Chapter 14
Cost-effectiveness and Potential of Greenhouse Gas Mitigation through the Support of Renewable Transport Fuels in Iceland

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Abstract The system dynamics model of Iceland's energy systems (UniSyD_IS) is used to explore the potential transition paths towards renewable transport fuels with implications for greenhouse gas (GHG) emissions and mitigation costs. The study focuses on Iceland's potential fuel pathways including renewable electricity, hydrogen from electrolysis, biogas from municipal wastes, bioethanol from lignocellulosic biomass, and biodiesel from oil seeds and waste oils.

The vehicle fleet is divided into light- and heavy-duty vehicles, and each fleet consists of different alternative fuel vehicles. The model allocates the forecasted fleet growth among different vehicle types based on consumers' preferences towards vehicle attributes and social network influences.

Oil price, carbon tax, renewable fuel supply–push, and government incentives are selected as the fundamental factors for scenario analysis. The results show that the transitions to renewable transport fuels seem to be feasible economically, initially, through biogas and then through uptake of hydrogen and electric vehicles. The cost-effectiveness analysis in UniSyD_IS indicates that the initial momentum

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A. Sayigh (ed.), *Renewable Energy in the Service of Mankind Vol I*,
DOI 10.1007/978-3-319-17777-9_14

of alternative fuels will not only mitigate GHG emissions but also could provide net benefits from an overall energy system and consumer perspective.

Keywords Alternative fuel vehicles · Renewable fuels · GHG mitigation · Cost-effectiveness

14.1 Introduction

Iceland is a leading country in developing and utilizing renewable energy resources to generate heat and electricity. Almost all of the generated electricity comes from hydro- and geothermal sources. However, Iceland has remained entirely dependent upon gasoline and diesel imports to sustain its transportation needs. Due to the growth of vehicles per capita and travel activities, greenhouse gas (GHG) emissions from road transport have been increasing rapidly during the past decade. Iceland's long-term vision includes deep reductions of net GHG emissions by 50–75 % by 2050, from the 1990 level [1]. However, to achieve these deep reductions in GHG emissions in the transport sector, a transition to alternative fuel vehicles (AFVs) will be required.

To examine the transition process towards a renewable transport, the system dynamics model of Iceland's energy systems (UniSyD_IS) is applied. UniSyD_IS is founded on the UniSyD_NZ model of New Zealand's energy economy, created by the Unitec Institute of Technology, New Zealand, in cooperation with Stanford University, USA. UniSyD_NZ has been employed to assess the impacts of AFVs on New Zealand's energy economy [2–4].

In this chapter, we focus on the renewable energy resources and apply UniSyD_IS model to evaluate the possible transition paths towards a renewable future transport in Iceland. The impact of climate mitigation policies to support the transition to renewable fuels in the transport sector is evaluated. Cost-effective policies to achieve deep cuts in GHG emissions are also identified.

In Sect. 14.2, model structure and methodology are briefly presented. Section 14.3 describes the main assumptions and data for analysis of transition to renewable transport fuels. Scenarios are defined in Sect. 14.4, simulation results are presented in Sect. 14.5, and Sect. 14.6 concludes the chapter.

14.2 Methodology

14.2.1 Model Structure

The UniSyD_IS model focusses on the energy supply sector with endogenous analysis of road transport energy demand. UniSyD_IS is a detailed resource and technology-specific model in which equilibrium interactions act across six key markets: electricity, hydrogen, biogas, bioethanol, biodiesel, and vehicle fleets. Gasoline and diesel supply sectors are exogenous. The detailed structure of the

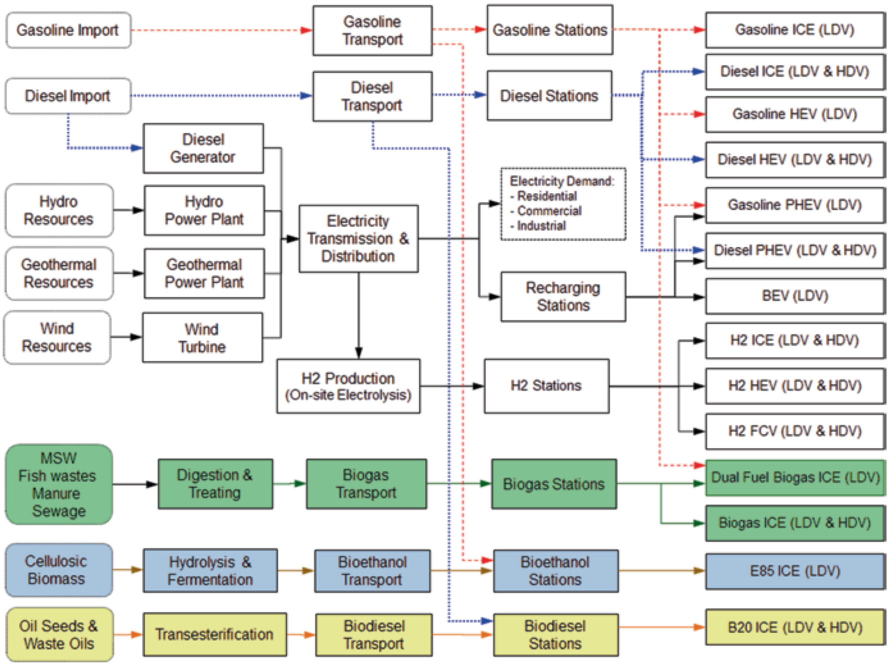

Fig. 14.1 Fuel supply pathways and the corresponding powertrain technologies. *LDV* light-duty vehicle, *HDV* heavy-duty vehicle, *ICE* internal combustion engine, *HEV* hybrid electric vehicle, *PHEV* plug-in hybrid electric vehicle, *BEV* battery electric vehicle

well-to-wheel (WtW) pathways modelled in UniSyD_IS is illustrated in Fig. 14.1. It shows Iceland's energy supply system, which includes conventional and alternative fuel supply pathways and the corresponding vehicle powertrains. Besides the imported petroleum products, the entire domestic fuel supply system begins from renewable resources (hydro, geothermal, wind, and biomass) and ends up to the different end users of transport sector. The transport fleet is divided into light(LDV)- and heavy-duty vehicle (HDV) fleets with the upper weight limit for LDVs being 3.5 tonnes.

14.2.2 Evolution of Vehicle Fleets

The total vehicle fleet is expected to continue growing based on historical rates until the vehicles per capita indicators approach a saturation level. Once the fleet growths of the LDV and HDV fleets are determined, the model allocates these fleets among vehicle types. The allocation is accomplished using a vehicle choice algorithm to forecast the market shares of new adopted vehicles. Consumers purchase the vehicles based on both their own preferences and the behaviour of other consumers.

The multinomial logit (MNL) model, according to Eq. (14.1), gives the probability $P_{k,t}$ that the consumers purchase vehicle type k at time t, on the basis of their preferences towards the vehicles' attributes [5]:

$$P_{k,t} = \exp\ (U_{k,t}) / \sum_k \exp\ (U_{k,t}), \tag{14.1}$$

where consumer utility U_{kt} relies on a set of monetary and nonmonetary attributes. The attributes are included in the consumer's utility function as in Eq. (14.2):

$$U_{k,t} = \beta_1 C_{k,t} + \beta_2 F_{k,t} + \beta_3 M_{k,t} + \beta_4 G_{k,t} + \beta_5 B_{k,t} + \frac{\beta_6}{R_{k,t}} + \beta_7 \exp(-\beta_8 A_{k,t}), \tag{14.2}$$

where $C_{k,t}$ is the purchase price for vehicle k at time t (\$), $F_{k,t}$ fuel cost (\$/km), $M_{k,t}$ annual maintenance cost (\$/year), $G_{k,t}$ GHG emissions (gCO_2eq/km), $B_{k,t}$ battery replacement cost (\$), $R_{k,t}$ vehicle range (km), $A_{k,t}$ fuel availability (relative to gasoline), and β_i consumer preferences towards vehicle attributes. Among these attributes, GHG emissions, fuel cost, battery cost, and fuel availability are calculated endogenously.

It is assumed that the probability of social influences equals the share of the consumers who have already adopted a particular vehicle. Total probability of purchasing vehicle k at time t ($\mathrm{TP}_{k,t}$) is the weighted average of consumer preferences and social influences probabilities:

$$\mathrm{TP}_{k,t} = \lambda_t \times \mathrm{SN}_{k,t} + (1 - \lambda_t) \times P_{k,t} \quad , \quad 0 \le \lambda_t \le 1, \tag{14.3}$$

where SN and P are probabilities for social influences and individual preferences, respectively. The weighting coefficient λ reflects the importance and strength of social influences for consumers.

14.3 Data and Key Assumptions

14.3.1 Electricity Supply Sector

Hydropower, geothermal, and wind are the main potential electricity generation technologies in Iceland. The cost of electricity produced from existing hydro plants is assumed to be 3.7 c/kWh [6]. Geothermal plants are assumed to emit 50 g/kWh of carbon dioxide [7]. Existing geothermal plants provide electricity at an aggregate cost of 3.6 c/kWh [6]. The future costs of hydro and geothermal capacities are modelled using supply curves in which unit generation cost is expected to increase with cumulative installed capacities. The average generation cost of 9.82 c/kWh is estimated for wind turbines [6]. A cost reduction of 1.8 % per year is applied to wind generation [4]. The costs of transmission and distribution are simplified to 1.05 and 3.5 c/kWh tariffs, respectively [8] , and the total grid loss is about 5.6 % [9].

14.3.2 Hydrogen Sector

Hydrogen can be produced by alkaline electrolysis technology. The forecourt electrolysis is modelled with the capacity of 1500 kg of hydrogen per day that can support about 1600 vehicles. The unit capital and operation and maintenance (O&M) cost of generation is US$ 1.1 per kg. The cost of compression, storage, and dispensing is US$ 2.47/kg [10]. A simple linear reduction is assumed for the costs of hydrogen production and delivery. Electrolysis electricity use will be reduced from 53.4 kWh/kg in 2015 to 44.7 kWh/kg in 2025 [10].

14.3.3 Biofuel Generation

Bioethanol in Iceland can be produced from cellulosic residuals. The lignocellulosic resource in Iceland consists of cereals, hemp, waste hay, paper, timber, and garden wastes. Total estimated resource potential used in the model is 0.78 pJ per year [11]. A constant supply curve is assumed for the lignocellulosic resource cost with US$ 0.4 per l produced bioethanol [12]. Five plant sizes of 2.5, 5, 10, 20, and 40 million l per year are assumed for bioethanol production. A simple power series trend line governs the capital cost of new bioethanol plant construction. The yearly operational and maintenance costs vary with bioethanol plant sizes [13]. A cost reduction of 0.8 % per year is applied to the capital and O&M costs during the study period [14].

Biodiesel in Iceland can be harvested from oil seeds, fish wastes, animal fat waste, and waste vegetable oils. Total resource potential for biodiesel production is 0.4 pJ per year [11]. UniSyD_IS uses an economy of scale supply curve for the total unit cost of biodiesel. The possible plant sizes are similar to bioethanol.

Potential resources for biogas production in Iceland are municipal solid wastes (MSW), fish wastes, manure, and sewage. Biogas resource potential is 1.72 pJ per year [11]. The average cost of raw material, including collection and transport, is US$ 0.33/m^3 produced biogas. The investment and O&M costs are approximately US$ 0.3 and US$ 0.28/m^3 for a production plant serving 30 kt of waste per year. This assumed plant can produce about 3.3 Mm^3 biogas per year [15]. New biogas plant sizes are considered to be of any of the 2.5, 5, 10, 20, and 40 Mm^3/year. Based on data in [16], a scaling factor exponent of −0.6 is used to adjust the unit cost of various plant sizes.

14.3.4 Vehicle Fleet

The average annual growth rates of LDVs and HDVs during the past decade were 4.7 and 4.1 %, respectively [17]. The saturation level used for vehicle-per-capita indicator is 0.85 for LDVs (0.8 for passenger LDVs) and 0.043 for HDVs. The starting values of 12,000 and 28,000 km per year are assumed for LDVs and HDVs, respectively [17, 18]. We use a fuel cost elasticity of −0.33 [19] to adjust the annual travel demand with respect to changes in fuel cost per km.

Table 14.1 shows the purchase price, annual vehicle price reduction, and maintenance costs of different alternatives for LDVs. Using the rough expert estimates, the price and cost data used for LDVs are scaled up by a factor of 10 to provide the average estimations for HDV data [20, 21].

It is assumed that the fuel economy of new vehicles follows a linear path from the current values to a high bound over time. The range of each vehicle in the model is increased corresponding to the fuel economy improvements.

14.4 Scenario Definition

Based on the changes in oil price, fuel availability, carbon tax, and government subsidies, eight scenarios are defined as explained in Table 14.2. Government incentives are the subsidies directed to battery electric vehicle (BEV) and fuel cell vehicle (FCV) as the promising zero emission vehicles (ZEVs).

To examine the effects of biodiesel, bioethanol, hydrogen, and electricity infrastructure, we define three cases of demand–pull with no initial infrastructure and supply–push with both low and high initial momentum. Table 14.3 defines the meaning of the supply–push cases used in the scenarios. Since a biogas plant is operating in Iceland, further initial supply–push is not needed for this fuel.

14.5 Simulation Results

Figure 14.2 shows the evolution of vehicle fleets for four selected scenarios. In the REF scenario, HEV_gasoline, HEV_diesel, and biogas vehicles are the attractive alternatives for LDVs due to the lower fuel cost per kilometre. For HDVs, the market share of diesel internal combustion engine (ICE) is gradually reduced and replaced by the hybrid option. In the REF+LP case, electric vehicles (EVs), including plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs), along with H2 vehicles (ICE_H2, HEV_H2 and FCV) take a share of less than 20 % in 2050 for both LDV and HDV fleets.

In the HC scenario, the market introduction of EVs and hydrogen (H2) vehicles are observed after 2040 when oil price and carbon tax are significantly increased. In the high cost+high push (HC+HP) scenario, the share of EVs rises quickly after 2030 due to the lower renewable electricity cost and enhanced infrastructure availability. The introduction of hydrogen vehicles starts from 2030 to 2035 and results in a market share by 2050 of 10 and 24 % for LDV and HDV fleets, respectively. Biogas keeps its contribution to the fleet mix and bioethanol and biodiesel account for maxima of only 1.7 and 1 %, respectively of the LDV fleet by 2050. The share of biodiesel in HDV fleet in 2050 would be 2.4 %. Zero-emission fuels, including

Table 14.1 Annual maintenance cost of vehicles, purchase price, and annual purchase price reduction

Powertrain (fuel type)	ICE (Gasoline)	ICE (E85)	ICE (Diesel)	ICE (B20)	ICE (Biogas)	ICE (Bio-gas dual)	ICE (H2)	HEV (Gasoline)	HEV (Diesel)	HEV (H2)	PHEV (Gaso-line)	PHEV (Diesel)	BEV (Elec-tricity)	FCV (H2)
Maintenance Cost ($/year) [21]	742	742	742	742	802	840	1176	660	660	1046	566	566	412	693
Purchase Price (k$) [22–26]	24.2	24.2	25.7	25.7	26.4	27.2	39.8	30.7	32.7	46.0	30.3[a]	32.3[a]	28.9[a]	117.7
Purchase Price Reduction (%/year) [23, 24, 26, 27]	–	–	–	–	0.06	0.06	0.5	0.236	0.236	0.736	0.47	0.47	0.43	2.9

ICE internal combustion engine, *HEV* hybrid electric vehicle, *PHEV* plug-in hybrid electric vehicle, *BEV* battery electric vehicle, *FCV* fuel cell vehicle

[a] The prices exclude the battery cost. Assuming the range values of 200 and 60 km for BEV and PHEV, the initial battery costs of US$ 19k and US$ 8.7k are estimated, respectively. The costs are reduced to US$ 6.2k and US$ 2.8k by 2050 (based on [28])

Table 14.2 Scenarios based on the changes in oil price, fuel availability, carbon tax, and government subsidies

Scenarios	Oil price	Carbon tax	Fuel availability	Government incentives
Reference (REF)	Constant (100$/bbl)	Constant	Demand–pull	–
	0% per year	US$ 25/tonne	no initial momentum	
Reference + Low supply–push (REF + LP)	Constant (100$/bbl)	Constant	Supply–push	–
	0% per year	US$ 25/tonne	low initial momentum	
Reference + High supply–push (REF + HP)	Constant (100$/bbl)	Constant	Supply–push	–
	0% per year	US$ 25 $/tonne	high initial momentum	
High costs (HC)	Increasing	High and Increasing	Demand–pull	–
	2% per year	100 $/tonne + 2% pa	no initial momentum	
High costs + Low supply–push (HC + LP)	Increasing	High and Increasing	Supply–push	–
	2% per year	100 $/tonne + 2% pa	low initial momentum	
High Costs + High Supply–Push (HC + HP)	Increasing	High and Increasing	Supply–push	–
	2% per year	100 $/tonne + 2% pa	high initial momentum	
High costs + High supply–Push + 10%Subsidy (HC + HP + LS)	Increasing	High and Increasing	Supply–push	ZEVs Subsidy
	2% per year	100 $/tonne + 2% pa	high initial momentum	10% of vehicle price
High Costs + High Supply–Push + 20%Subsidy (HC + HP + HS)	Increasing	High and Increasing	Supply–push	ZEVs Subsidy
	2% per year	100 $/tonne + 2% pa	high initial momentum	20% of vehicle price

Table 14.3 Assumptions on initial supply–push

Alternative fuels	Low initial momentum	High initial momentum
Biodiesel	One small plant size with capacity of 2.5 Ml/year	One medium plant size with capacity of 5 Ml/year
Bioethanol	One small plant size with capacity of 2.5 Ml/year	One medium plant size with capacity of 5 Ml/year
Hydrogen	One forecourt electrolyzer unit with capacity of 1500 kg/day	Two forecourt electrolyzer units each with capacity of 1500 kg/day
Electricity	1% as initial fuel availability index and increasing with growth of EVs	2% as initial fuel availability index and increasing with growth of EVs

electricity and hydrogen, account for 39% of total energy use by 2050. This share can reach to 53% by including low-emission biofuels.

To explore the impact of renewable supply–push policies, the differences in annual and cumulative GHG emissions between the main scenario variants are shown in Fig. 14.3 (left). Renewable fuel supply–push policies result in an increasing trend

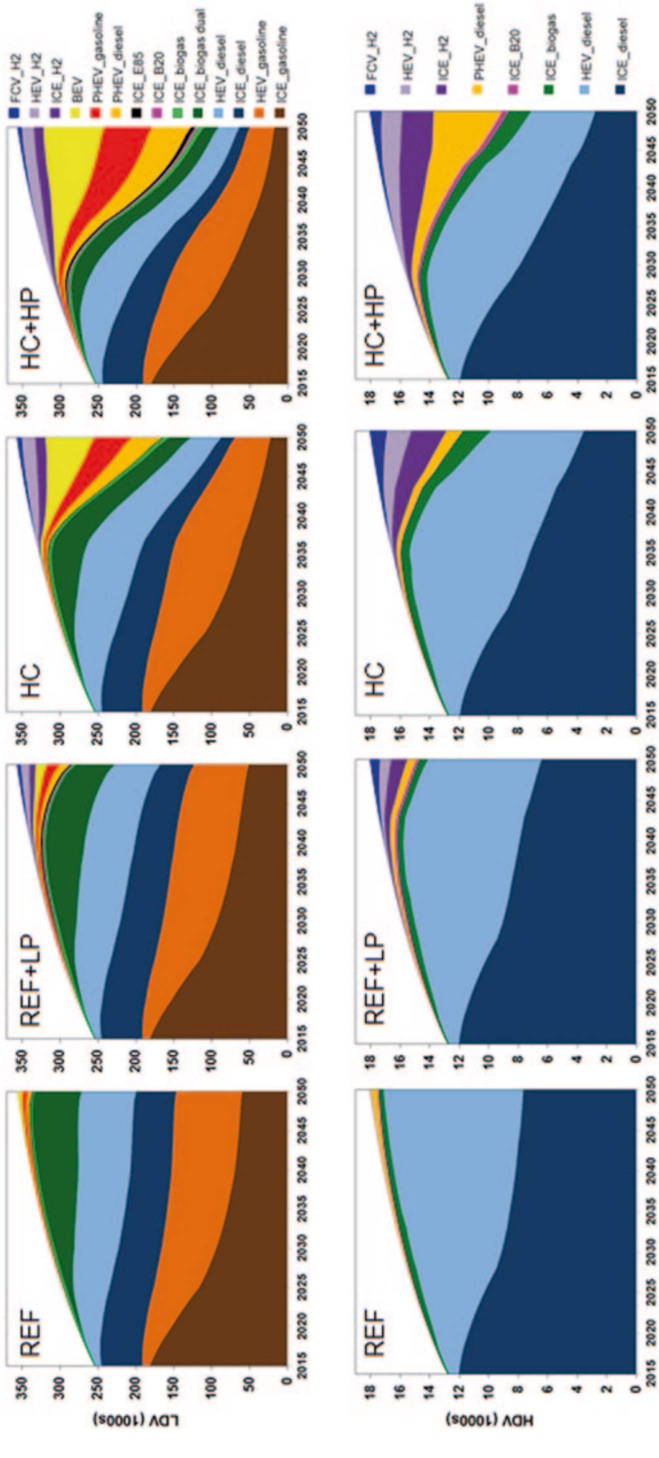

Fig. 14.2 Evolution of Iceland's LDV (*top*) and HDV (*bottom*) fleets in different scenarios. *FCV* fuel cell vehicle, *HEV* hybrid electric vehicle *ICE* internal combustion engine, *BEV* battery electric vehicle, *PHEV* plug-in heavy electric vehicle

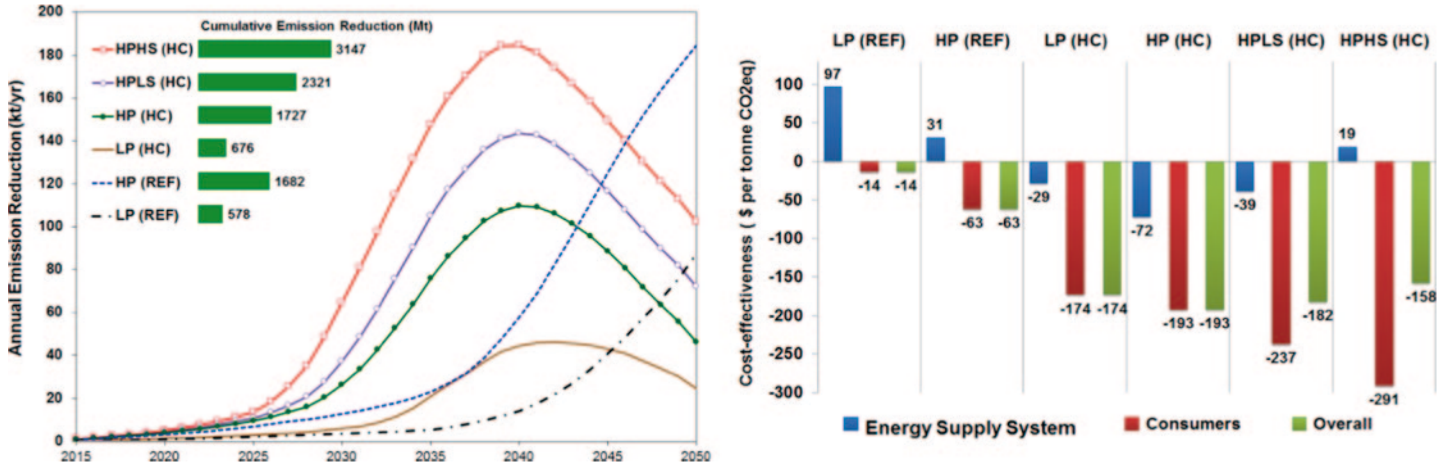

Fig. 14.3 Potential of GHG mitigation (*left*) and cost-effectiveness of mitigation measures from different perspectives (*right*)—LP (*REF*): impact of low supply–push in REF scenario; HP (*REF*): impact of high supply–push in REF scenario; LP(*HC*): impact of low supply–push in HC scenario; HP (HC): impact of high supply-push in HC scenario; HPLS (*HC*): impact of high supply-push with 10 % subsidy in HC scenario; HPHS (*HC*): impact of high supply–push with 20 % subsidy in HC scenario. *HC* high cost, *REF* reference

for GHG mitigation over time. Supply–push policies in the high-cost condition provide greater mitigation potential. The maximum annual mitigation is reached by 2040 and, thereafter, the higher levels of fuel costs reduce the mitigation potential through supply–push strategies.

Figure 14.3 (right) compares the cost-effectiveness of supply–push and government incentives towards renewable fuels. The cost-effectiveness of each mitigation strategy is expressed as the increased cumulative discounted costs divided by the resulted cumulative avoided emissions. The costs can be explored from two perspectives—energy system or consumers. Energy system costs include gasoline and diesel imports, supply costs of renewable fuels (i.e. biofuels, hydrogen, and electricity), and the entire WtW GHG emission cost. In addition, government incentives through ZEV subsidies can be included with the above cost items.

Consumer costs in the transportation sector include the cost of conventional and alternative fuels as well as the capital and operating costs of vehicles. Since the fuel cost is composed of all of the energy system costs excluding the subsidies, consumers' vehicle ownership costs reflect the overall cost of fuel chains and transport system. To estimate the overall benefits (energy system and consumers) in the cases with government incentives, total vehicle subsidies are subtracted from the net consumer benefits.

Comparing the total present value of costs (assuming the discount rate of 7%) and cumulative emissions of REF+LP scenario against the REF scenario reveals the mitigation cost of US$ 97 per tonne CO_2eq from the energy system perspective. The greater supply–push in the REF scenario enables significant reductions in emissions with the cost of US$ 31 per tonne CO_2eq. In the HC conditions, any supply–push policy leads to a negative mitigation cost, which means that emission reductions can provide net benefits for the energy system. However, the higher subsidy rate of 20% for ZEVs raises the government expenses and, hence, the mitigation cost rises to US$ 19 per tonne CO2eq.

The cost-effectiveness of supply–push policies will be always negative from consumer and overall perspectives. Higher government subsidy along with strong supply–push would be the most cost-effective scenario from the consumer perspective with the net benefit of US$ 291 per tonne. High supply–push in HC condition could be the most cost-effective at reducing GHG emissions from energy system and overall perspectives with the net benefits of US$ 72 and US$ 193/ per tonne, respectively.

14.6 Conclusions

The comparative analysis of scenarios shows that until 2030–2035, the majority of alternative vehicles in Iceland will be hybrid (diesel and gasoline) and biogas vehicles. In the long run, the study suggests EVs as a winner among AFVs, as biofuel vehicles suffer from the limited resource potential and the higher costs of small-capacity biofuel-generating plants in Iceland, while a hydrogen pathway needs longer time to be well established. H2 vehicles would be expected to play a significant role after 2040 with maximum H2 demand requiring 19 forecourt electrolyzer units with capacity of 1500 kg/day by 2050. Maximum transport electricity demand requires about 1 TWh of additional electricity generation out of total generation of 60 TWh by 2050 (through each of wind, hydro, and geothermal), around 46 % of which will be needed for hydrogen production.

The cost-effectiveness analysis indicates that the initial momentum of renewable fuels for mitigation of GHG emissions can provide overall long-term benefits through consumers' fuel cost saving and reduced fuel import costs. Government incentives through ZEV subsidies can achieve a deeper reduction in GHG emissions. A higher subsidy rate, which causes a greater mitigation, is more cost-effective from a consumer perspective and less cost-effective from an overall perspective.

Infrastructure development costs for refuelling/charging stations have not been fully explored in the current version of UniSyD_IS model. It implies that the full picture of total costs has not been captured in the analysis and, hence, future work will be required to capture the development and cost of refuelling and recharging station.

Acknowledgments The preparation of this chapter has been supported by the Norden Top-level Research Initiative sub-programme "Effect Studies and Adaptation to Climate Change" through the Nordic Centre of Excellence for Strategic Adaptation Research (NORD-STAR).

References

1. NORDEN and IEA (2013) Nordic energy technology perspectives: pathways to a carbon neutral energy future. Paris: IEA
2. Leaver J, Gillingham K, Leaver L (2009) Assessment of primary impacts of a hydrogen economy in New Zealand using UniSyD. Int J Hydrogen Energy 34(7):2855–2865
3. Leaver J, Gillingham K (2010) Economic impact of the integration of alternative vehicle technologies into the New Zealand Vehicle fleet. J Cleaner Prod 18(9):908–916
4. Leaver J, Gillingham K, Baglino A (2012) System dynamics modeling of pathways to a hydrogen economy in New Zealand. Unitec ePress, Auckland
5. Train K (2009) Discrete choice methods with simulation. Cambridge University Press, Cambridge
6. Johannsson S (2011) IceScot: submarine power cable from Iceland to Scotland. Annad veldi ehf, Reykjavik. http://www.veldi.is/Frett/13858. Accessed 2013
7. NEA (2012) http://www.nea.is/the-national-energy-authority/energy-statistics/gas-emissions-from-geothermal/. Accessed 2013
8. Orkuveita Reykjavíkur (2012) http://www.or.is/Fyrirtaeki/Rafmagn/Verdskra. Accessed 2012
9. Statice, "Energy Statistics" (2012) http://www.statice.is/Statistics/Manufacturing-and-energy/Energy. Accessed 2013
10. NREL, "DOE H2A Production Analysis" (2012) http://www.hydrogen.energy.gov/h2a_production.html. Accessed 2013
11. Sundberg M, Guðmundsson J, Guðmundsson M (2010) Biofuel production in Iceland: survey of potential raw materials and yields to 2030. MANNVIT Engineering, Reykjavik
12. IEA-ETSAP and IRENA (2012) Technology policy brief: production of liquid biofuels. http://www.iea-etsap.org. Accessed 2012

13. Gnansounou E, Dauriat A (2010) Techno-economic analysis of lignocellulosic ethanol: a review. Bioresource Technol 101:4980–4991
14. IEA (2011) Technology roadmap: biofuels for transport. International Energy Agency (IEA), Paris
15. Danielsson DI (2011) Bio-methane production expansion in Iceland, a cost-benefit analysis. Master Thesis, Aarhus University
16. Murphy J, McCarthy K (2005) The optimal production of biogas for use as a transport fuel in Ireland. Renewable Energy 30:2111–2127
17. Shafiei E, Davidsdottir B, Leaver J, Stefansson H, Asgeirsson EI (2014) Potential impact of transition to a low-carbon transport system in Iceland. Energy Policy 69:127–142
18. Road Traffic Statistics (2013) Iceland road traffic statistics. http://ww2.us.is/node/52. Accessed 2013
19. Dahl CA (2012) Measuring global gasoline and diesel price and income elasticities. Energy Policy 41:2–13
20. Schmid E, Knopf B, Bauer N (2012) REMIND-D: a hybrid energy-economy model of Germany. Potsdam Institute for Climate Impact Research, Potsdam
21. IEA & ETSAP (2011) Energy demand technologies. http://iea-etsap.org/Energy_Technologies/Energy_Demand.asp. Accessed 2013
22. Van Vliet O, Kruithof T, Turkenburg W, Faaij A (2010) Techno-economic comparison of series hybrid, plug-in hybrid, fuel cell and regular cars. J Power Sources 195:6570–6585
23. Kloess M, Muller A (2011) Simulating the impact of policy, energy prices and technological progress on the passenger car fleet in Austria- a model based analysis 2010–2050. Energy Policy 39:5045–5062
24. Thiel C, Perujo A, Mercier A (2010) Cost and CO_2 aspects of future vehicle options in Europe under new energy policy scenarios. Energy Policy 38:7142–7151
25. JRC-IE (2011) Well-to-wheels analysis of future automotive fuels and powertrains in the European context, tank-to-wheels report, version 2c (March). European Commission Joint Research Centre, Luxembourg
26. Offer GJ, Howey D, Contestabile M, Clague R, Brandon NP (2010) Comparative analysis of battery electric, hydrogen fuel cell and hybrid vehicles in a future sustainable road transport system. Energy Policy 38:24–29
27. Thomas C (2009) Fuel cell and battery electric vehicles compared. Int J Hydrog Energy 34:6005–6020
28. Gerssen-Gondelach SJ, Faaij AP (2012) Performance of batteries for electric vehicles on short and tonger term. J Power Sources 212:111–129