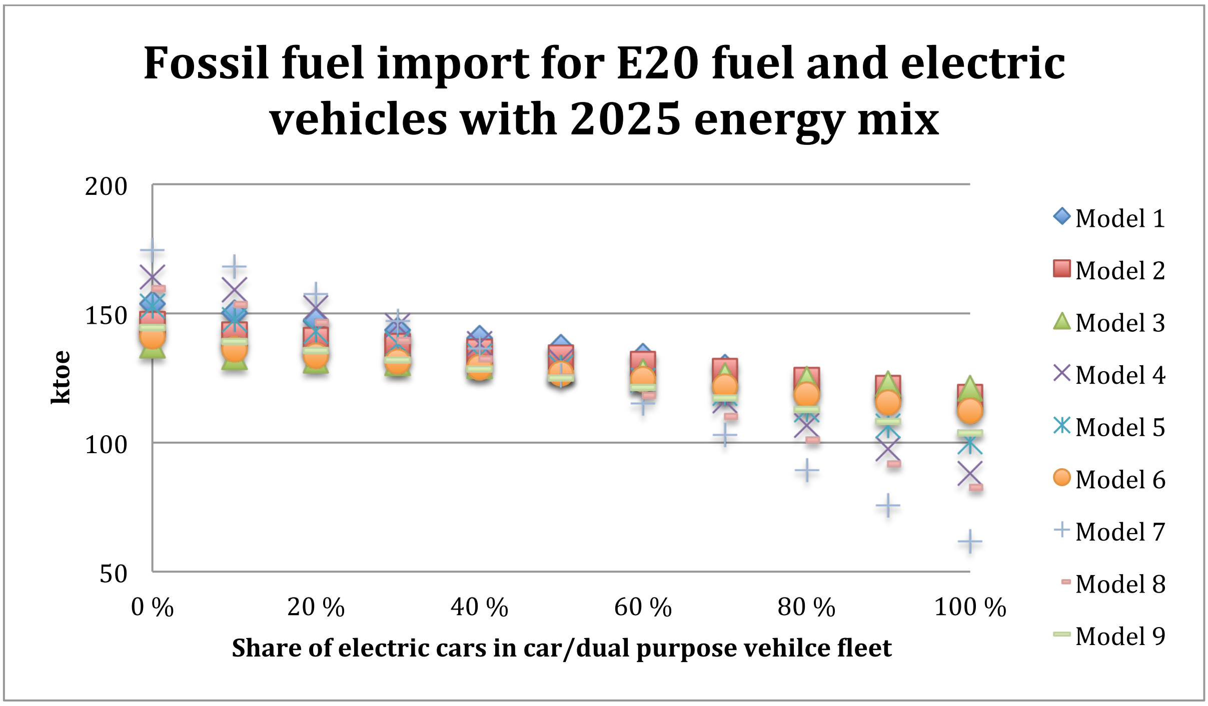


Figure 8.2.c: Import of fossil fuels for private transport for 0-100% electric car fleet with 2025 energy mix and E20 for gasoline-fuelled cars/dual purpose vehicles.

8.3 Scenario C: Electricity generated from coal

The third scenario considered is one where the electricity used to fuel the electric vehicles is generated from coal from the planned pulverized coal power plant. This scenario reflects a case where electric vehicles are connected to the grid and the required additional electricity is provided by the coal plant. Hence the electric vehicles are not used as batteries for the grid, they are just an extra consumption, and there is no smart charging with regards to variable renewable energy sources. This can be the case for both night time charging and unchecked charging of electric vehicles.

8.3.1 From conventional fuel to electricity

The reduction of required fossil fuel import ranges from 5 to 49% with an all-electric car/dual purpose vehicle fleet compared to a conventional fleet. Although all the electricity generation in this scenario is fossil fuel based, there is still a reduction in required import of fossil fuel for all models. Hence, converting coal to electricity is a more efficient use of energy than using conventional vehicles, for electric vehicles consuming 0.15kWh/km. Figure 8.3.a shows the impact switching from conventional fuels to electricity based on coal.

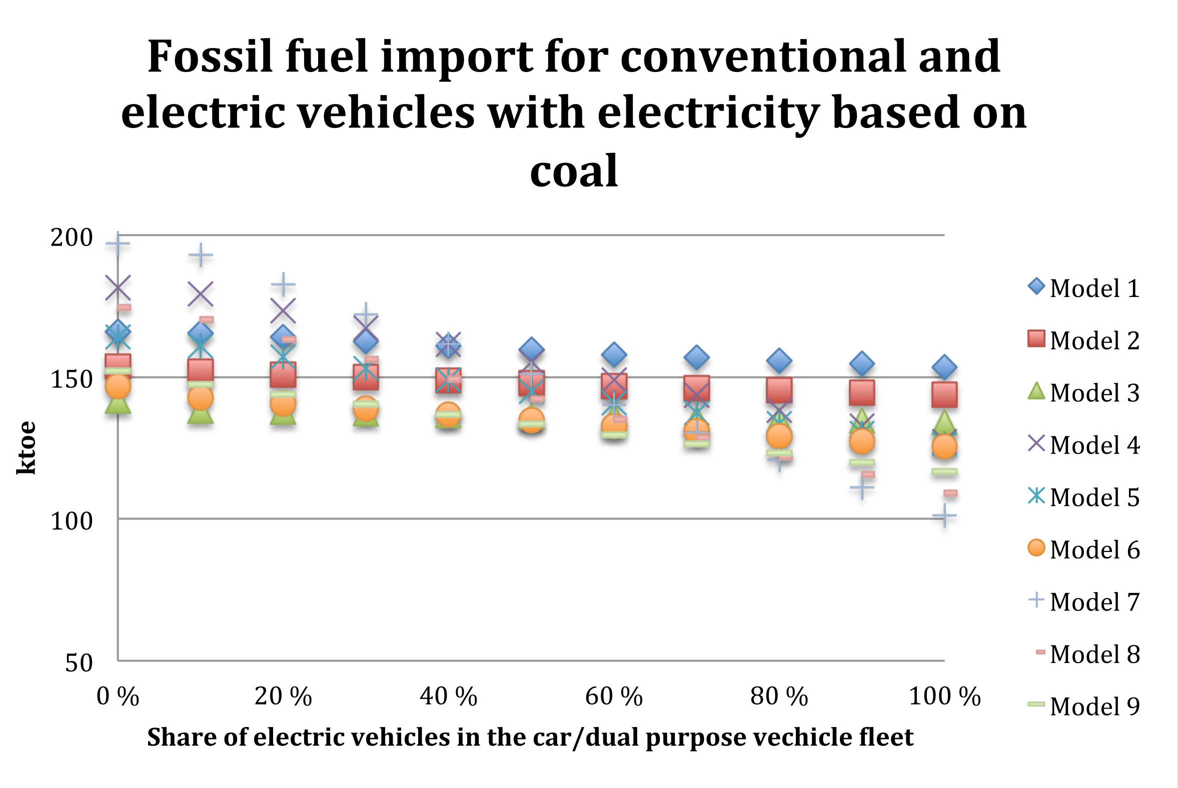


Figure 8.3.a: Import of fossil fuels for private transport for 0-100% electric car fleet with coal-based electricity.

8.3.2 From E10 to electricity

The reduction of required fossil fuel import ranges from 4 to 46% with an all-electric car/dual purpose vehicle fleet compared to a conventional fleet with E10 for gasoline-fuelled vehicles. All models, model 1, 2 and 3, with 0.07 lge/km fuel intensity have a decrease of 4% in required import of fossil fuels. Figure 8.3.b shows the impact of switching from conventional vehicles to electric cars/dual purpose vehicles, when all gasoline-fuelled cars/dual purpose vehicles are fuelled by E10.

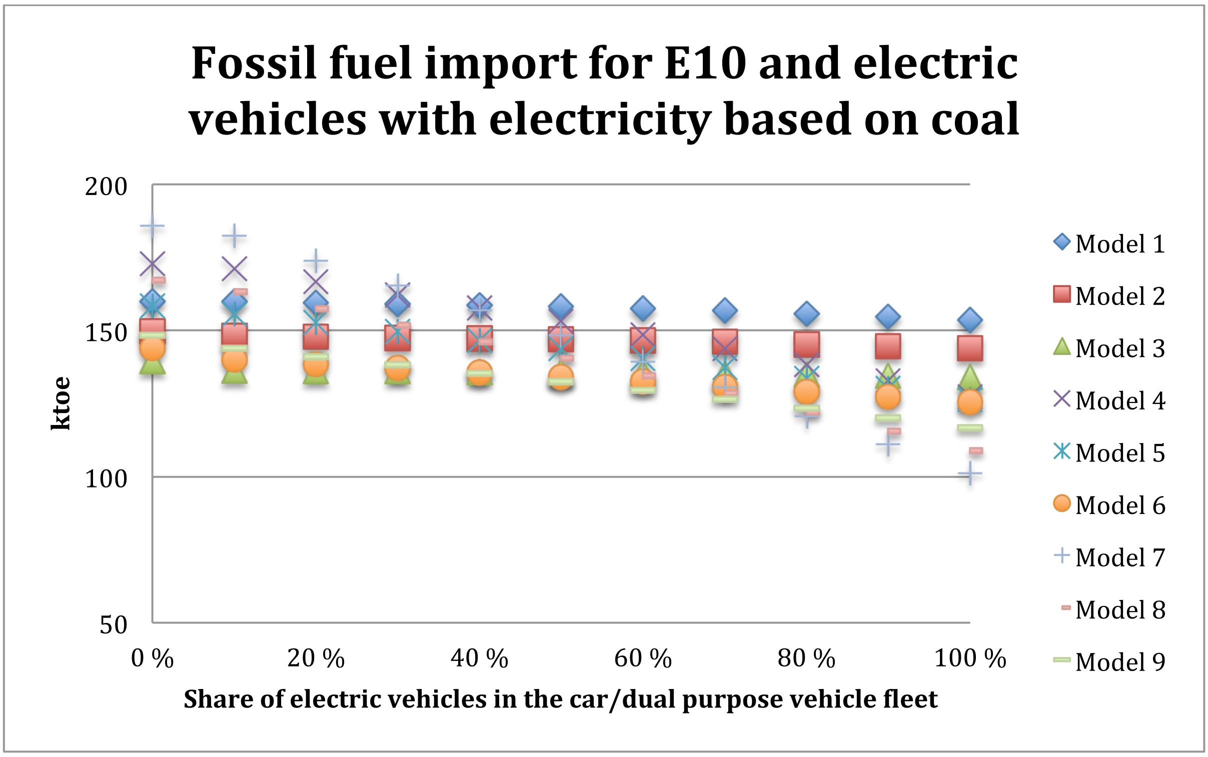


Figure 8.3.b: Import of fossil fuels for private transport for 0-100% electric car fleet with coal based electricity and E10 for gasoline-fuelled cars/dual purpose vehicles.

8.3.3 From E20 to electricity

The reduction of required fossil fuel import ranges from 0 to 42% with an all-electric car/dual purpose vehicle fleet compared to a conventional fleet with E10 for gasoline-fuelled vehicles. For model 1, 0.07 lge/km and 30km/day, there is no difference for import of fossil fuels for a conventional vehicle fleet with E20 fuel for gasoline-fuelled cars/dual purpose vehicles and an all-electric car/dual vehicle fleet. In fact for all models with 0.07 lge/km the required import of fossil fuels increases between a 10% and 60% share of electric vehicles. This means that the conventional vehicles using E20 fuel has a better efficiency than electric vehicles with coal based electricity. Figure 8.3.c shows the impact of switching from conventional vehicles to electric cars/dual purpose vehicles, when all gasoline-fuelled cars/dual purpose vehicles are fuelled by E20.

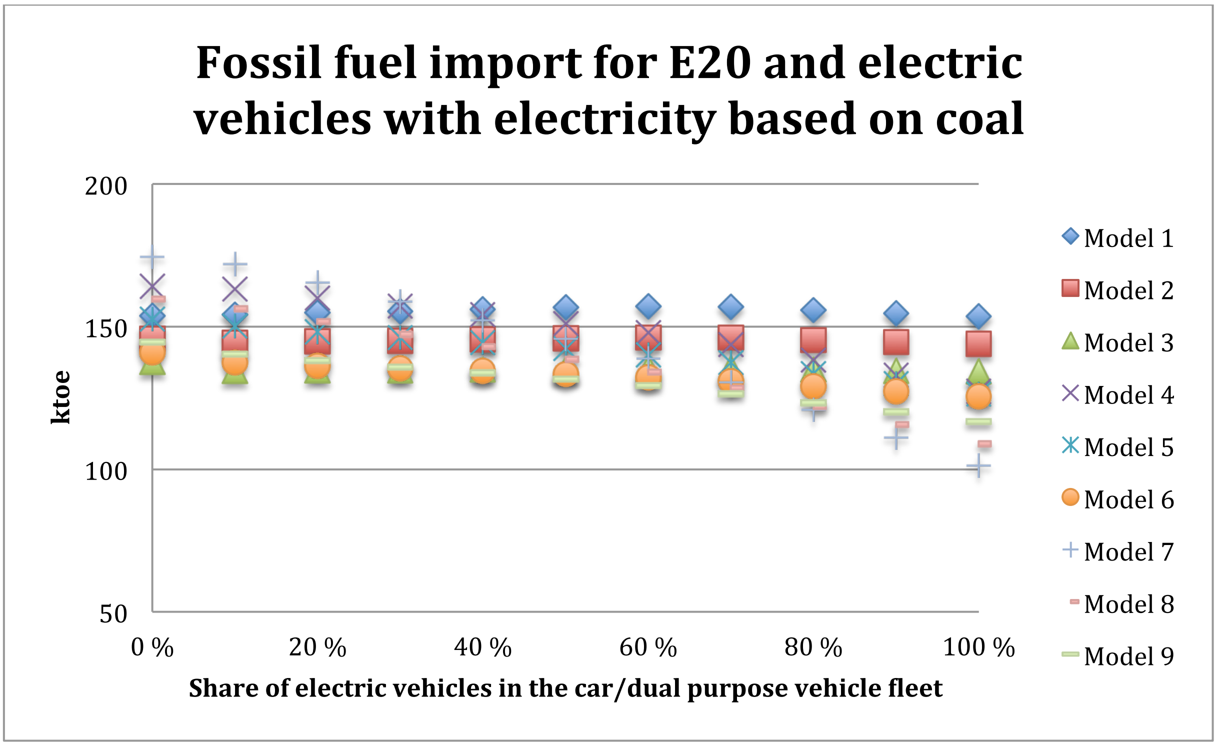


Figure 8.3.c: Fossil fuels import for private transport for 0-100% electric car fleet with coal based electricity and E20 for gasoline-fuelled cars/dual purpose vehicles.

8.4 Scenario D: Electricity generated from renewable energy sources

The fourth scenario considered is one where all electric vehicles are fuelled by electricity from renewable energy sources such as solar, wave or wind power. This scenario reflects both the case where electric vehicles are used as storage for the grid by intelligent charging with electricity generated by variable renewable energy sources and the case where electric vehicles are charged by solar panels independent of the grid.

8.4.1 From conventional fuel to electricity

The reduction of required fossil fuel import ranges from 26 to 94% with an all-electric car/dual purpose vehicle fleet compared to a conventional fleet. The remaining fossil fuels requirement for the all-electric cars/dual purpose vehicle fleet is solely gasoline used to fuel the motorcycles and autocycles. Figure 8.4.a shows the impact switching from conventional fuels to electricity based on renewable energy.

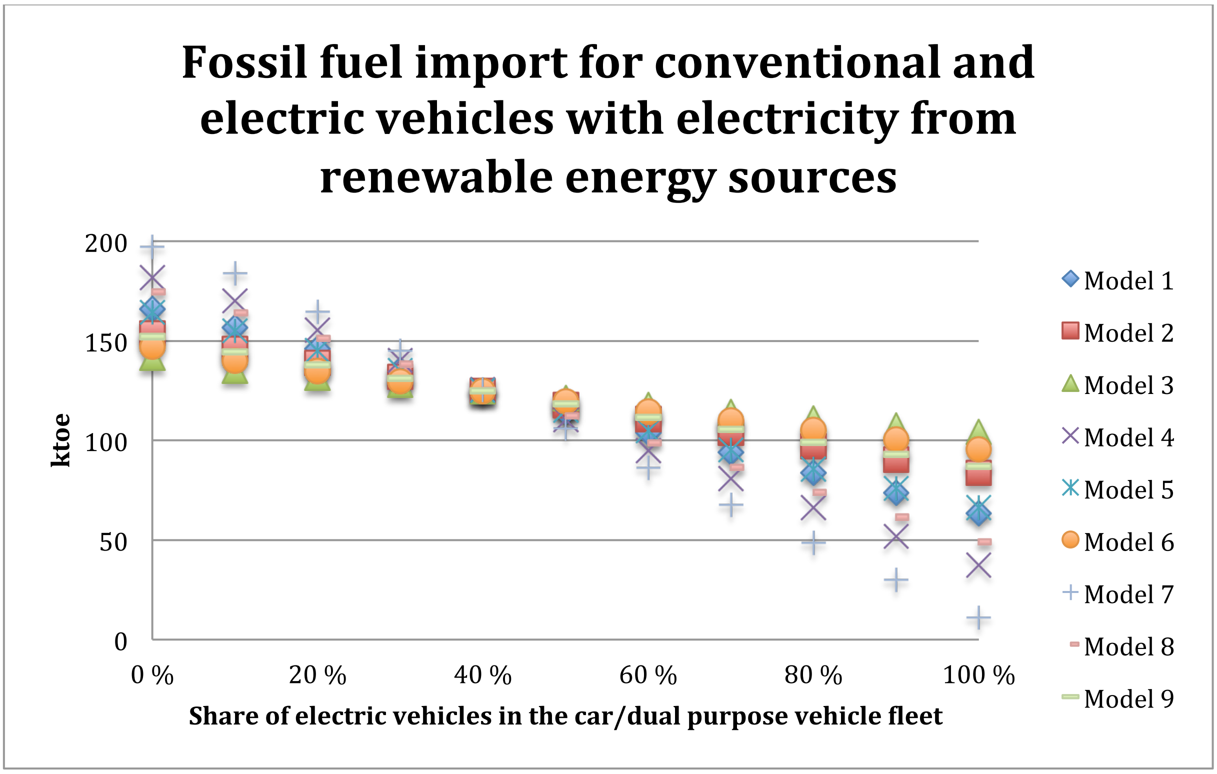


Figure 8.4.a: Import of fossil fuels for private transport for 0-100% electric car fleet with electricity generated from renewable energy sources.

8.4.2 From E10 to electricity

The reduction of required fossil fuel import ranges from 25 to 94% with an all-electric car/dual purpose vehicle fleet compared to a conventional fleet. Figure 8.4.b shows the impact switching from conventional fuels to electricity based on renewable energy and E10 for gasoline-fuelled cars/dual purpose vehicles.

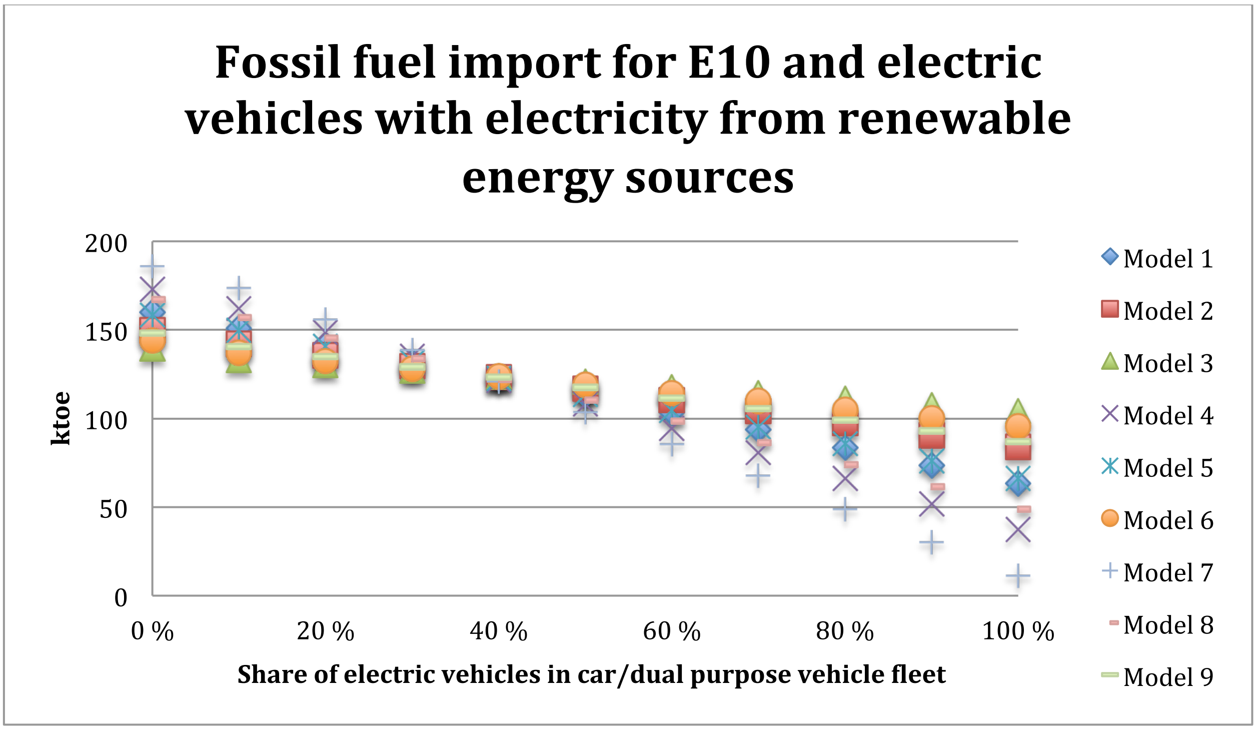


Figure 8.4.b: Import of fossil fuels for private transport for 0-100% electric car fleet with electricity generated from renewable energy sources and E10 for gasoline-fuelled cars/dual purpose vehicles.

8.4.3 From E20 to electricity

The reduction of required fossil fuel import ranges from 24 to 94% with an all-electric car/dual purpose vehicle fleet compared to a conventional fleet. Figure 8.4.c shows the impact switching from conventional fuels to electricity based on renewable energy and E20 for gasoline-fuelled cars/dual purpose vehicles.

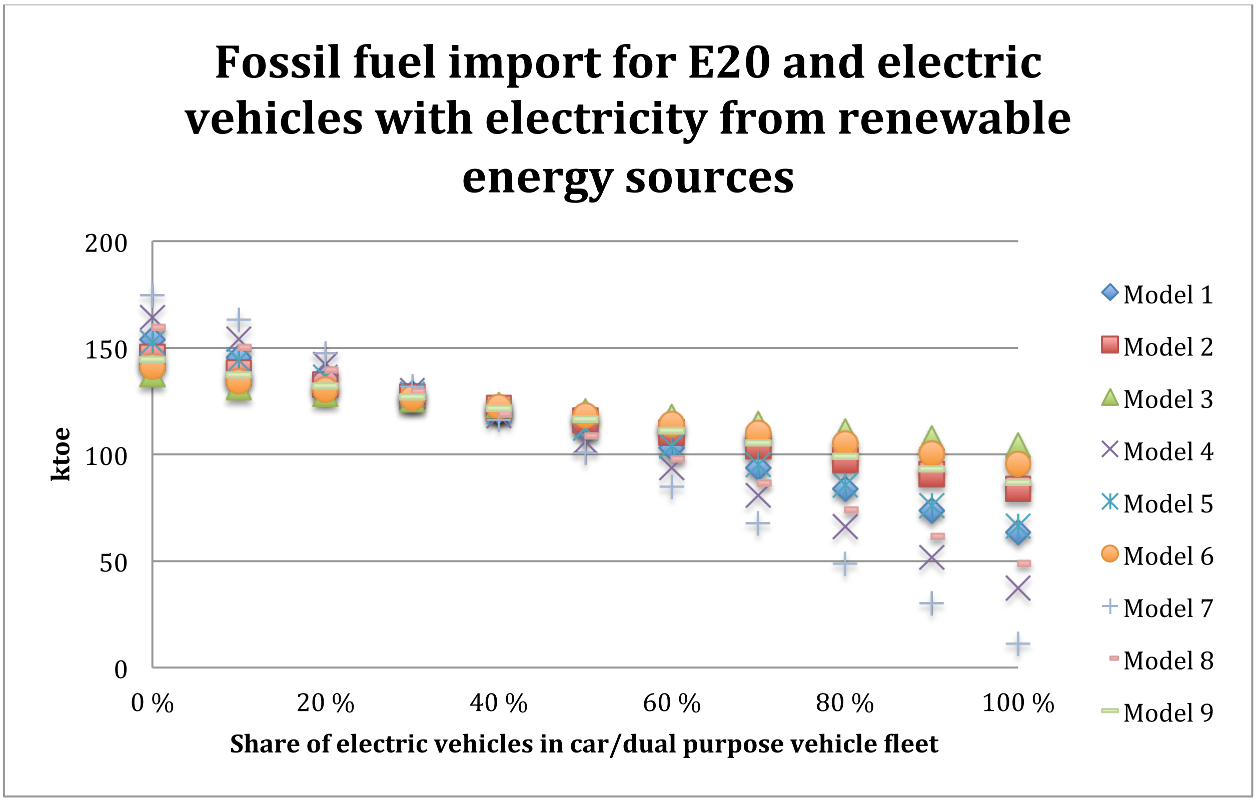


Figure 8.4.c: Import of fossil fuels for private transport for 0-100% electric car fleet with electricity generated from renewable energy sources and E10 for gasoline-fuelled cars/dual purpose vehicles.

8.5 Comparison of fossil fuel import costs of the different scenarios

In this section the different components of the required fossil fuels from the four scenarios are considered. Model 5 is chosen as comparison because it is mid range for both fuel intensity and distance travelled. In these figures, ethanol blends are not considered. The inclusion of these would decrease the amount of gasoline for a share of electric vehicles between 0 and 60%. At the end of this section the 2010 prices for import are used to compare the import cost of the fossil fuels required for the different scenarios, this is also based on model 5 and conventional fuels.

We can observe that the energy mix for scenario A is composed mainly of coal and fuel oil. In addition we see that motorcycles and autocycles as modelled here consume more fossil fuel than an all-electric car fleet. Figure 8.1.d shows the different fossil fuel that must be imported using the consumption data for model 5.

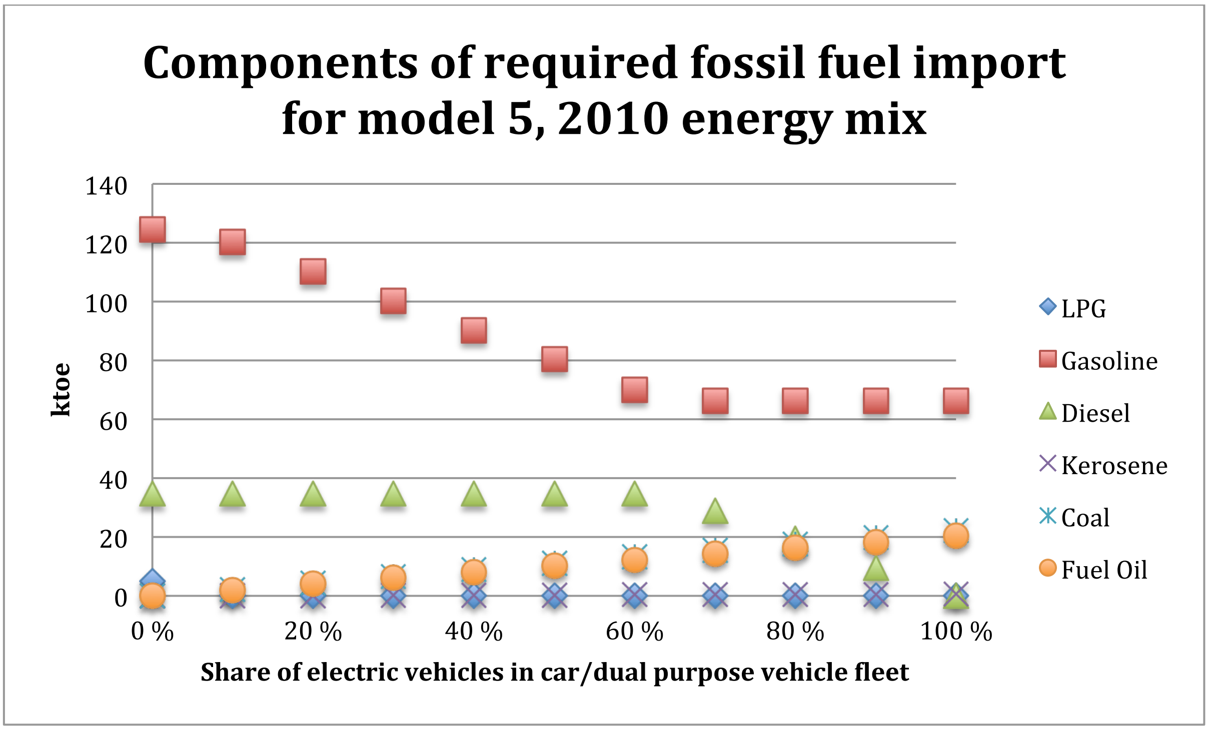


Figure 8.1.d: Components of the required fossil fuel import for model 5 and 2010 energy mix.

Compared to scenario A, in scenario B the consumption of fuel oil is much lower. Figure 8.2.d shows the different fossil fuel that must be imported using the consumption data for model 5 with the 2025 energy mix.

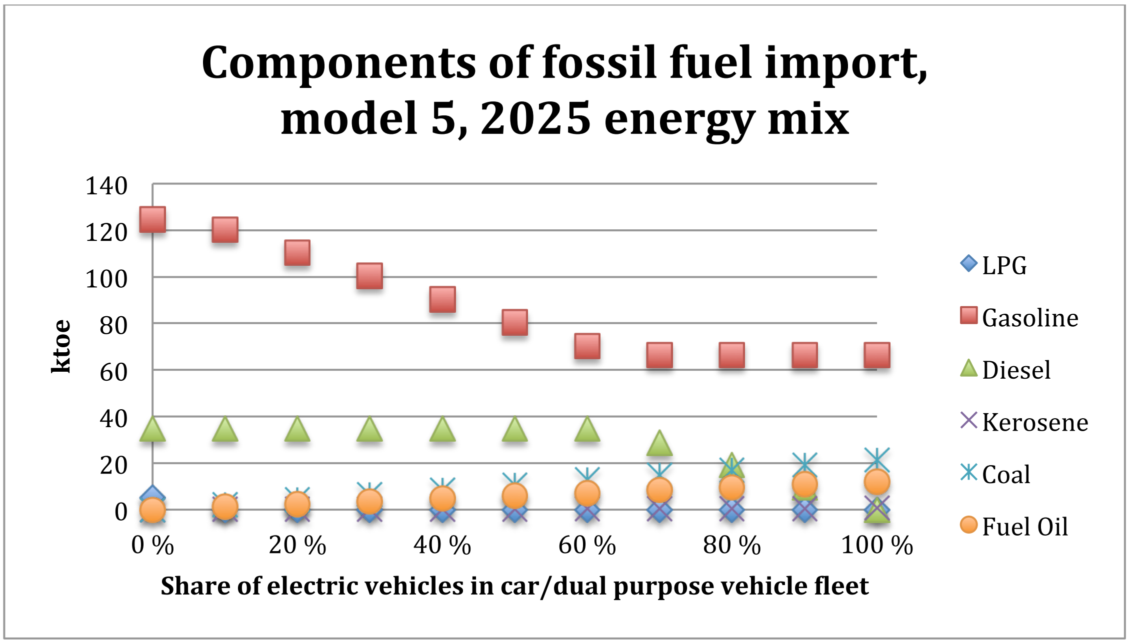


Figure 8.2.d: Components of required fossil fuel import for conventional and electric vehicles with consumption model 5 and the 2025 energy mix.

As Scenario C only considers electricity generated from coal, the only component due to electricity consumption in electric vehicles is that of coal. Figure 8.3.d shows the different fossil fuel that must be imported using the consumption data for model 5 with the coal based electricity.

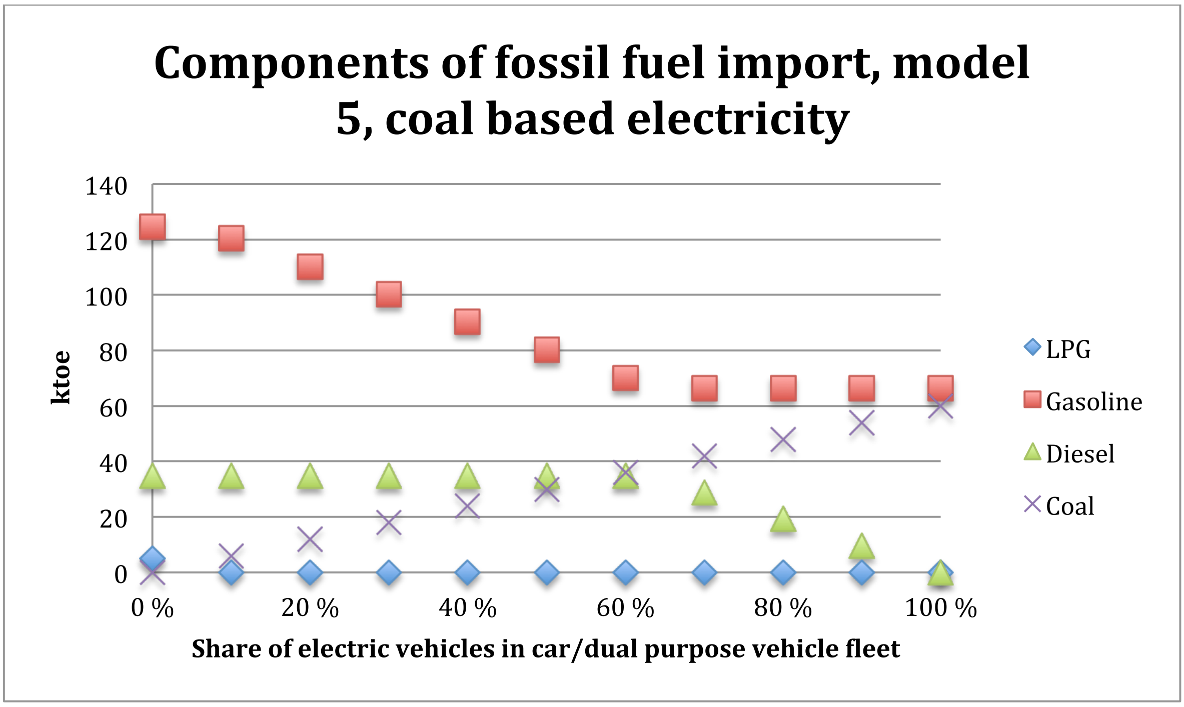


Figure 8.3.d: Components of required fossil fuel import for conventional and electric vehicles with consumption model 5 and coal based electricity.

As the electricity generation in scenario D is based on renewable energy there are no components that represent the consumption of fossil fuel that is used to fuel electric vehicles. Figure 8.4.d shows the different fossil fuel that must be imported using the consumption data for model 5 with the electricity generated from renewable energy.

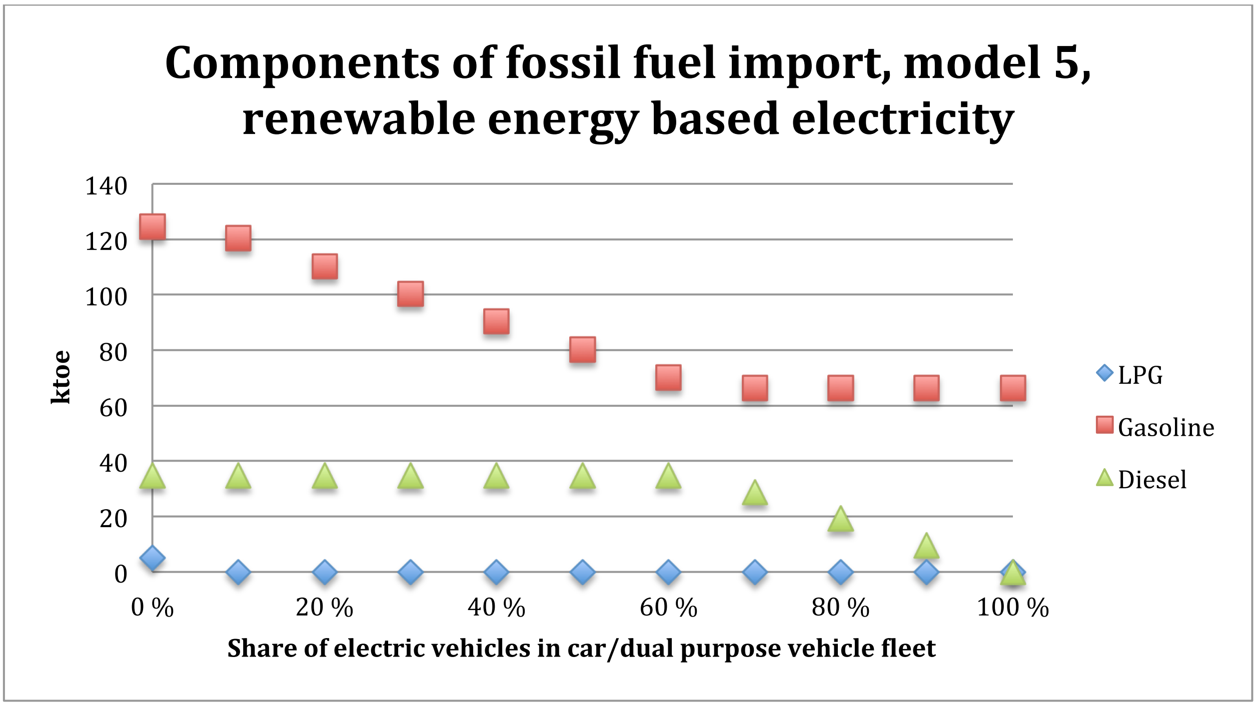


Figure 8.4.d: Components of required fossil fuel import for conventional and electric vehicles with consumption model 5 and renewable energy based electricity

The prices used are average import prices for 2010[39]. It is clearly shown that fuel for electric vehicles has a much lower import cost than fuel for conventional vehicles, for all scenarios. The renewable energy based scenario has the least import cost while the 2010 electricity mix scenario has the most import cost. Both the coal based and the renewable energy based scenarios require a lower import cost than that of the 2010 and 2025 electricity mix scenarios. The only fossil fuel for transport for a 100% share of electric vehicles in the renewable energy scenario is the gasoline required to fuel the motorcycles and auto cycles. In addition coal prices are much lower than petroleum prices. Forecasts, by the IEA, show that crude oil prices are expected to rise by 35% from 2011 to 2035, while coal prices only will rise by 1.2% the same period[14]. Figure 8.5.a compares the costs of importing fossil fuels required based for conventional and electric vehicles, based on consumption model 5.

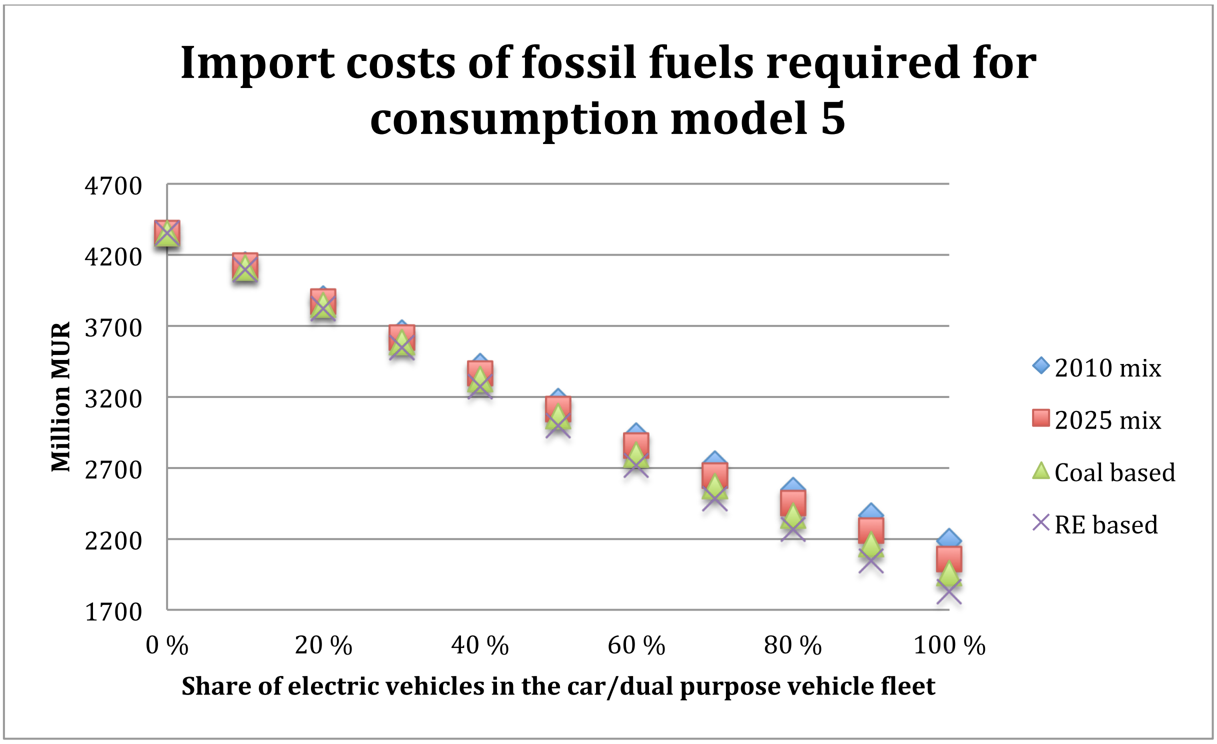


Figure 8.5.a: Import costs of fossil fuels required for conventional and electric vehicles with consumption model 5.

8.6 Comparison of the different scenarios

All four scenarios considered here show that replacing the car fleet with electric vehicles will reduce the fossil fuel dependency for the private transport on Mauritius. The only exception is scenario C where the electricity is generated from coal, when compared to an E20 fuel for gasoline-fuelled vehicles.

Scenarios A and B, with the 2010 and 2025 energy mix, gives an idea of how the fossil fuel consumption would be if the added electricity generation for fuelling electric vehicles have the same source mix as that of the actual electricity generation in 2010 and if the target for

2025 had taken electric vehicles into consideration. However both these scenarios require extra installed capacity from renewable energy sources to be realistic, as the planned and existing renewable energy capacity is fully exploited by regular electricity demand. If electric vehicles replaced the car/dual-purpose vehicle fleet today, scenario C is the most realistic scenario. Especially when considering the challenges for grid capacity and accompanying solution of nighttime charging discussed in chapter 7. The added electricity demand due to electric vehicles would come from coal, and thus the scenario with the least effect on fossil fuel imports is the most probable in the short term.

Scenario D, where electricity generation is based on renewable energy sources gives the largest possible decrease of fossil fuel import. To realise this scenario all required power capacity for the electric vehicles must be new installed capacity in the form of PV power plants, rooftop solar panels or other renewable energy power plants. In addition, measures must be taken to ensure that the electricity grid can handle that amount of variable renewable sources, either by using electric vehicle batteries as storage or have another type of storage for the grid. Ultimately, electric vehicles in scenario D will not only give the largest reduction of fossil fuels import required for private transport, it also has the potential to reduce the fossil fuel imports required for general electricity generation. As such scenario D is considered the long-term goal of electricity generation for use in electric vehicles.

Although some consumption models in scenario C give little or no reduction of fossil fuels import, the cost of importing coal is much less than that of importing conventional fuels for vehicles. In addition, to be able to realise scenario D, the electric vehicles must be imported and implemented first. Then as general electricity demand grows, electric vehicle batteries can be used to facilitate the incorporation of electricity generation from renewable energy sources into the grid.

9. Conclusion: Can Mauritius reduce its dependency of fossil fuels through the use of biofuels and electric vehicles?

Examining alternatives to fossil fuel energy for use in Mauritius has shown that it is entirely possible to significantly reduce the islands dependency on fossil fuels with the right political will and some technological investment. The analysis in this thesis has shown that using both biofuels and electricity to fuel the private land transport will reduce the islands' fossil fuel dependency.

Reduction in fossil fuel dependency can be achieved in two main ways: Firstly by reducing the use of private vehicles by creating incentives to change individual behaviour or secondly, by changing the type of energy used to fuel private vehicles. Both require a certain political will and power to implement and it is likely that tackling the problem from both these perspectives will result in the largest possible effect on fossil fuel dependency.

If no measures are taken to limit vehicle ownership and use or regulate the type of fuel used, the consumption and therefore required gasoline and diesel import will most likely continue to increase similar to the way it has in the past few years. In order to reduce this trend, important initiatives will be to create and maintain a well functioning and attractive public transit system. This can be achieved by implementing measures discussed throughout this thesis, specifically, building a light rail transit or a separate bus-way would go some way to encourage a shift away from private vehicle use. In addition other government incentives to limit private vehicle use, such as congestion pricing and encouraging use of non-motorized transport have proved effective in reducing private vehicle use elsewhere and should be pursued.

Aside from reducing overall use of private land vehicles, changing the type of energy used to fuel vehicles will also reduce fossil fuel dependency. There are two main ways this can be achieved. Firstly, the existing car fleet can run on a different fuel blends such as use of an ethanol blend. Secondly, encouraging a shift from conventional vehicles to electric vehicles can be implemented.

The implementation of an ethanol blend for gasoline-fuelled cars/dual-purpose vehicles alone will reduce the required fossil fuels import for private land transport with about 1,4% to 5,6% for E10 and about 2,8% to 11,2% for E20. As the required ethanol is relatively easily obtained from existing island resources, this is a measure that should be implemented as soon as possible. Sugar manufacturers or other private companies can utilize the molasses from sugar production to produce ethanol. Existing distribution systems for fuel can then be used to distribute the ethanol to consumers after it is blended with gasoline to the correct proportions. Because most manufacturers does not give warranty on cars to run on more than 10% ethanol, the E10 should be implemented for all gasoline fuelled cars/dual purpose vehicles. However, for cars/dual-purpose vehicles that have no trouble running on an E20 blend, E20 is the percentage blend that should be implemented, as it doubles the reduction of import of fossil fuels compared to the E10 blend.

The main part of the analysis in this thesis has been the impact of using electric vehicles and has considered different scenarios for electricity production. For all scenarios considered, with exception of a few models for electricity based on coal and an E20 ethanol blend, there has been a significant reduction of fossil fuel imports when using electric vehicles. As a result the thesis concludes that as a long-term goal, Mauritius should strive to use electric vehicles instead of conventional vehicles. There are obstacles that need to be tackled in order for this to happen. Particularly, incentives must be given to encourage the procurement of electric vehicles. This can be achieved, for example, by implementing taxation incentives to make purchasing electric vehicles competitive with conventional vehicles.

If incentives are successfully put in place to encourage a shift of the car fleet to that of an entirely electric car fleet, the electric requirement and the strain on the electricity grid must be considered. This has been discussed throughout the thesis, and although this may cause a potential problem due to different peak demands, there are different measures that will mitigate this problem. A simple method such as nighttime charging is likely to mitigate the problem. Even if a more sophisticated system like a vehicle-to-grid system cannot be implemented at the moment, the nighttime charging system is a sufficient measure to assure that there is no overdue strain on the grid. Existing electric vehicles on the island will, at a later date, be able to incorporate measures such as vehicle-to-grid and can be used as storage to facilitate more renewable sources in the grid. It can therefore help decrease the import of fossil fuels not only for the transport sector but also for electricity generation in general.

As a short-term measure, the Mauritian government should focus on reducing the overall use of private vehicles and in addition implement ethanol blends as fuels for conventional vehicles. For the long term, to facilitate a larger reduction of fossil fuels dependency the goal for Mauritius should be to replace the conventional vehicle fleet with electric vehicles. Although initial investments in vehicles and batteries may be high, electric vehicles are the best option of gaining as much self-sufficiency for fuel consumption as possible.

Further research should be made into the potential and options for using electric vehicle batteries as storage for the grid and what measures must be made to implement and operating a V2G system or other means of utilizing the batteries for storage. Before implementation of any system with electric vehicles, a detailed analysis of expected investment and operating costs involved in having such a system must be conducted. It is also recommended that further research into the potential of biodiesel production on the island should be conducted, as well as the potential for substituting biodiesel or electricity for fossil fuels in larger vehicles such as buses and trucks.

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Appendix

A. Conversion factors

	Ton	toe
Gasolene	1	1.08
Diesel oil	1	1.01
Dual purpose kerosene (DPK)	1	1.04
Fuel oil	1	0.96
Liquefied petroleum gas (LPG)	1	1.08
Coal	1	0.62
Bagasse	1	0.16
Fuel Wood	1	0.38
Charcoal	1	0.74

1 GWh is equivalent to 86 toe for electricity

1 toe = 41.84 GJ = 0.011 GWh

Source: CSO, *Digest of energy and water statistics - 2011*, 2012.

1US Galleon = 3.785 litres
1 mile = 1.6093 km

Source: Harvey, L.D.D., *Energy and the new reality* 2010, London: Earthscan.

B. Overview of interviews conducted

Here is an overview of the interviews conducted and the general topics of the conversations. Although many of the conversations cover the same topics, there were not a specific set of questions that were asked at each interview. All interviews were done in cooperation with Marie Loe Halvorsen as preparation for both our theses.

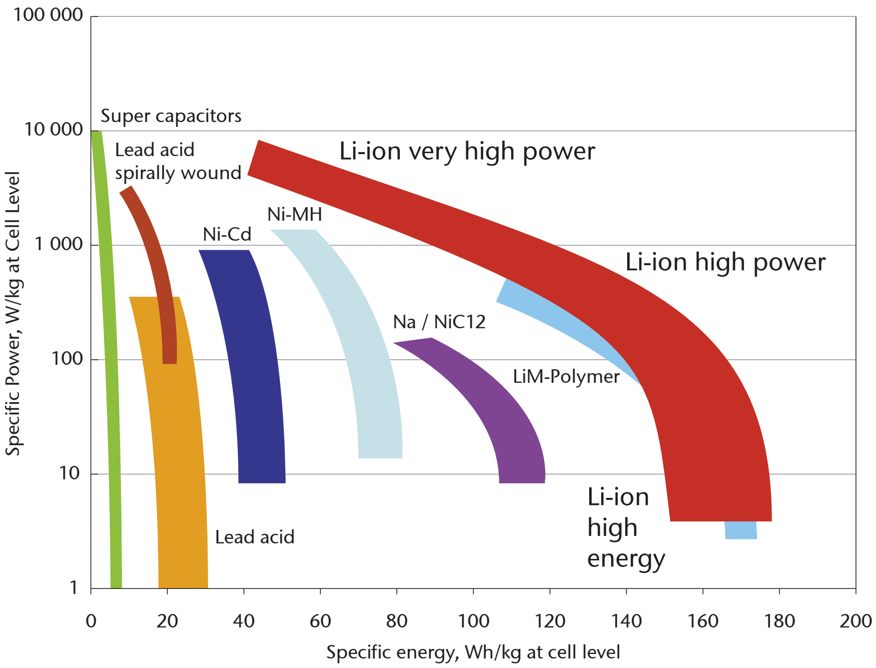
Date:	Interviewees:	Topics:
August 24th 2012	Dr Dinesh Surroop; Senior lecturer - University of Mauritius	Possibilities for use of biofuels on Mauritius, electricity generation on Mauritius.
August 27th 2012	Sanjay Sookhraz; Environmental Affairs	Power plants on Mauritus; both CEB and IPP,

	Officer, M. Shamshir Mukoon; Manager and Rakesh Dhununjay; Corporate Planning & Research – Central Electricity Board (CEB)	Electricity grid, Electricity tariffs, Plans for new power plants, measures to reduce electricity consumption and peak demand.
August 30th 2012	Dr. Khalil Elahee; MA. (Cantab), Ph.D – University of Mauritius	MID project, electricity generation, prospects for ethanol blends and other biofuels, electric vehicles, public transit.
September 3rd 2012	Arshad Bauccha; Marketing Manager – Nissan, ABC Motors Co. Ltd. Mauritius	Sales prospects and prices, Nissan Leaf (electric car), taxation on vehicles, average distances travelled.
September 4th 2012	Vishal Rajjoo; Sales Assistant – Toyota (Mauritius) Ltd.	Sales prospects and prices, hybrid cars, taxation on vehicels
September 11th 2012	Diary Romooah; Transport Planner – National Transport Authority	Congestion around Port Louis, plans for future transport on Mauritus, Bus service and prospects for public transit, biofuels, electric and hybrid vehicles
September 14th 2012	Sanjay Sookhraz; Environmental Affairs Officer and Rajsingh Busgeeth; Electrical Engineer – Central Electricity Board	Visit to the Midland dam, and La Champagne power plant. Hydropower on Mauritius, Small Independent Power Producers (SIPP).
September 19th 2012	Rajiv Ramlugon; Group Chief Sustainability Officer, Curtis Catacoopen; Mechanical & Safety Engineer and Pierre Sagnier; Project Development Manager – Omnicane	Presentation of Omnicane operations, tour of sugar factory and power plant at La Baraque, L'Escalier, Mauritius.
October 18th 2012	Thomas Hylland Eriksen; Professor – University of Oslo	Political and social organisation on Mauritius, Political will and action.

C. Fuel consumption models for Mauritius

Model number	Fuel intensity (lge/km)	Average distance travelled (km/day)
1	0.07	30
2	0.07	20
3	0.07	10
4	0.10	30
5	0.10	20
6	0.10	10
7	0.13	30
8	0.13	20
9	0.13	10

D. Specific energy and specific power of different battery types.



Source: International Energy Agency. Directorate of Sustainable Energy, P. and Technology. *Technology roadmap. Electric and plug-in hybrid electric vehicles*. © OECD/IEA 2009; Available from: http://www.iea.org/papers/2009/EV_PHEV_Roadmap.pdf

E. Supporting graphs and tables for chapter 4

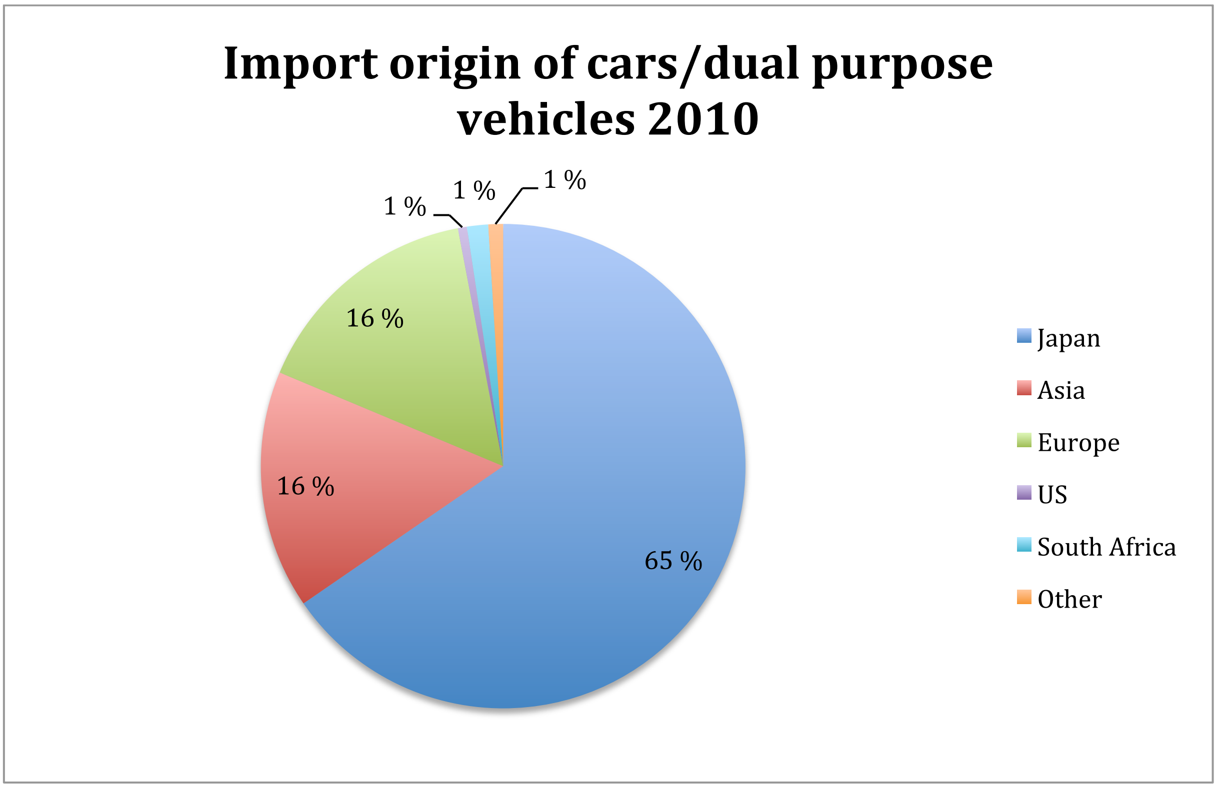


Figure 4.1.b: Import origin of cars and dual-purpose vehicles 2010.
Source: CSO, *Digest of road transport and road accident statistics 2011*, 2012.

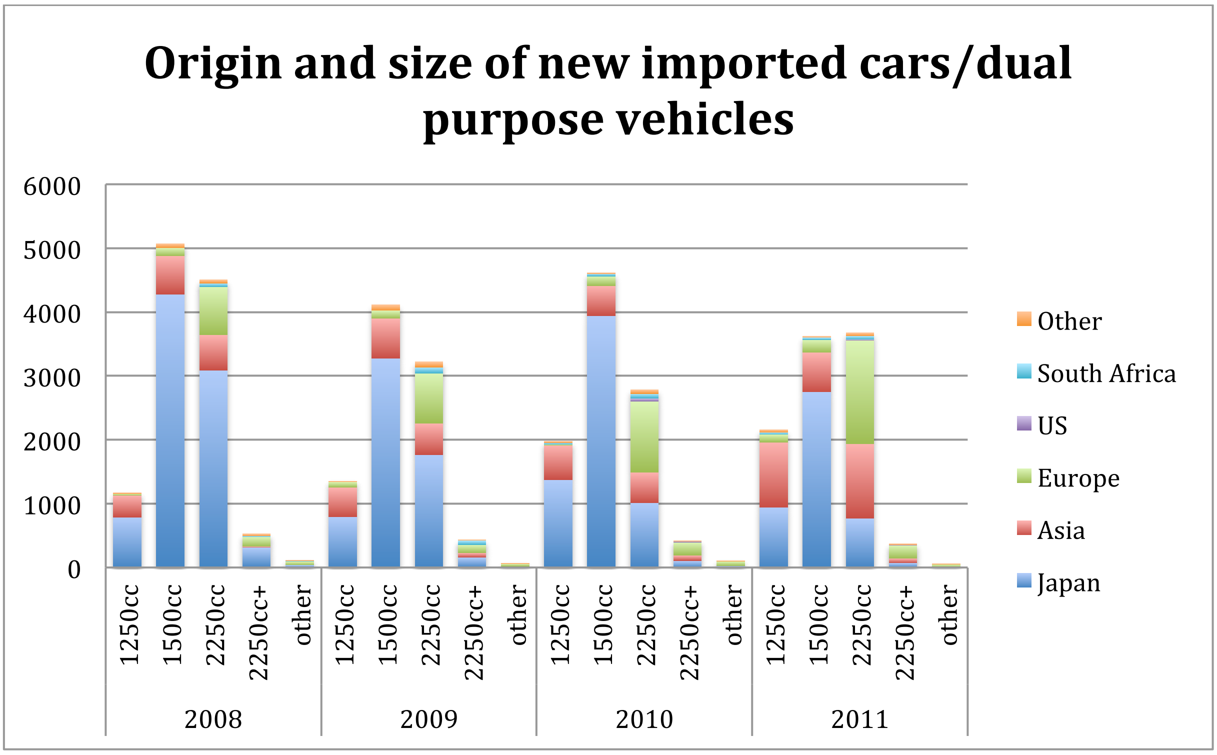


Figure 4.1.c Origin and size of new imported cars/dual purpose vehicles.
Sources: CSO, *Digest of road transport and road accident statistics 2011*, 2012.
CSO, *Digest of road transport and road accident statistics 2009*, 2010.

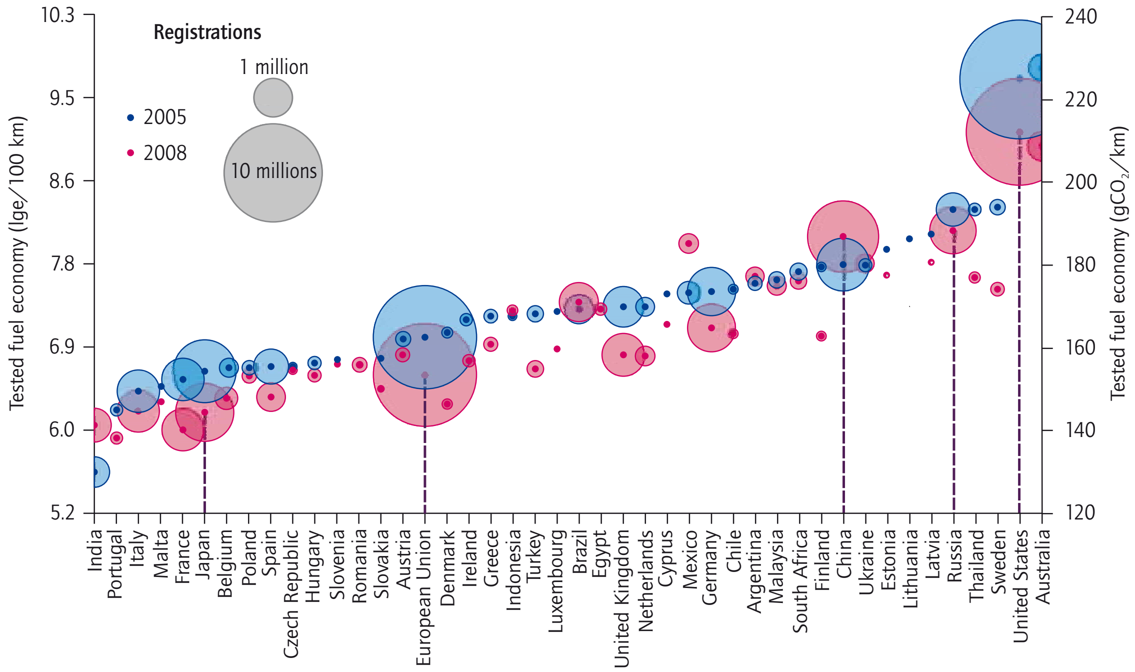


Figure 4.4.a: Average tested fuel economy for selected countries, 2005 and 2008.
Source: International Energy Agency. *Fuel economy of road vehicles*. © OECD/IEA 2012; Available from: http://dx.doi.org/10.1787/9789264185029-en.

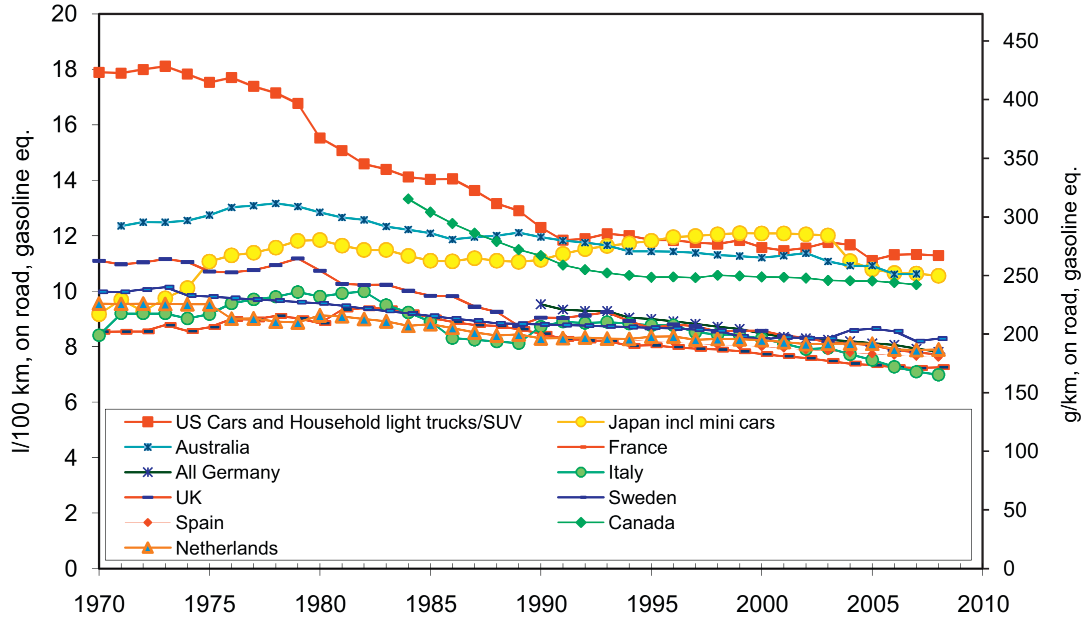


Figure 4.4.b: On road fuel intensity for US, Australia, Japan and European countries.
Reprinted from Transport Policy, **18**(2), Schipper, L., *Automobile use, fuel economy and CO2 emissions in industrialized countries: Encouraging trends through 2008?*, p.358-372., Copyright (2011), with permission from Elsevier.

Table 4.5.b: Average density of gasoline, diesel and LPG.

Fuel	Density	l/ton
Gasoline	0.737	1357
Diesel	0.85	1176
LPG	0.542	1844

Sources: State of California, Gasoline Gallon Equivalent of Alternative Fuels. Available from http://www.energyalmanac.ca.gov/transportation/gge.html.

Harvey, L.D.D., *Energy and the new reality* 2010, London: Earthscan.

F. Supporting tables for chapter 6

Table 6.2.a: Ethanol and gasoline consumption for different consumption models for 2010 with E10 assuming the same energy use for E10 as for gasoline.

Consumption Model:	Fuel intensity (lge/km)	Average distance (km/day)	Total ethanol (million l)	Total gasoline (million l)	Total E10 (million l)
1	0.07	30	8.0	71.7	79.7
2	0.07	20	5.3	47.8	53.1
3	0.07	10	2.7	23.9	26.6
4	0.10	30	11.3	102.5	113.9
5	0.10	20	7.6	68.3	75.9
6	0.10	10	3.8	34.2	38.0
7	0.13	30	14.8	133.2	148.0
8	0.13	20	9.9	88.8	98.7
9	0.13	10	4.9	44.4	49.3

Table 6.2.b: Ethanol and gasoline consumption for different consumption models for 2010 with E20 assuming the same energy use for E10 as for gasoline.

Consumption Model:	Fuel intensity (lge/km)	Average distance (km/day)	Total ethanol (million l)	Total gasoline (million l)	Total E10 (million l)
1	0.07	30	16.4	65.6	82.0
2	0.07	20	10.9	43.7	54.7
3	0.07	10	5.5	21.9	27.3
4	0.10	30	23.4	93.7	117.2
5	0.10	20	15.6	62.5	78.1
6	0.10	10	7.8	31.2	39.1
7	0.13	30	30.5	121.9	152.3
8	0.13	20	20.3	81.2	101.5
9	0.13	10	10.2	40.6	50.8

G. Supporting table for chapter 7

Table 7.1.c Capacity of each power plant on Mauritius 2011.

Central Electricity Board (CEB)			**Independent Power Producers (IPP)**		
	Plant capacity (MW)			**Plant capacity (MW)**	
	Installed	**Effective**		**Installed**	**Effective**
Hydro:					
Champagne	30.0	28.0	**Thermal:**		
Ferney	10.0	10.0	Firm producers[1]	258.8	240.5
Tamarind Falls	11.1	7.0	F.U.E.L.	36.7	33.0
Le Val	4.0	4.0	Compagnie Thermique de Belle Vue	71.2	62.0
Reduit	1.2	1.0			
Cascade Cecile	1.0	1.0	Consolidated Energy Limited	28.4	25.5
Magenta	0.9	0.9			
La Nicoliere F.C	0.4	0.4	Compagnie Thermique du Sud	32.5	30.0
La Ferme	1.2	1.2			
Total	**59.8**	**53.5**	Compagnie Thermique de Savannah	90.0	90.0
Wind:					
Island of Rodrigues	**1.3**	**1.3**			
Thermal:					
Island of Mauritius	378.8	339.6	Continuous producers[2]	27.0	23.6
St Louis	113.2	78.6	Medine	13.0	10.0
Fort Victoria	49.6	48.0	Mon Loisir	14.0	13.6
Nicolay	78.0	76.0	Landfill gas		
Fort George	138.0	137.0	Sotravic Ltd	2.0	2.0
Island of Rodrigues	9.8	8.9			
Total	**388.6**	**348.5**			
Total	**449.7**	**403.3**	**Total**	**287.8**	**266.1**

Total plant capacity	**Installed**	**Effective**
1. Island of Mauritius	726.4	659.2
CEB	*438.6*	*393.1*
IPP	*287.8*	*266.1*
of which involved in export to CEB	*278.7*	*227.5*
2. Island of Rodrigues (CEB)	11.1	10.1
Total	**737.5**	**669.3**

1 Producing electricity **all year** round with bagasse/coal

2 Producing electricity with bagasse **only** during crop season

Source: CSO, *Digest of energy and water statistics - 2011*, 2012.