2.5 FUEL EFFICIENCY ANALYSIS IN ELECTRIC DRIVE

All stages of the life cycle were considered, starting from

a. The extraction of natural resources to produce materials and

b. Ending with conversion of the energy stored on board the vehicle into mechanical energy for vehicle displacement and

c. Other purposes (heating, cooling, lighting, etc.).

In addition, vehicle production stages and end-of-life disposal contribute substantially when quantifying the life cycle environmental impact of fuel-propulsion alternatives.

The analysis were conducted on six vehicles, each was representative of one of the above discussed categories. The specific vehicles were:

1. Toyota Corolla (conventional vehicle),
2. Toyota Prius (hybrid vehicle),
3. Toyota RAV4EV (electric vehicle),
4. Honda FCX (hydrogen fuel cell vehicle),
5. Ford Focus H_2 -ICE (hydrogen ICE vehicle),
6. Ford Focus H_2 -ICE adapted to use ammonia as source of hydrogen (ammonia-fueled ICE vehicle).

Two environmental impact elements were accounted for in the:

a. Air pollution (AP) and

b. Greenhouse gas (GHG) emissions

The main GHGs were CO_2,CH_4, N_2O, and SF_6 (sulphur hexafluoride), which have GHG impact weighting coefficients relative to CO_2 of 1, 21, 310, and 24,900, respectively. For AP, the airborne pollutants CO, NO_X,SO_X, and

VOCs are assigned the following weighting coefficients: 0.017, 1, 1.3, and 0.64, respectively.

The vehicle production stage contributes to the total life cycle environmental impact through the pollution associated with

a. The extraction and processing of material resources,

b. Manufacturing and

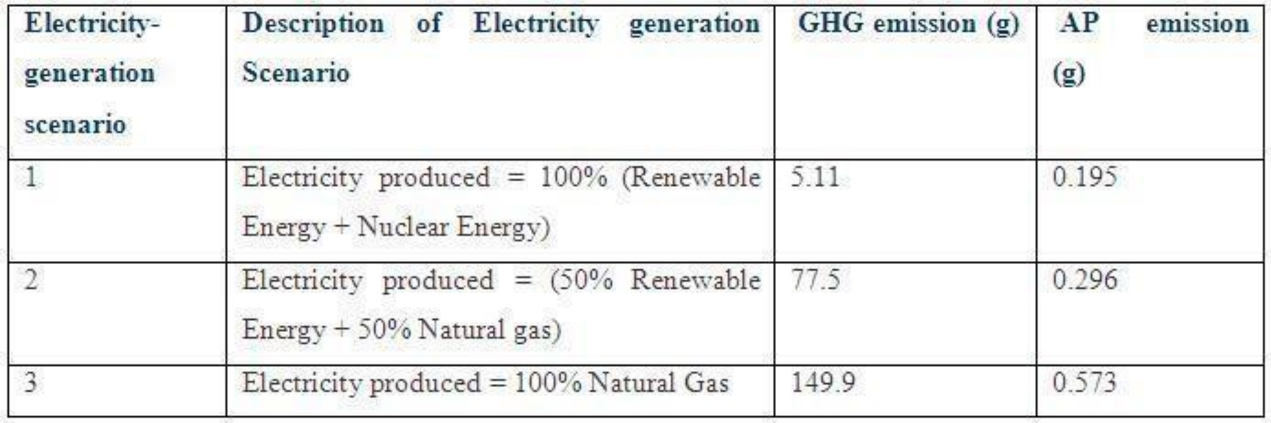
c. The vehicle disposal stage.

Additional sources of GHG and AP emissions were associated with the fuel production and utilization stages. The environmental impacts of these stages have been evaluated in numerous life cycle assessments of fuel cycles.

Regarding electricity production for the electric car case, three case scenarios were considered here:

1. When electricity is produced from renewable energy sources and nuclear energy;
2. When 50% of the electricity is produced from renewable energy sources and 50% from natural gas at an efficiency of 40%;
3. When electricity is produced from natural gas at an efficiency of 40%.

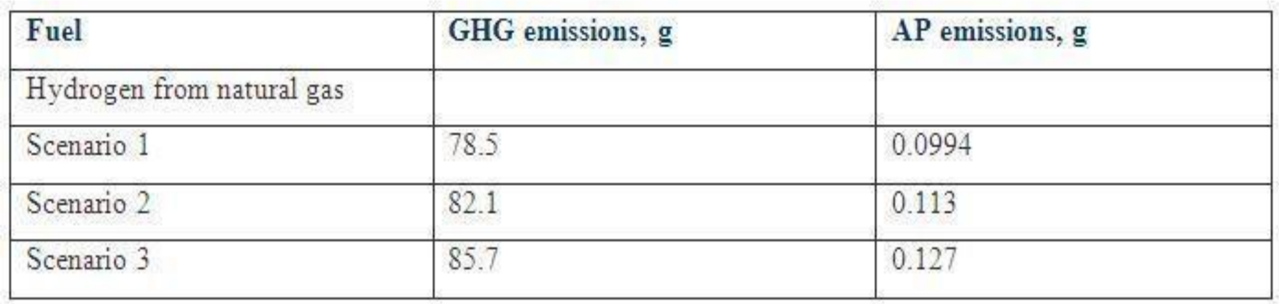
AP emissions were calculated assuming that GHG emissions for plant manufacturing correspond entirely to natural gas combustion. GHG and AP emissions embedded in manufacturing a natural gas power generation plant were negligible compared to the direct emissions during its utilization. Taking those factors into account, GHG and AP emissions for the three scenarios of electricity generation were presented in Table 2.



Electricity-generation scenario	Description of Electricity generation Scenario	GHG emission (g)	AP emission (g)
1	Electricity produced = 100% (Renewable Energy + Nuclear Energy)	5.11	0.195
2	Electricity produced = (50% Renewable Energy + 50% Natural gas)	77.5	0.296
3	Electricity produced = 100% Natural Gas	149.9	0.573

Table2: GHG and air pollution emissions per MJ of electricity produced

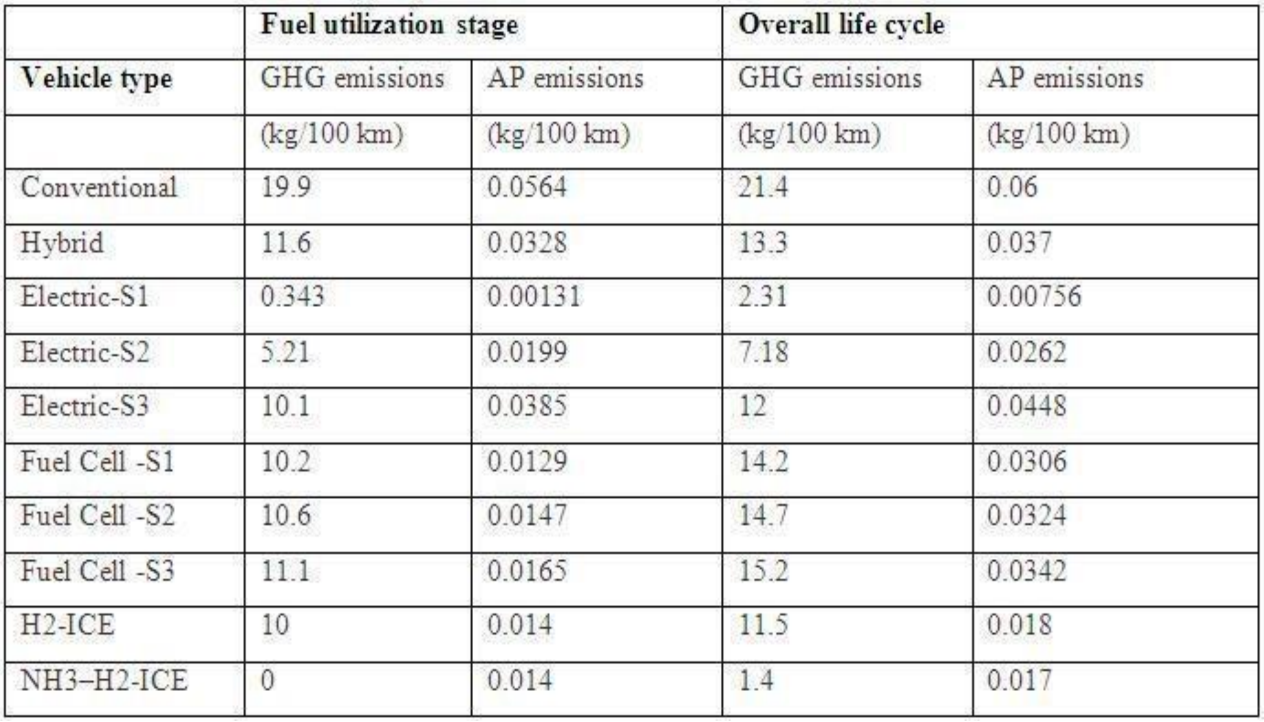
Hydrogen charging of fuel tanks on vehicles requires compression. Therefore, presented case considered the energy for hydrogen compression to be provided by electricity.



Fuel	GHG emissions, g	AP emissions, g
Hydrogen from natural gas		
Scenario 1	78.5	0.0994
Scenario 2	82.1	0.113
Scenario 3	85.7	0.127

Table 3: GHG and air pollution emissions per MJ fuel of Hydrogen from natural gas produced

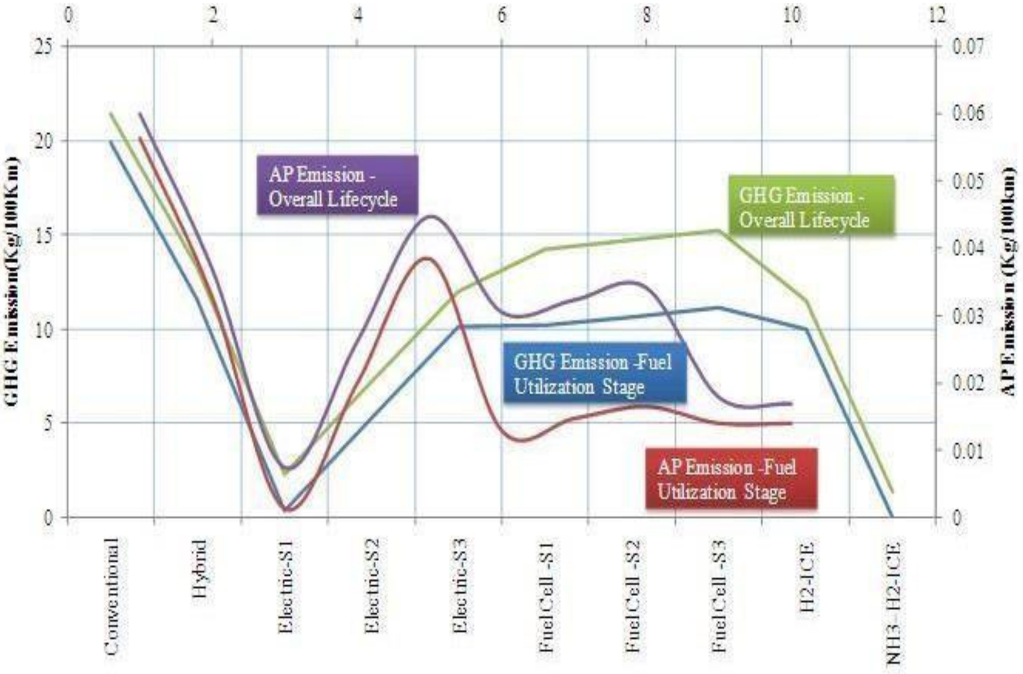
GHG and AP emissions were reported for hydrogen vehicles for the three electricity-generation scenarios considered (see table 3), accounting for the environmental effects of hydrogen compression.



	Fuel utilization stage		Overall life cycle	
Vehicle type	GHG emissions	AP emissions	GHG emissions	AP emissions
	(kg/100 km)	(kg/100 km)	(kg/100 km)	(kg/100 km)
Conventional	19.9	0.0564	21.4	0.06
Hybrid	11.6	0.0328	13.3	0.037
Electric-S1	0.343	0.00131	2.31	0.00756
Electric-S2	5.21	0.0199	7.18	0.0262
Electric-S3	10.1	0.0385	12	0.0448
Fuel Cell -S1	10.2	0.0129	14.2	0.0306
Fuel Cell -S2	10.6	0.0147	14.7	0.0324
Fuel Cell -S3	11.1	0.0165	15.2	0.0342
H2-ICE	10	0.014	11.5	0.018
NH3–H2-ICE	0	0.014	1.4	0.017

Table 4. Environmental impact associated with vehicle Overall Life cycle and Fuel Utilization.

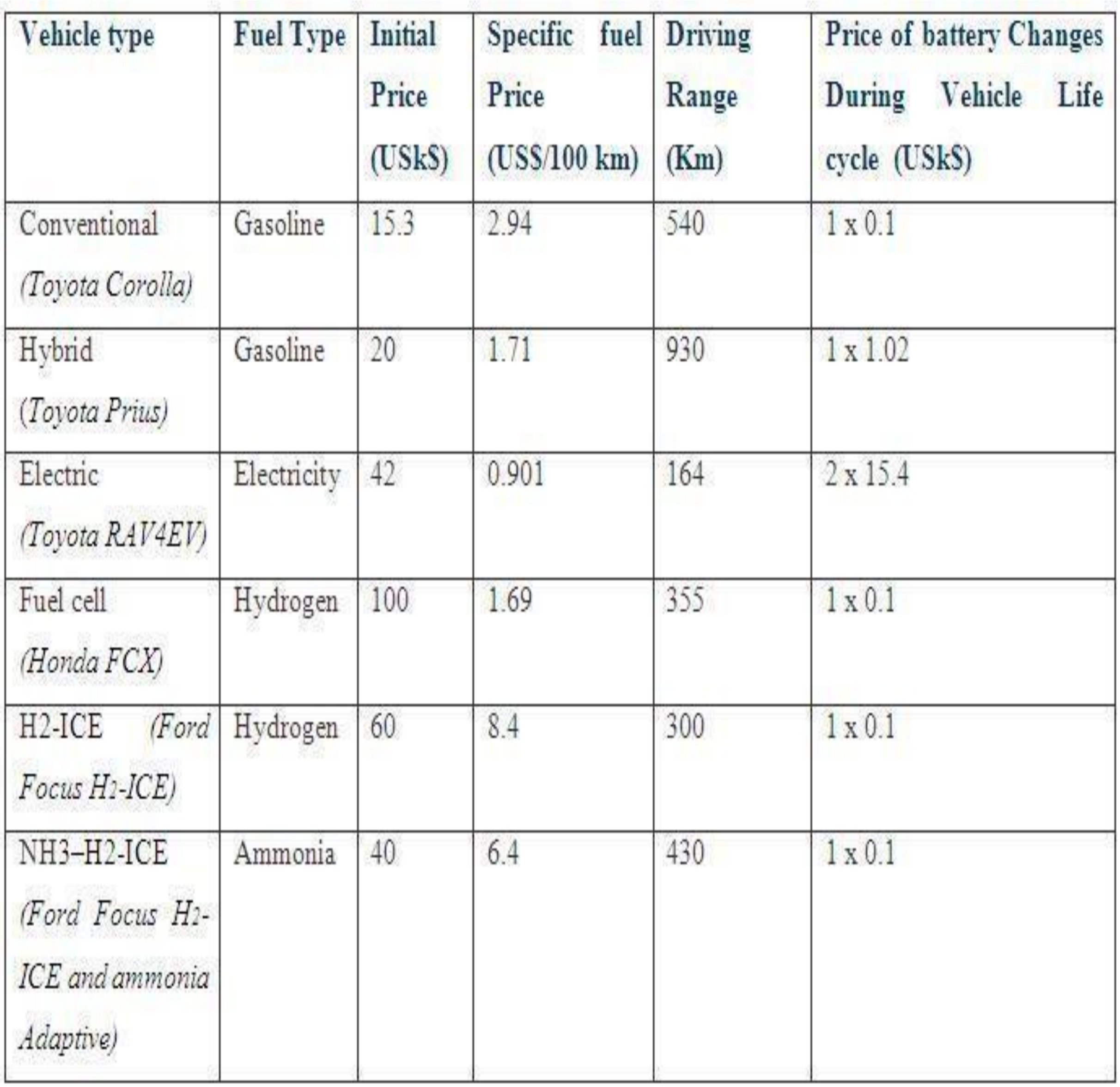
The environmental impact of the fuel utilization stage, as well as the overall life cycle is presented in Table 4. The H2-ICE vehicle results were based on the assumption that the only GHG emissions during the utilization stage were associated with the compression work, needed to fill the fuel tank of the vehicle. The GHG effect of water vapor emissions was neglected in this analysis due its little value,. For the ammonia fuel vehicle, a very small amount of pump work was needed therefore, ammonia fuel was considered to emit no GHGs during fuel utilization.



ECONOMICAL ANALYSIS

A number of key economic parameters that characterize vehicles were:

This case neglected maintenance costs; however, for the hybrid and electric vehicles, the cost of battery replacement during the lifetime was accounted for. The driving range determines the frequency (number and separation distance) of fueling stations for each vehicle type. The total fuel cost and the total number of kilometers driven were related to the vehicle life (see Table 1).



Vehicle type	Fuel Type	Initial Price (USk$)	Specific fuel Price (US$/100 km)	Driving Range (Km)	Price of battery Changes During Vehicle Life cycle (USk$)
Conventional *(Toyota Corolla)*	Gasoline	15.3	2.94	540	1 x 0.1
Hybrid *(Toyota Prius)*	Gasoline	20	1.71	930	1 x 1.02
Electric *(Toyota RAV4EV)*	Electricity	42	0.901	164	2 x 15.4
Fuel cell *(Honda FCX)*	Hydrogen	100	1.69	355	1 x 0.1
H2-ICE *(Ford Focus H_2-ICE)*	Hydrogen	60	8.4	300	1 x 0.1
NH3–H2-ICE *(Ford Focus H_2-ICE and ammonia Adaptive)*	Ammonia	40	6.4	430	1 x 0.1

Table1: Technical and economical values for selected vehicle types.

For the Honda FCX the listed initial price for a prototype leased in 2002 was USk$2,000, which is estimated to drop below USk$100 in regular production. Currently, a Honda FCX can be leased for 3 years with a total price of USk$21.6. In order to render the comparative study reasonable, the initial price of the hydrogen fuel cell vehicle is assumed here to be USk$100. For e electric vehicle, the specific cost was estimated to be US$569/kWh with nickel metal hydride (NiMeH) batteries which are typically used in hybrid and electric cars. Historical prices of typical fuels were used to calculate annual average price.

RESULTS OF TECHNICAL–ECONOMICAL–ENVIRONMENTAL ANALYSIS:

In present situation this case study provides a general approach for assessing the combined technical– economical–environmental benefits of transportation options. This analysis showed that the hybrid and electric cars have advantages over the others. The economics and environmental impact associated with use of an electric car depends significantly on the source of the electricity:

a. If electricity is generated from renewable energy sources, the electric car is advantageous to the hybrid vehicle.

b. If the electricity is generated from fossil fuels, the electric car remains competitive only if the electricity is generated on-board.

c. If the electricity is generated with an efficiency of 50–60% by a gas turbine engine connected to a high-capacity battery and electric motor, the electric car is superior in many respects.

d. For electricity-generation scenarios 2 and 3, using ammonia as a means to store hydrogen onboard a vehicle is the best option among those analysed (as shown in figure 2).

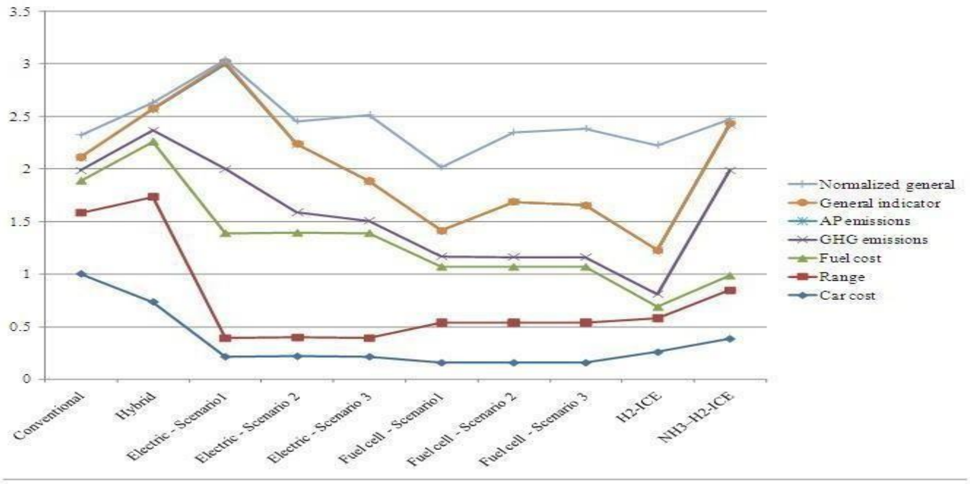


Figure2: Normalized economic and environmental indicators for six vehicle types

The electric car with capability for on-board electricity generation represents a beneficial option and is worthy of further investigation, as part of efforts to develop energy efficient and ecologically benign vehicles. The main limitations of this study were as follows:

(i) The use of data which may be of limited accuracy in some instances;
(ii) (ii) The subjective ness of the indicators chosen; and
(iii) The simplicity of the procedure used for developing the general indicator without using unique weighting coefficients.

Despite these limitations, the study reflects relatively accurately and realistically the present situation and provides a general approach for assessing the combined technical–economical–environmental benefits of transportation options.