Electric Vehicles in Conjunction with Roof-top Solar Power Generation Systems for Homes: Impact On The Carbon Footprint and Energy Efficiency of Sri Lankan Transportation Sector

O.S.D. De Silva and M.A.V.J. Muthugala

Presented by: O.S.D. De Silva

Introduction: Net Metering with Solar PV

- Electricity consumers can generate electricity using Solar PV for their consumption, while the excess can be exported to the national grid and can be imported for use when needed.
- The consumer will be billed for the net amount of energy consumed.
- Net energy (kWh) = Energy Imported (kWh) – Energy Exported (kWh)

Introduction: Electric Vehicles

- Driven by electric motors.
- Electricity is stored in a rechargeable battery.
- Batteries must be recharged using electricity.
- Zero tailpipe emission

(Source: Plug-In Electric Vehicles: What Role for Washington?, David B. Sandalow, SBN-13: 978-0-8157-0305-1)

Methodology

- Identification of consumer categories based on the daily distance travelled.
- Estimation of electrical energy and gasoline requirement.
- Comparative analysis of CO2 emission from Conventional Gasoline Engine Vehicles (CGEV) and Electric Vehicles (EV).
- Estimation of total CO2 reduction in Sri Lankan transportation system for selected cases.

Identification of Consumer Categories

- Calculation of Electricity Requirement and Gasoline Requirement.
- Calculation of CO2 Emission from CGEV and EV.

Identification of consumer categories

- Three categories were identified based on the daily distance travelled. (25km, 50km, 100km)
- Monthly distance travelled = (Daily distance traveled×20)+(Daily distance travelled×10×50%)
- City and highway combined fuel economy of 30 kWh per 100 US miles assumed for EV.

(Source: http://www.fueleconomy.gov/feg/evsbs.shtml)

- City and highway combined fuel economy of 12 km per liter of gasoline assumed for similar size conventional gasoline engine vehicle.

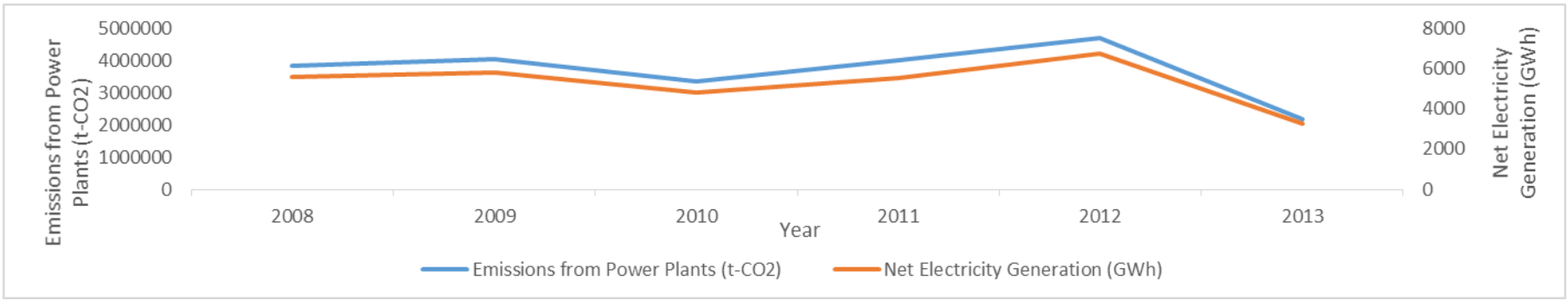
Calculation of Electricity Requirement and Gasoline Requirement

Daily Distance Travelled (km)	Monthly Distance Travelled (km)	EV - Electrical Energy Requirement (kWh) per month	CGEV – Gasoline Requirement (Liters) per month
25	625	117	52
50	1250	234	104
100	2500	469	208

Calculation of Emission due to Electricity Generation

Operating Margin – 2013 (Source: Sri Lanka Energy Balance – Sri Lanka Sustainable Energy Authority)	
Emissions from Power Plants (t-CO2)	2186060.78
Net Electricity Generation (GWh)	3259.96

- Average weight of CO2 emitted per kWh of electricity generated = 0.67kg



CO2 Emission Factors

- Average weight of CO2 emitted per liter of burnt gasoline = 2.3kg

(Source: Fuel consumption guide 2013, ISSN 0225-9214)

- Average weight of CO2 emitted per kWh of electricity generated = 0.67kg

CO2 Emission from Different Customer Categories

Daily Distance Travelled (km)	Monthly Distance Travelled (km)	EV - Electrical Energy Requirement (kWh) per month	CGEV – Gasoline Requirement (Liters) per month	**CGEV - CO2 from Gasoline (kg) per month**	**EV - CO2 from Electricity Generated (kg) per month**
25	625	117	52	**119.79**	**78.52**
50	1250	234	104	**239.58**	**157.03**
100	2500	469	208	**479.17**	**314.06**

Percentage Reduction of CO2 from CGEV to EV= 34.5%

Roof-top Solar PV Generation Systems for Homes

- Calculation of Total Efficiency of the Process of Converting Solar Power to Electricity.
- Calculation of Required Roof-top Space for Different Consumer Category.

Calculation of Total Efficiency of the Process of Converting Solar Power to Electricity

- Solar resource in Colombo area = 5kWh/m2/day

(Source: Solar Resource Assessment for Sri Lanka and Maldives, National Renewable Energy Laboratory.)

- Following De-rating factors were assumed,
- Deration for manufacturer production tolerance = 5%
- Deration for operation temperature = 10%
- Deration for dust and dirt deposited over time = 7%
- Deration due to module mismatch and wiring losses = 5%
- Deration due to losses in the inverter = 10%

- Panels are assumed to be oriented to face the true south.
- Efficiency of converting solar power to electricity by polycrystalline panels = 15%

(Source: Design of a Rooftop Solar Net Metering System, WDAS Wijayapala)

- Overall Efficiency of the Equipment = 95% x 90% x 93% x 95% x 90% = 68%
- **Total Efficiency of the process of converting solar power to electricity = 15% x 68% = 10.2%**

Required Roof-top Space for Solar PV Generation Systems for Homes

- Solar resource of 5kWh/m2/day will produce

= 5 kWh/m2/day x 10.2%

= 0.51 kWh/m2/day

Daily Distance Travelled (km)	Monthly Distance Travelled (km)	EV - Electrical Energy Requirement (kWh) per month	EV - Electrical Energy Requirement (kWh) per day	Required Solar PV panel area (m2)	Considering a 20% of space for panel frames and access space. Required roof top (m2)
25	625	117	3.91	8	9
50	1250	234	7.81	15	18
100	2500	469	15.63	31	37

Impact on CO2 Emission and Efficiency

- Impact of Replacing a Certain Percentage of Petroleum Energy for CGEV with Electrical Energy for EV for a year.
- Primary Energy to Power Conversion Efficiency of EV vs. CGEV.

Efficiency Factors

- Efficiency of a CGEV (Tank to Power) = 20%
- Efficiency of a EV (Grid to Power) = 80%

(Source: Plug-In Electric Vehicles: What Role for Washington?, David B. Sandalow, SBN-13: 978-0-8157-0305-1)

(Electric Vehicle Efficiency Analysis, Source: http://www.saxton.org/EV/efficiency.php)

- Deration for engine losses, wind resistance losses, braking losses, etc. were taken into account in the above vehicle efficiencies.

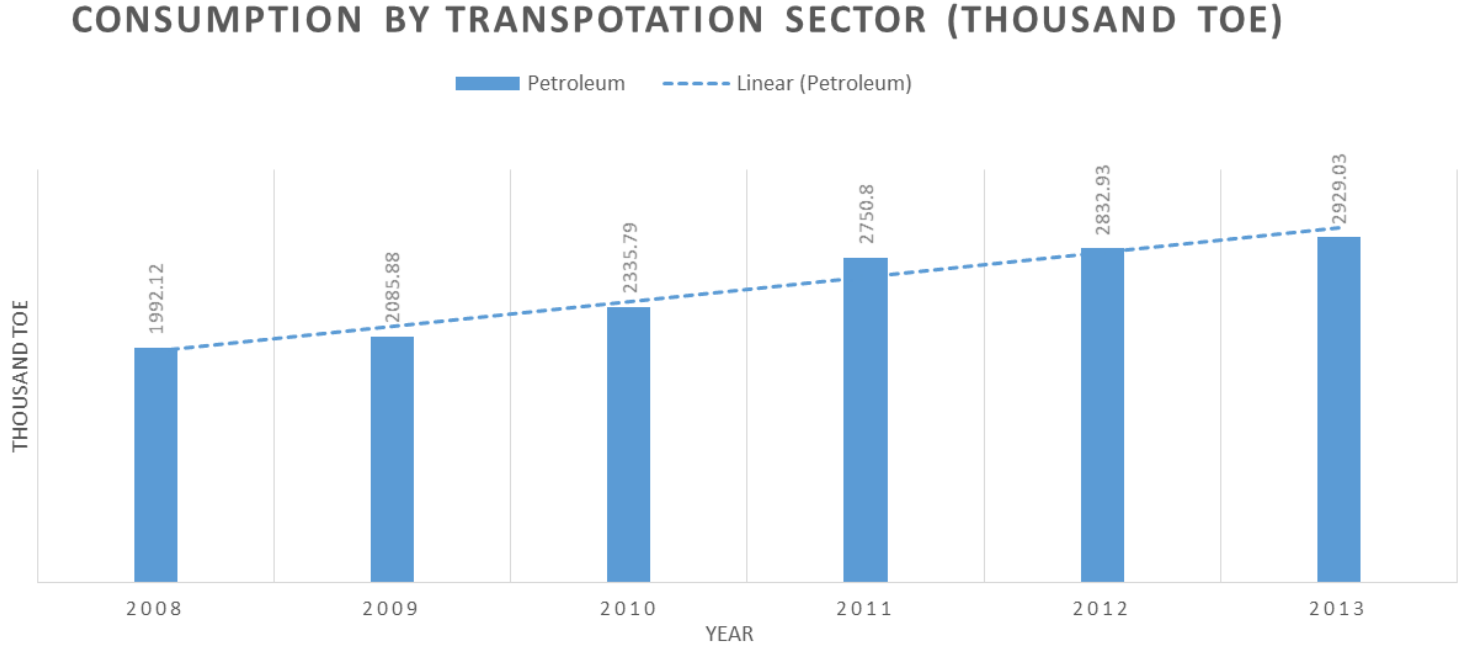
- Electricity (TOE/GWh) = 86

(Source: Sri Lanka Energy Balance, Sri Lanka Sustainable Energy Authority)

Impact of Replacing Petroleum Energy for CGEV with Electrical Energy for EV for a year

Replacing Petroleum Energy for CGEV with Electrical Energy for EV for a year	2% of Energy out of 2013 consumption	5% of Energy out of 2013 consumption
Petroleum Energy (thousand toe)	58.58	146.45
Equivalent Energy (kWh)	681169767.44	1702924418.60
Equivalent liters of Gasoline	76535928.93	191339822.3
CGEV - CO2 from Gasoline (MT) per year	176032.6	440081.6
EV - Electrical Energy Requirement (kWh) per year	Equivalent Energy (kWh) * Efficiency of CGEV (20%) / Efficiency of EV (80%)	
	170292441.9	425731104.7
EV - CO2 from Electricity Generated (MT) per year	114095.9	285239.8
Saving of CO2 (MT) per year	**61936.7**	**154841.7**

Increasing Trend of Energy Consumption of the Transport Sector

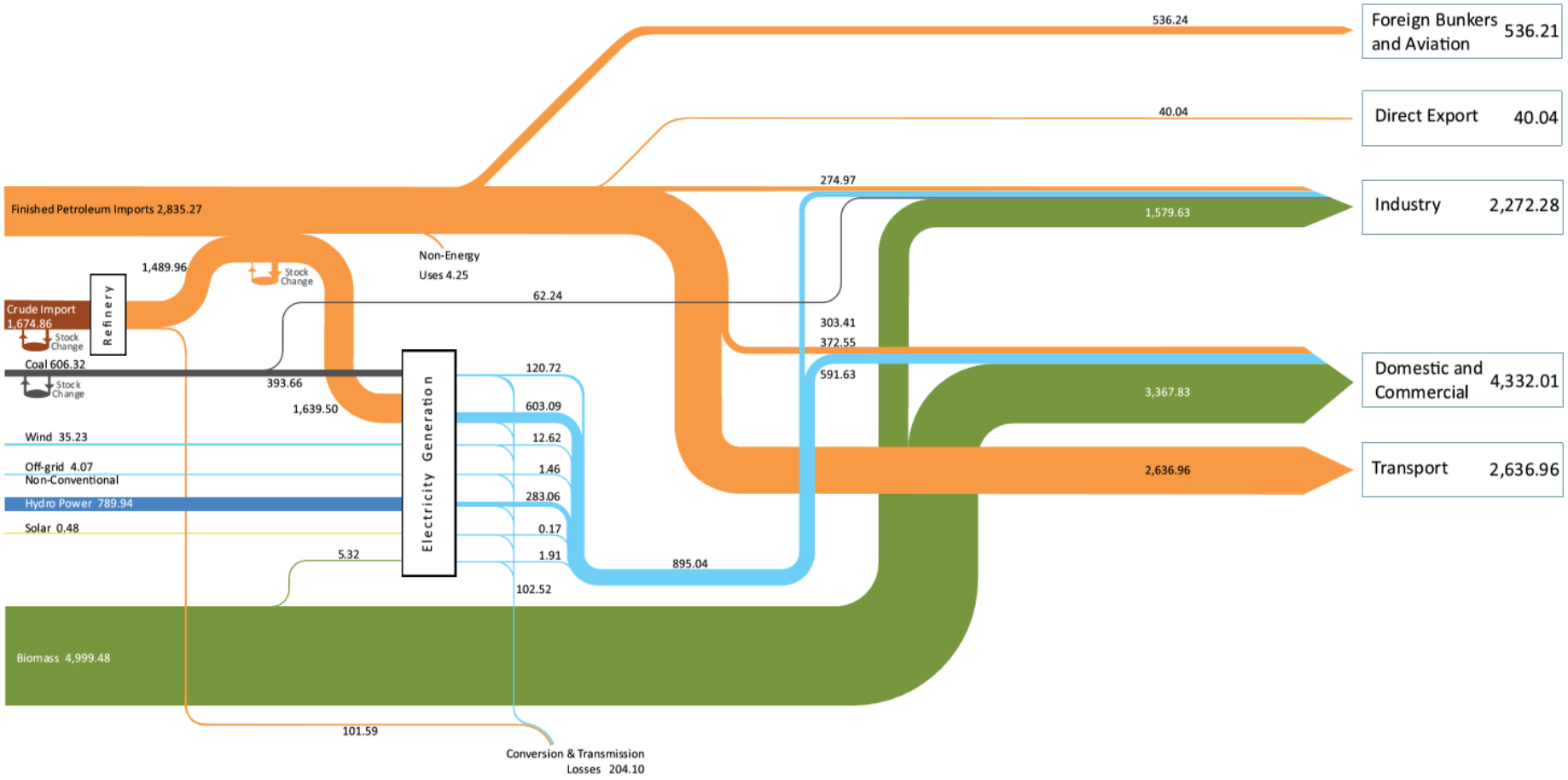


(Source: Sri Lanka Energy Balance, Sri Lanka Sustainable Energy Authority)

Efficiency of Electricity Generation and Calculation of Overall Efficiency of EV

Primary Energy Source	Energy (ktoe)
Coal	393.66
Petroleum	1639.5
Wind	35.23
Hydro power	789.94
Solar	0.48
Biomass	5.32
Total Energy Input	2864.13
Output	895.04
Net output	(Output)-(Off Grid NCRE)= 890.97
Off-Grid NCRE	4.07
Efficiency of Electricity Generation	(Net Output)/(Total Input)= 31%
Overall Efficiency of EV (Primary Energy to Power)	=80% x 31% = **25%** Higher than the CGEV efficiency

Energy Flow Diagram – 2012



Energy Flow Diagram - 2012 (ktoe)

(Source: Sri Lanka Energy Balance 2012, Sri Lanka Sustainable Energy Authority http://www.energy.gov.lk/pdf/EB_2012.pdf)

Conclusions

- EV in conjunction with roof-top solar PV generation systems for homes, increase the energy efficiency and reduce the CO2 emission.
- According to the daily distance travelled, required approximated roof-top space for solar PV generation systems for homes vary.
- Even without the solar PV electricity generation system integrated,
  - Energy efficiency of primary energy to power conversion, is higher in EV compared to CGEV.
  - Reduced CO2 emission in EV (considering grid emission) compared to CGEV.

Thank You