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Electric Vehicle Possibilities using Low Power and Light Weight Range Extenders

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Abstract

Electric cars have the disadvantage of a limited range, and drivers may experience a range anxiety. This range anxiety can be solved by adding a range extender. But, the range extender should be light so as not to significantly increase the weight of the original vehicle. In urban areas with dense traffic (usually developing countries), the average speed around cities is typically lower than 50km/h. This means, the rolling resistance losses are more important than aerodynamic losses, and a weight reduction results in a bigger electrical range. Therefore, smaller and lighter range extenders are of much interest. The contribution of this paper is to indicate the possibility of range extenders with less than 25 kg with a capacity of 150 to 200 cc to suit a condition where weight counts. In this paper, the cost, environmental and grid impacts of going electric are also discussed. The effect of high altitude and driving style on the performance of an electric vehicle is assessed. The challenges and opportunities of vehicle electrification between countries with decarbonated power generation and fossil fuel dominated power generation are highlighted. Throughout the article, the case of Ethiopia is taken as an example.

Keywords: Electric Vehicles, range extender, ICE, green house gas emissions

1 Introduction

Electric mobility seems increasingly beneficial; both from an environmental and from an economical point of view, compared to conventional mobility [1]. However, the road towards total vehicle electrification still poses some big challenges. Currently, the main hurdle resides in the electrical storage technology [2]-[4]: compared with liquid fuels, they display much lower specific energy, energy density and refuelling/recharging rate. The issues of limited driving range and long charging time are both centred on the battery package of the car. But charging time can also be affected by the electric grid that supplies the power [5].

A series hybrid electric vehicle configuration uses the Internal Combustion Engine (ICE) as a prime mover of the generator coupled to the engine, and an electric motor to provide movement to the vehicle. This system can run with a small engine output in a stable operation efficiency region, supplying and generating electricity to the traction motor being sufficient for the average consumption [6]. This allows a reduction of fuel consumption and a better sizing for the engine [7].

Typical car trips are within the driving range of efficient electric vehicles (EVs), as almost 90% of daily car use [8] is for less than 40 km, while occasional trips exceed the EV range. In [9], it has been shown that even with limited range; electric vehicles could provide a large fraction of transportation needs. However, for the occasional extended range; the additional battery cost is extremely high. A solution to overcome this limitation is to start from a pure electric vehicle concept and include a range extender. Range extenders are small electricity generators operating only when required. The range extender consists of four parts: a combustion engine, a generator, a power electronic converter and a fuel tank, as shown in Figure 1. The generator is used to transform mechanical energy to electrical energy. A power electronic converter, interfacing the starter/ generator to the battery-bus of the electric vehicle, helps in starting and adapting the torque speed curve.

The BLDC starter/generator coupled with the IC engine acts as a starter motor during the engine starting (motoring) mode [10].

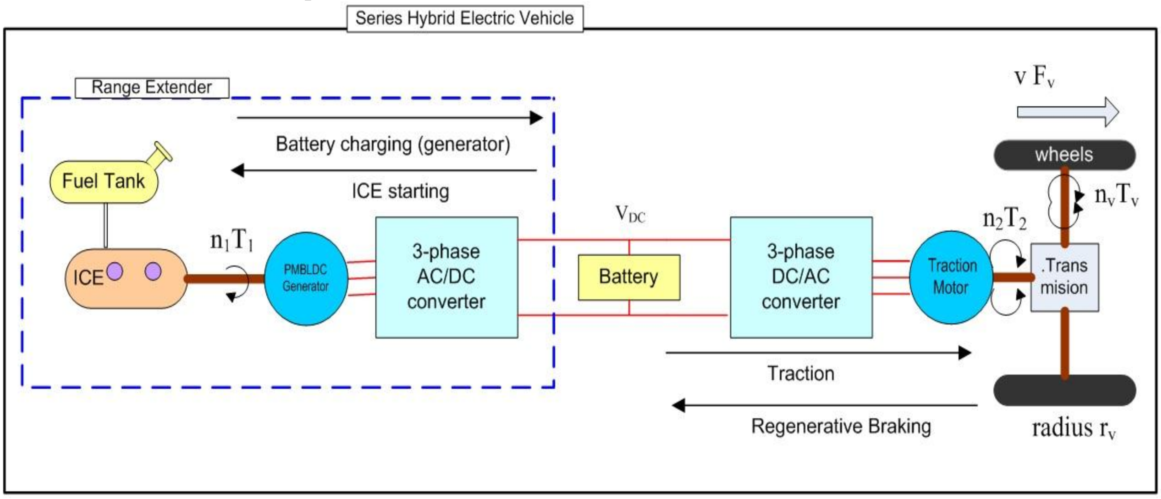

Figure1: Series Hybrid Electric Vehicle Architecture

2 Power and Torque Requirements for a Range Extender

In countries where the highway speed is limited, electric vehicles combined with low power and low weight range extenders can do the job of electric mobility. However, range extenders with a power up to 30kW, might be useful in Germany where long distance sustained speeds of 150km/h are allowed and realistic.

A way to reduce weight is using the generator as a cranking motor. The accelerating torque (resultant torque) which is applied as an engine starting torque is the difference of the torque produced from the starter/generator working as a starting motor minus the compression and friction torque. In the motoring case, the ICE acts as a load, and therefore applies a negative torque to the starter/generator.

2.1 Starter/generator Torque Requirements

The starter/generator under consideration is permanent magnet BLDC out runner machine which starts the engine in motoring mode and works as a generator once the engine has been started.

The electric machine needs to have motoring and generating capability, high power density, high efficiency high starting torque and reasonably a wide speed range to meet performance specifications.

2.2 Modeling of the compression torque (T_c) based on piston motion

The two commonly used 4 stroke combustion engines in production are the SI-engines (Spark Ignited) used for vehicles using gasoline, and the CI-engines (Compression Ignited) used for diesel engines. Here we deal with SI engine at full throttle, but the same methodology can be used to CI-engines.

Engine parameters:

$B = 68mm$, $L_s = 54mm$, $a = \frac{L_s}{2}$, $l_c = 1.5\, L_s$

Assuming an adiabatic compression, the equation for torque on the crankshaft due to the compressive force acting up on the piston can be expressed as:

$$T_c(\theta) = \left[P_{in}\left(\frac{V_c+V_d}{V_{BC(\theta)}}\right)^{\gamma} - P_a\right] \cdot \frac{d}{d\theta}\, V_{BC}(\theta) \qquad (1)$$

Note that when adapted, these engines can deliver considerably more power, as in kart competition.
γ: specific heat ratio , 1.4 for air, assuming adiabatic compression.
$P_a = 100\ kPa$, ambient pressure
$P_{in} = 90\ kPa$, intake pressure
P_{in} is pressure in cylinder at beginning of compression, usually nearly atmospheric.
V_d: displacement volume, m^3
V_C: clearance volume, m^3
V_{BC}: total volume, m^3

Table 1: Engine specifications

Model	G200F
Type	Single cylinder, 4-stroke gasoline
Rated Power (kW/3600rpm)	4.1
Max. torque (Nm/rpm)	12.4/2500
Fuel Consumption (gr/kWh)	≥ 313
Bore x Stroke (mm)	68x54
Displacement (cc)	196
Compression ratio	8.5:1
Dimension –Length(mm)	342
Dimension –Width(mm)	376
Dimension –Height(mm)	335
Net weight (kg)	16.5

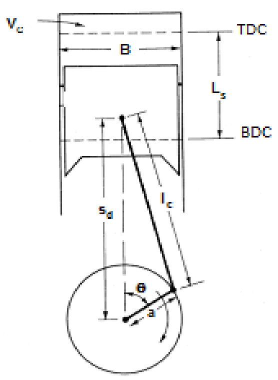

Figure 2: Geometric parameters of a cylinder [11-12].

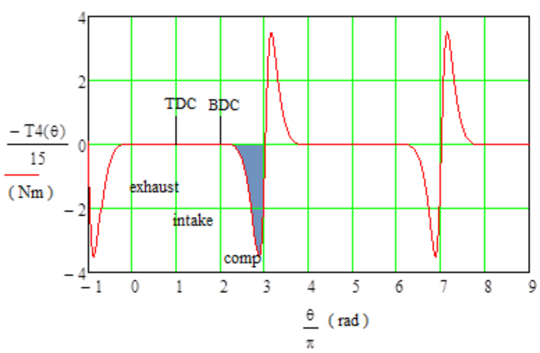

Figure 3: Compression torque as a function of Cranking Angle

The energy required for compression is:

$$W_c = \int_{V_{BC}}^{V_c} (P_c(V) - P_a)\,.\,dV = \int_0^{3\pi} T_c(\theta)\,.\,d\theta = 49.043\,J \quad (2)$$

The compression torque is averaged in one and half cycle (3π) considering from the start of exhaust 0 till the end of compression at 3π, as indicated in Fig.3.The BLDC torque requirement should be greater than the sum of the average compression torque in one and half cycle (3π) and the friction torque.

$$T_m > \frac{W_c}{3\pi} + T_f \quad (3)$$

For the IC engine under consideration, the friction torque T_f, in a new condition, which is rather worst case, was measured and found to be 2Nm, approximately. The effect of valves is neglected as compared to the worst case of friction torque. Therefore, an outer runner BLDC motor used at a torque (T_m) capability of just above 7.2 Nm is sufficient for the engine starting requirement. The resulting torque accelerates the inertia of engine and generator. The inertia of the engine including the flywheel is estimated at 12.347×10^{-3} kg.m^2 and that of generator at 3.031×10^{-3} kg.m^2.
The dynamic torque equation for the system is:

$$J \frac{d}{dt} \Omega_a(t) = T_m - T_f - T_c \quad (4)$$

For the graph plotted in Fig.4, a motor torque $T_m = 7.5\ Nm$ is used. The two consecutive portions, with a sudden fall of the engine speed, indicate the first two successive compression instances. From 0 to 0.2 seconds, as the engine speed $\Omega_a(t)$ increases, the angular displacement $\theta(t)$ also increases in a parabolic fashion. After the engine speed went up to about 80 rev/s (764 rpm), it slumped rapidly to almost 50 rpm, due to the effect of the compression stroke. During this time, the curve of the angular displacement $\theta\ (t)$ almost leveled out, which is a sign of an engine stall. But then, the speed made a sharp rise. It can be observed that the second compression is successful enough that the engine speed did not show a significant decrease as compared to the first compression stroke. Generally, if the first compression instance is not successful, then the second would do the job.
The analysis is done at full throttle (worst case), a reduced throttle would need less energy and less torque. As shown in Figure 5, when the motor torque is below the specified value, for instance $T_m = 7\ Nm$, the engine starts but stops just after 0.2 seconds since the starting torque is not sufficient enough for the starting requirement of the engine.

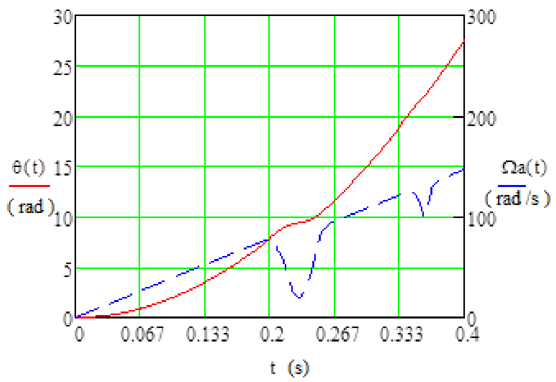

Figure 4: Angular displacement and angular speed as a function of time, when T_m=7.5 Nm.

After 0.2 seconds, the decline of the speed curve *Ωa(t)* of the engine indicates deceleration to end up stalling.

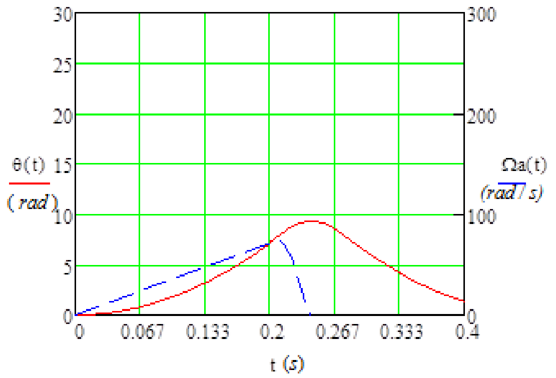

Figure 5: Angular displacement and angular speed as a function of time, when T_m=7 Nm.

A swift drop in the angular displacement curve *θ (t)* shows that the piston of the engine is not capable to overcome the compression, and hence returns back to the bottom dead center (BDC). The 200 cc engine has a typical full load torque of 12Nm. If 7.25Nm is on the limit, it means that the nominal torque is largely sufficient to start the engine. It means that the converter has not to be over-sized to also perform a starting function.

3 Sizing of Components for a Low Power and Light Weight Range Extender

In order to minimize the energy consumption of a range extended electric vehicle, there is a need of having a technological means to reduce weight, aerodynamic drag and rolling resistance of the vehicle. Material substitution, vehicle redesign and vehicle downsizing can lead to a light weight vehicle [13]. As the overall weight decreases, the energy requirements of the range extender components (internal combustion engine, starter/generator and power electronic unit) may be lowered and therefore can be downsized accordingly. Wind resistance can be reduced through redesigning the body to a more aerodynamic shape and also by the use of slippery panels [14].

3.1 Selection and Sizing of ICE

The highest power to weight ratio is still obtained with two stroke engines. However, two-stroke engines are unfavorable for emission level requirements; techniques such as direct fuel injection are required in order to reduce exhaust emissions [15].

Direct Fuel Injected two-stroke engine, compared to its two-cylinder four-stroke counterpart, would have a smaller size, weight and a lower cost. This cost would be lower but still a direct injection increases the price. Even a significantly higher fuel economy can be expected. A single-cylinder DI two-stroke gasoline engine installed as range extender in an EV will probably be the best challenger when compared to a more conventional four- stroke engine[16],[17]. However, the DI technology has the tendency to emit unburned particles [18].

However, commercialization objectives require the use of an engine for which production feasibility is proven. For this reason, engines only with production feasibility are considered as range extender prime movers. Due to the fact that DI techniques are still under development by engine manufacturers and may not be readily available in a given time frame for the given power, it is probable that two-stroke engines are ruled out for the range extender application.

Table 2: Assumed vehicle performance parameters

Parameter	Value	Remark
Maximum Vehicle speed, V_{max}	90 km/h	
Maximum continuous cruising speed, V_{cmax}	70km/h	
Acceleration time, t_a	8s	assuming from 0 to Vf=50km/hr in 8 sec
Gradeability, Z	20%	
Averaged hill climbing	5%	at 40km/h
Maximum traction motor efficiency, η_{m2}	0.93	
Generator efficiency, η_{g1}	0.93	
Rectifier efficiency, η_{r1}	0.97	
Inverter efficiency, η_{i2}	0.97	

The internal combustion engine does not need to supply the maximum traction power. Instead, it should be sized so that the vehicle can meet the maximum (continuous) cruising speed.
A cruising speed V_{cmax} of 70km/h requires traction power of:

$$P_v = \frac{1}{2} C_D A_f \rho_a V_{cmax}^3 + \mu_r mg V_{cmax} \quad (5)$$

Assuming the simplistic efficiencies (Table 2) for the series components (generator, rectifier, inverter, motor), the required ICE power rating, in terms of the traction power P_v given in (6), is:

$$P_{ICE} = \left(\frac{P_v}{\eta_{g1} \cdot \eta_{r1} \cdot \eta_{i2} \cdot \eta_{m2} \cdot}\right) \quad (6)$$

Note that the required ICE power rating is significantly lower than the maximum required traction power. The designer can always oversize it or take lower efficiency drives in account. If gravel or sandy roads are considered, the required energy will be significantly higher, but probably corresponding to lower average speeds.
Another view is to consider two main operation points: A maximum power point which is higher than (6) and a maximum efficiency power point which may be even lower than (6).

Table 3: Vehicle parameters

Parameter	Value
Wheel radius, $\boldsymbol{r_v}$	0.3m
Mass of vehicle+driver,$\boldsymbol{m}$	1100kg
Rolling resistance coefficient, $\boldsymbol{\mu_r}$	0.0085
Aerodynamic drag coefficient,$\boldsymbol{C_D}$	0.29
Area of car seen from front, $\boldsymbol{A_f}$	2 m2
Density of air, $\boldsymbol{\rho_a}$	1.225kg/m3
Force of gravity, g	9.81m/s2

3.2 Sizing of Starter/Generator for a Range Extender

During normal operation the rotational movement of the ICE is transformed to electrical energy by the permanent magnet brushless dc machine working as a generator. During starting operation the permanent magnet brushless dc machine functions as a starting motor.
In the hybrid electric mode, generator takes mechanical power:

$$P_{ICE} = T_1 n_1 \left(\frac{2\pi}{60}\right) \quad (7)$$

The generator is sized based on the ICE power rating,

$$P_{g1} = \eta_{g1} P_{ICE} \quad (8)$$

It is also possible to design high frequency generators, i.e. machines using 10 poles running at 6000 rpm with frequencies of 500Hz and even more. However, by this, a modification of the combustion engine power unit becomes necessary [19].

3.3 Power Electronics Sizing

It is important to have an efficient power electronic system in order to have an improved range in all electric operation and a fuel economy as well. The instantaneous matching of the available motor torque with the required vehicle torque at any desired speed is made possible by the power electronic control, thereby avoiding the necessity of multiple gearing for matching torque-speed [20].
Converter output PWM carrier frequencies are usually above 5000 Hz as frequencies about l000Hz are to be avoided because of acoustic reasons. The electric power P_1 produced via the rectifier can be expressed as:

$$P_1 = P_{r1} = \eta_{g1} \eta_{r1} P_{ICE} \quad (9)$$

Where η_{g1} and η_{r1} are efficiencies for generator and rectifier (AC/DC converter).
The electric power P_1 charges the battery and/or supplies a part of or the entire traction powerP_2.
In order to meet the packaging goals for the automotive environment, the power electronic components must be designed to operate over much higher temperature range [21, 22]. As it has been stated in [23], to maintain a steady bus voltage, the bus voltage ripple must be minimized.
The DC-link capacitor, as in Fig.6, filters the ripple current generated by the inverter, and decouples the effects of the inductance from the DC voltage source to the inverter part of the drive by providing a low impedance path for the high frequency ripple current.
A decisive requirement for DC link capacitors is their ability to handle ripple current, and the choice has conventionally been a choice between electrolytic and film capacitors.
The major advantage of electrolytic capacitors is their low cost per unit capacitance. However, it is misleading to conclude solely from this that

electrolytic capacitors are more cost effective solutions for DC links [24]. The ripple current rating is often the most important factor for this application. Because of the relatively low ripple current rating of electrolytic capacitors, it is often necessary to install more capacitance than is necessary in order to meet the ripple current requirements. Therefore, comparing the cost per unit amp of ripple current rating is more useful, and often results in film capacitors, where ripple current is not usually the limiting factor.

Hence, using film capacitors would mean the designer has to only consider the minimum capacitance value required for the system. As a result, designs which use film technology frequently save space [25].

Even though film capacitors do cost more per µF than electrolytic capacitors, the amount of capacitance needed for an inverter DC link capacitor design is much less for a film capacitor than an electrolytic capacitor since the film capacitor is not limited by ripple current rating like the electrolytic capacitor is. Film capacitors are advantageous over electrolytic capacitors in terms of size, weight, lifetime, inverter efficiency and cost [26], [27]. If a film capacitor is used, more current ripple has to be absorbed by the battery as a compromise.

For some simulations, Advanced Vehicle Simulator (ADVISOR) software is used.

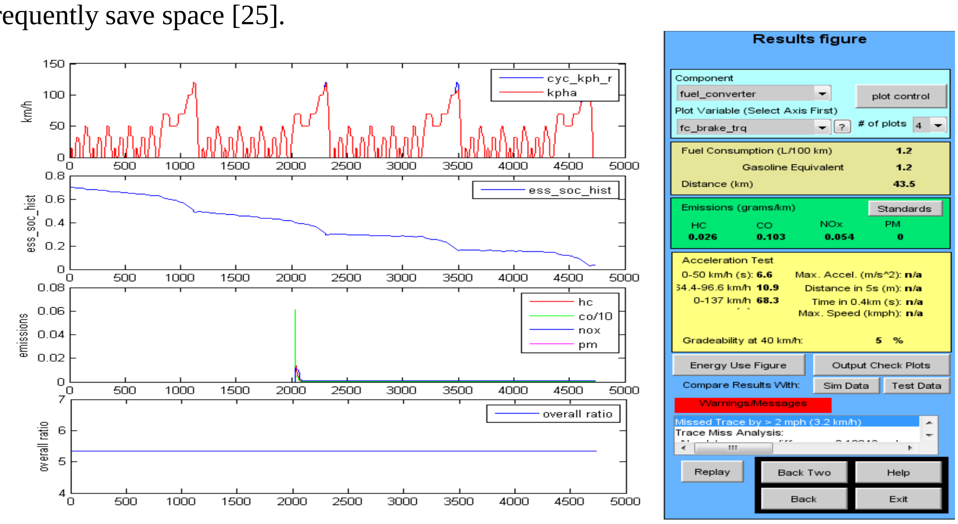

Figure 6: Plots for 4 cycle of NEDC with 1100 kg vehicle weight

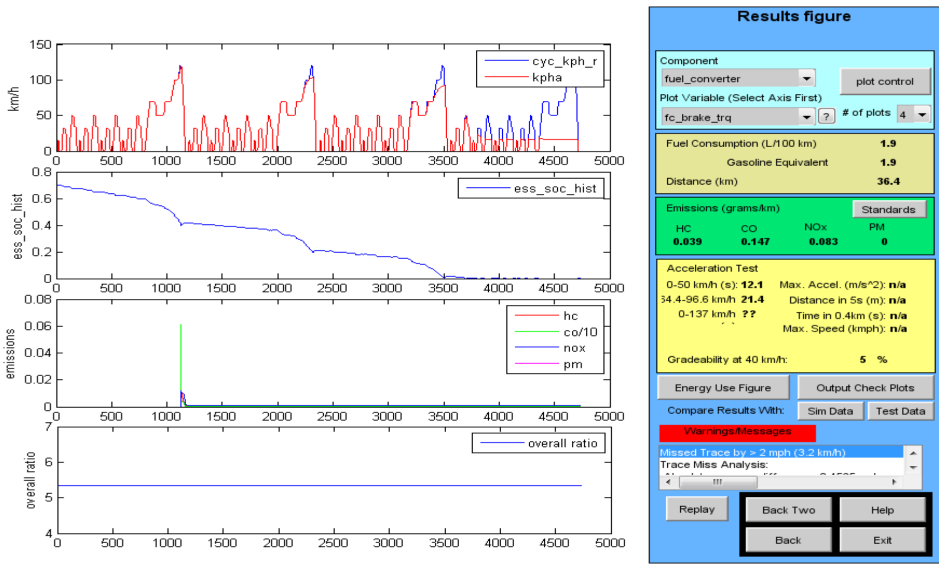

Figure 7: For 4 cycles of NEDC with 2000 kg vehicle weight

The following conditions were considered: Series Vehicle, ICE power 4 kW, generator power 4 kW, traction motor power of 16 kW, mass of vehicle of 1100 kg, hill climbing 5% at 40 km/hr as given in Table 1, Table 2 and Table 3.

For the inputs given, the series hybrid vehicle goes all-electric for almost the first two cycles of NEDC (Fig.6). and no emissions were released as no petrol fuel was used. In Fig.7, the vehicle goes all-electric for the first cycle, and at the beginning of the second cycle, it then starts using the gasoline. Keeping other parameters the same and making a difference only in the weight of the vehicle, a diffeence in the performance of the vehicle is observed. In Fig.6 (with lighter weight), the battery goes till the end of the fourth cycle without a complete discharge, higher fuel economy and lower emissions as compared to that of Fig.7. For the heavier weight of vehicle (Fig.7), there is a big difference between the requested and attained speeds in the fourth drive cycle.

4 Vehicle Electrification Impacts on Grid and Cost

Car electrification entails costs and grid impacts. But these impacts differ from country to country depending on the power generation mix they have. The impacts will be discussed comparing countries where the energy mix is of coal dominated and countries where power generation is mainly of renewable energy sources.

4.1 Associated costs of driving electric vehicles

Fuel prices in Ethiopia as of 2014 are 0.718€/litre and 0.78€/litre for diesel and petrol respectively, and for electric vehicles the average electricity rate is around 0.024 €/kWh. This will make range extended PHEVs and BEVs have the lowest operating costs due to the reduced price for electricity, and low usage of the ICE of the PHEV to recharge the battery.

According to [28], [29], the estimated current cost of a battery pack is between 400 and 600 €/kWh which makes BEVs have higher initial costs. The battery pack used in the Nissan Leaf has an estimated cost of 530 €/kWh (12,720 € for the 24 kWh battery) and the Chevrolet Volt battery has an estimated cost of 420 €/kWh (6720 € for the 16 kWh battery) corresponding to 35% and 16% of the total cost of the vehicle respectively. In 2020, the price per kWh is expected to be approximately 250 €, or 4000–6000 € for a 16–24 kWh battery pack. As the gap between electricity prices and petroleum widens, and as production volumes increase, cost will come down and PHEVs will become more attractive in the long run [30].

As to [31], 10 kWh of battery capacity would give a performance of roughly 4 litres of petrol equivalent. Due to the way the batteries and battery chargers work, considering efficiency of 80% for both the battery charger and the battery itself, we actually consume about 16 (or 10/0.64) kWh of electricity. This means, for the Ethiopian case where electricity rate is around 0.024 €/kWh, roughly €0.40 (16*0.024) would be added to the house electric bill for the equivalent of 4 litres of petrol. On the other hand, 4 litres of petrol in Ethiopia costs around €3.

4.2 Impacts on existing electric grid

The electrification of cars will certainly have an impact on the grid due to the need of recharging the battery pack. Knowing the magnitude of demand arising from the additional plug-in fleet and meeting the energy requirement as per the demand is very important aspect of handling the impact. The daily energy needed to recharge the entire BEV and PHEV has been dealt in [32], [33].

The daily energy needed to recharge the entire BEV fleet can be estimated as:

$$E_{BEV}(n) = A_{BEV}.EC_{BEV}(n).[\%PEV(n).N_{car}(n)] \quad (10)$$

where A_{BEV} is the BEV autonomy to be guaranteed on a daily base, assumed equal to 41 km, which corresponds to 15,000 km /year. $\%PEV$ is the share of the PEVs at year n within the private car fleet N_{car}.

The BEV power demand (i.e. PBEV (n)) can therefore be easily calculated dividing $E_{BEV}(n)$ by the recharging time $T_{ch,PHEV}$.here assumed equal to 1 h.

PHEV autonomy, differently than BEV, can rely on the sole fuel availability to be run in charge sustained mode after battery depletion.

The voltage and amperage of the connection to the electric grid are the factors which affect the power demand on the grid. Then the recharging time is determined by capacity of the battery to be recharged [34].

$$P_{PHEV}(n) = \frac{E_{PHEV}(n)}{T_{ch,PHEV}} \quad (11)$$

where the charging time $T_{ch,PHEV}$ was assumed equal to 7 h. In Ethiopia, a battery pack can draw a maximum of 16 A at 220 V from a regular power socket. This means, a maximum of 3.52 kWh energy can be stored in 1 hour. In order to fully charge a battery with a nominal capacity of 8 kWh, we would actually need around 10 kWh (8/0.8) of electricity, assuming a 20% charging loss. This means for 7 hours of charging during the night, the battery draws roughly 6.5 A at 220 V.

Apart from the different factors which affect the performance of electric vehicles discussed above, the type of power source from which the battery of an electric vehicle charges is that really matters when it comes to emission reduction. Therefore, in order to be benefited out of going electric, it is necessary to look into the grid mix of a given country.

5 Effect of High Altitude and Driving Style

5.1 Effect of altitude in energy consumption

In higher altitudes the air drag will be lower, and of course less dense. If there is a downhill section on a hilly road, low power level will be required and even braking have to occur frequently. If, on the other hand, there is an upcoming uphill section on a hilly road, a high power level will be required for hill climbing [35]. However [28], certain factors like elevation profile and the energy recovered while braking , though play an important role in the overall performance of an EV, they are not accounted in drive cycles like NEDC (see Fig.6 and 7).

As altitude increases, air becomes thinner. As air is required for combustion, and there is less available at higher altitudes**,** the engine makes less power. In general, a naturally aspirated engine will lose about 3 percent of its rated power for every 1,000 feet (about 1%/100m) of altitude gained**.** However, one can get higher miles-per-gallon at higher elevations [36].

HP Loss = (elevation x 0.03 x horsepower @ sea level)/1000

In Ethiopia, the capital city, Addis Ababa, is at an altitude of 2300 to 2400 m above sea level. This means a naturally aspirated internal combustion engine of a range extender will experience a loss of about 20 percent of its power compared to sea level. An altitude difference of 1000m and 1000kg corresponds to [37]:

$W_a = M \, \Delta h \times g$

That is 9.81MJ/1000m/ton= 2.725 kWh/1000m/ton

M: Mass of the vehicle, Δh: altitude difference. On the other hand, when driving down hill one should be aware of overcharging the battery as it may require a resistive dissipating means to prevent overcharging.

5.2 Effect of driving style in energy consumption

The driver's driving style and the auxiliary equipment of the vehicle [28] are the other factors which affect the energy balance. In order to reduce the extra power requirement due to the auxiliary equipment, at low speeds it is recommended to circulate air with the windows open rather than using the air conditioner of the car. Instead of using an aggressive driving style, a driving style with moderate accelerations and speed, minimizing the time at which the electric motor runs at full power and maximizing the energy recovered through regenerative braking, optimizes the vehicle range.

6 What Matters for an Electric Vehicle to be Green or not?

In order to have a better overview of the impact of electric vehicles on the climate, it is appropriate to consider the magnitude of emissions arise from both electricity supply and vehicle manufacturing.

Both electric and hybrid electric vehicles offer CO2 emissions reductions; however an EV charged by electricity derived from carbon intensive sources would only achieve marginal savings over an Internal Combustion Engine (ICE). A vehicle charged from decarbonised electricity offers significant savings [38].

As far as the GHG emission is concerned, the use phase dominates the overall impacts when it comes to a fossil fuel dominated electricity mix. However, for an electricity mix where the renewable energy source is dominant, the production phase of a BEV is the one that dominates the overall environmental impact [39, 40].

According to [41], an electric vehicle has an estimated manufacturing emissions of 70 g CO2 e/km over its lifetime, and its wall-to-wheel energy use, for instance of that Nissan Leaf, is 211wh/km. Out of the total emissions arise from consuming grid electricity, 80% comes directly from fuel combustion, 10% from fuel production indirectly, and 10% results due to the losses in transmission and distribution, though this varies from country to country.

Table 4: Mix of sources for electric generation in Ethiopia as of 2012[42].

Type	*Capacity (MW)*	*Generation (TWh/year)*	*% share of total*
Hydro	1950	6.2	99.2
Diesel	130	0.01	0.16
Wind	80	0.03	0.48
Geothermal	7	0.01	0.16
Total	2167	6.25	100

In Ethiopia [44], by 2030 the total electric generation installed capacity will be around 25,000 MW out of which 22,000 MW, 2,000 MW and 1,000 MW will be from hydro, wind and geothermal power plants, respectively. Table 5 shows the ongoing and planned renewable energy source projects. This makes Ethiopia a place where the future of electric vehicles is promising. Electric vehicles can't be taken as a standalone means for emission reduction unless they are deployed with an aggressive expansion for more green energy sources.

According to [41],[44], the carbon emissions for petrol vehicle manufacturing over its lifetime, and petrol production are estimated at 40 gCO2 e/km and 0.46 kg CO2 e/litre, respectively.

In other words, considering all the emission components carbon intensity of petrol combustion (2.31 kg CO2 e/ litre), manufacturing of petrol vehicle (40 gCO2 e/km) and petrol production (0.46 kg CO2 e/litre), a hypothetical petrol vehicle with fuel economy of 220 MPG_{US} (1 L / 100 km) will emit around 7 kg CO2 e/100 km. This means, driving an electric vehicle in Paraguay and Ethiopia, where all the electric car emissions (70 g CO2 e/km) result from the vehicle manufacturing, is equivalent to driving a petrol vehicle of 1litre/100km fuel economy. Needless to say, that this is sensitive to vehicle manufacturing assumptions. In the coal based countries, grid powered electric vehicles are no better than conventional petrol vehicles, and possibly worse. The difference in the magnitude of carbon emissions between the low carbon countries and coal based countries (see Fig.8) is the result of the differences in electric power sources feeding the grid.

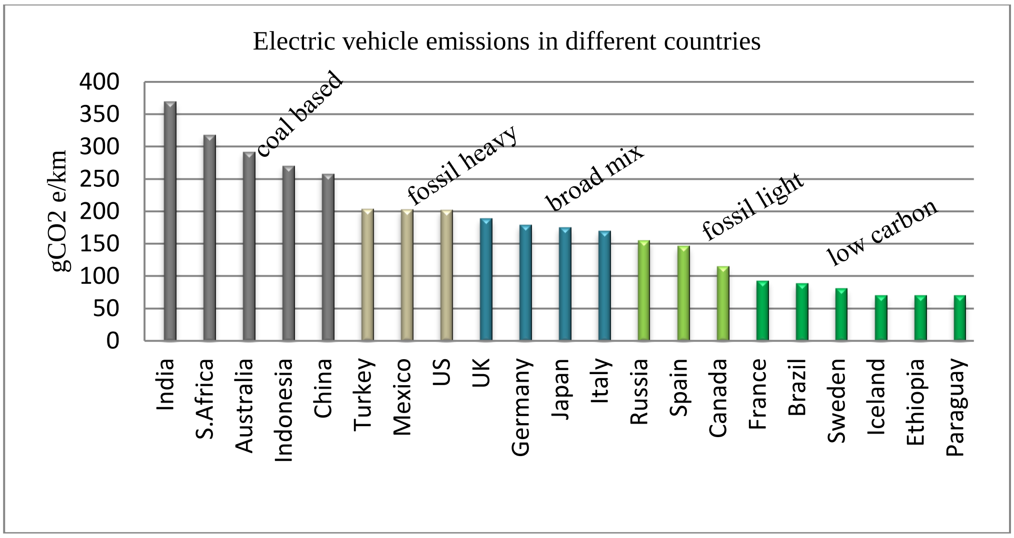

Figure 8: Electric vehicle emissions for different countries [41, 44-49]

Therefore, the climate benefit of vehicle electrification differs from country to country depending on the type of energy mix. If we only look on the electric cars themselves, and neglect where the electricity for battery charging comes from, it would not give the whole picture of what really happens. Hence, the research on electric vehicles should be accompanied with exploration of means to increase the share of renewable energy sources. The data in Fig.8 include the emissions for vehicle manufacturing, direct fuel combustion and indirect fuel production.

Table 5: Ongoing and planned wind farm, geothermal and hydropower projects [45-47]

s.no.	Project	Capacity (MW)				Commissioning year
		Wind	Geothermal	Hydro	Total	
1	Adama I wind farm	51			51	2012
2	Ashegoda wind farm	120			120	2014
3	Aysha wind farm	300			300	2015
4	Adama II wind farm	153			153	2015
5	Debre Birhan wind farm	100			100	2015
6	Assela wind farm	100			100	2015
7	Aluto Langano		70		70	2015
8	Hidassie (GERD)			6000	6000	2015
9	Fincha Amerti Nesh			97	97	2015
10	Gilgel Gibe III			1870	1870	2015
11	Chemoga Yeda I			162	162	2015
12	Chemoga Yeda II			118	118	2015
13	Halele			96	96	2015
14	Worabesa			326	326	2015
15	Gilgel Gibe IV			1472	1472	2015
16	Tendaho		100		100	2018
17	Corbetti		75		75	2018
18	Abaya		100		100	2018
19	Tultlu Moya		40		40	2018
20	Dofan		60		60	2018
21	Galema I wind farm	250			250	2020
22	Mosebo Harena	40			40	2020
23	Geba I			215	215	2020
24	Geba II			157	157	2020
25	Genale Dawa III			254	254	2020
26	Genale Dawa IV			246	246	2020
27	Gilgel Gibe V			660	660	2020
28	Tekeze II			450	450	2020
29	Mend Aya			2000	2000	2020
30	Beko Abo			2100	2100	2020
31	Wabi Shebele 18th			87	87	2020
32	Dedessa			613	613	2020
33	Birbir			467	467	2020
34	Dabus			425	425	2020
35	Tams			1000	1000	2020
36	Border			800	800	2020
37	Genale Dawa V			100	100	2020
38	Kara Dodi			1600	1600	2025
	Total	1116	445	21,315	22,876	

7 Conclusion

The lightest engines for range extenders would be the DI two-stroke engines. However, DI two-stroke engines may be ruled out of the choice due to production feasibility issues. The compression torque, which acts against the motor starting torque, has been modeled starting from a piston motion. For effective starting, the torque produced by the starter/generator and the flywheel effect of the rotating inertia must overcome the compression torque and friction torque. The required peak torque rating is much lower than the peak compression torque and even lower than the average torque in the generating mode. An outrunner permanent magnet BLDC motor is a good candidate as a starter/generator for lightweight and low power range extenders. The switching devices will not have to be oversized for starting the range extender.

In selecting the DC link capacitors, it has been seen that film capacitors are advantageous over electrolytic capacitors in terms of size, weight, lifetime, inverter efficiency and cost.

For a successful deployment of electric vehicles, increasing the share of renewable energy sources is vital. Countries like Paraguay, Ethiopia, Iceland and Sweden have gone far in this regard.

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