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The cost effectiveness of mitigating greenhouse gas emissions in Iceland

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HÁSKÓLI ÍSLANDS

The cost effectiveness of mitigating greenhouse gas emissions in Iceland

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All over the world, governments face the task of meeting greenhouse gas (GHG) emission targets at the lowest possible cost. Although GHG emissions are derived from similar sources in many countries, and therefore governments can use similar abatement solutions there are subtle differences depending on a number of factors, ranging from access to resources, climate and development stage. Iceland is an interesting case in this context. It is highly developed and rich in natural resources and renewable energy but has faced many problems typical for developing nations such as massive deforestation and desertification. This affects the Icelandic emission profile and the ways in which Iceland can most cost effectively reduce its greenhouse gas emissions.

The Icelandic emissions profile differs from most other countries in at least three important respects (see Figures 1 and 2). First, the fractional share derived from electricity and heat production is relatively low, as 100% of all electricity and 90% of all heat in the country is produced from low-carbon energy sources. This effectively eliminates mitigation choices in e.g. buildings, which in most countries have represented mitigation at a low cost or even at a net benefit (IPCC, 2007).

Second, the fractional shares from industrial production and transportation are relatively high. This is due to the high shares of low-carbon energy in the Icelandic primary energy mix, increasing the relative fractions of the sectors that rely on fossil fuels.

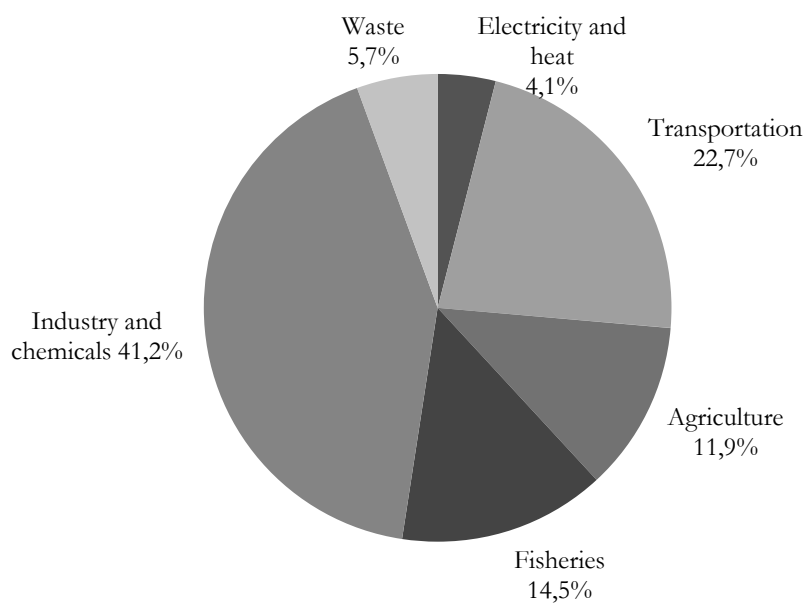


Figure 1. Fractional shares of greenhouse gas emissions in 2007 (Umhverfisstofnun, 2010)

Third, Iceland has suffered over millennia severe land-degradation and as a result emissions due to land-use, land-use-change and forestry (LULUCF) contribute a significant proportion of total greenhouse gas emissions (Umhverfisstofnun 2010). Emissions that are derived from activities that occurred before 1990 are not accounted for towards Kyoto commitments, but on net they amount to 27% of total emissions in 2007 (Brynhildur Davíðsdóttir et al., 2009).

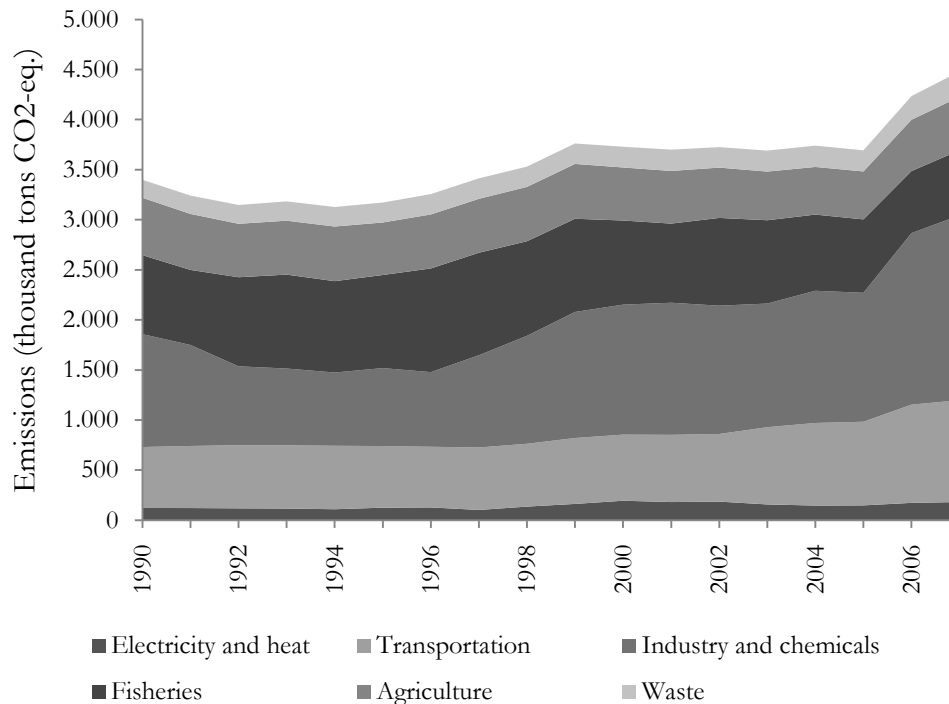


Figure 2. Greenhouse gas emissions by sector, 1990 to 2007 (Source: Umhverfisstofnun, 2010)

Greenhouse gas emissions in Iceland were 4.482 thousand tons in 2007 (CO₂ eq.). That amounts to a 32% increase from 1990 levels. Emissions increased in all sectors between 1990 and 2007, except fisheries (18% reduction) and agriculture (7% reduction). The greatest increase in emissions was from the ferrous alloys industry (91%) and the aluminum industry (72%) (Figure 2).

Iceland is party to the UNFCCC and has commitments under the Kyoto Protocol. According to the Kyoto commitments, net emissions should not exceed 10% increase beyond 1990 levels. In addition, according to provision 14/CP.7 of the Kyoto Protocol, new industrial projects that increase national emissions by over 5% are exempt up to an annual quota of 1600 tons of CO₂ per year from 2008 to 2012.

A new climate change strategy was adopted by the Icelandic government in February of 2007. The short term vision of the strategy is to reduce net greenhouse gas emissions in Iceland by 20 – 40% compared to 1990 levels by 2020. Parallel to this vision, the Ministry for the Environment set up an expert committee, tasked with assessing mitigation possibilities for the Icelandic economy (Brynhildur Davíðsdóttir et al., 2009). This paper is partially built on the work of the expert committee, and has a twofold objective: first, to provide the first comprehensive assessment of all currently foreseeable mitigation options of the Icelandic economy, illustrating the potential emissions and mitigation pathway for Iceland until the year 2020 using mitigation supply curves. Second to assess based on the analysis of mitigation options, if the short-term strategy adopted by the Icelandic government is feasible and to draw some policy implications.

The paper is divided to four sections. The first section introduces relevant literature with respect to mitigation supply curves. The second section provides an overview over the methods used in the analysis. The third section presents the results, followed by a discussion.

Mitigation supply curves

Mitigation supply curves (MSC) are originally derived from the literature on energy conservation supply curves. The early curves developed after the two oil price shocks in the 1970s were aimed at reducing crude oil consumption [\$/bbl] and later for the saving of electricity consumption [\$/kWh] (Joskow & Marron, 1992; Farugui et al., 1990). Later a similar concept was used in the context of abatement cost curves for abatement potential and cost of air pollution (see e.g. Silverman, 1985; Rentz et al., 1994 and an overview in Spash, 2002, 2007).

MSC capture the relationship between the cost associated with the last unit of mitigation for varying amounts of mitigation, compared to a baseline emissions scenario. Thus, an MSC allows the analysis of the cost of the last mitigated unit of greenhouse gasses for a defined mitigation level. MSC curves have been popular with policy makers because of their simple presentations of climate mitigation economics. Not surprisingly, in the climate negotiations leading up to the Copenhagen summit in 2009, many nations relied in part on what are called technology MSC to determine their negotiations targets.

Technology MSC

Technology mitigation supply curves (Technology MAC) are built upon baseline development of GHG emissions, emission reduction potential and the corresponding cost of single mitigation measures, including new technologies, fuel switches, sequestration and efficiency improvements. Subsequently, the measures are ranked from cheapest to most expensive to represent the costs of achieving incremental levels of mitigation. This concept was first applied to the reduction of crude oil and electricity consumption in the 1970s with the earliest examples of carbon-focused curves dating back to the early 1990s (Jackson, 1991). Technology MSC curves have received much attention in recent years due to a number of detailed country studies from McKinsey & Company (2010).

The principal advantages of technology MSC curves is that they are easy to understand and in general, marginal costs and the mitigation potential is unambiguously assigned to one mitigation option. Furthermore, the technological detail can be extensive, depending on the refinement of the study. Technology MSC curves, however do have some drawbacks that must be kept in mind.

Those include:

- Since technology MSC curves do not consider behavioral aspects, institutional nor implementation barriers to the realization of mitigation methods, the curves only capture the technological potential of different mitigation measures.
- Technoogy MSC curves are based on a narrow assesment of mitigation cost, and do not capture e.g. benefits of mitigaton action derived from improved health, or the loss in utility from e.g. swithcing from a large to a smaller vehicle.

- Technology MSC curves do not capture economic feedback processes that over time can lower mitigation cost, they tend to overestimate the cost of mitigation (Spash, 2002, 2007). They also do not capture macroeconomic costs/benefits of mitigation and the feedback impact GHG mitigation can have on e.g. economic growth, labor markets, economic structure and thus emissions.
- Care must be taken not to include cost of e.g. reforestation activities that are primarily undertaken for reasons other than carbon sequestration. In the Icelandic context such activities are assumed as reforestation at past business as usual reforestation rates as the reason for reforestation in the past has not been mitigation of GHG.

The premise behind this analysis was to (1) assess mitigation potential as well as the realism of the Icelandic mitigation targets and (2) to assess where the Icelandic government should focus their efforts with respect to climate change policy. This required a methodology that can simultaneously assess mitigation potential and cost, be internally consistent and thus enable comparison in terms of cost between mitigation options within and between different economic sectors in Iceland. The technology MSC fits this requirement.

Methods

Following the methodological approach recommended by the IPCC technical unit for WG3, mitigation potential and cost of GHG mitigation is assessed based on the following steps (Meyer, personal communication).

1. Assessment of past GHG emissions by sector from 1990 to 2007.
2. Preparation of Business as Usual (BAU) emissions levels scenarios to 2020.
3. Identifying mitigating technologies and measures for each sector.
4. For each technology or measure, mitigation potential and costs (capital costs, O&M costs in addition to operational benefits) are assessed. Annualized unit cost of mitigation is assessed using a 5% discount rate and the lifetime of each investment option¹.
5. Assessment and ranking of within-sector mitigation options as well as assessment and ranking of between-sector mitigation options creating greenhouse gas mitigation supply curves within and between sectors.

The sectors included are: (1) energy production, (2) industry, (3) fisheries, (4) transportation, (5) agriculture, (6) waste management as well as (7) forestry and land-reclamation (LULUCF).

Assessment of past GHG emissions by sector

Assessments are in all cases based on official reported emissions values as submitted by the Icelandic Environmental Agency to the UNFCCC, however reorganized by sector as described above, as fits better Icelandic GHG emissions data and thus mitigation action.

Business as Usual (BAU) emissions levels scenarios to 2020

¹ For example: lifetime of vehicles is assumed 10 years, the lifetime of energy related investments is 20 years and investments in sequestration options is 50 years.

The business as usual scenario is designed to illustrate expected emissions given no change in behavior or government policy with regard to sectors affecting emissions levels. In light of considerable uncertainty with regard to development of the Icelandic industrial sector, in particular the aluminum industry, two BAU scenarios are developed. Box 1 and 2 capture core differences between the two scenarios.

Box 1. Scenario 1
Economic growth and population growth <ul style="list-style-type: none"> · Economic growth; 2.65% annually to 2020 · Population growth; 357 thousand inhabitants in 2020 Transportation based on the low-growth case scenario in the fossil fuel energy use forecast (Orkusparnefnd 2008). Industrial Forecast: Production assumed to continue current levels of production

Box 2. Scenario 2
Economic growth and population growth <ul style="list-style-type: none"> · Economic growth; 3.65% annually to 2020 · Population growth; 365 thousand inhabitants in 2020 Transportation based on the high-growth case scenario in the fossil fuel energy use forecast (Orkusparnefnd 2008). Industrial Forecast: Production assumed to increase according to already licensed expansions or already licensed new industrial

Mitigation Measures, Potential and Cost Assessment

Mitigation measures describe technological possibilities to reduce emissions of greenhouse gasses beyond the BAU emissions scenario. The impact of individual mitigation measures on total emissions, that is mitigation potential for each measure is described for each sector, and in total in wedge diagrams (Pacala & Socolow, 2004).

Net cost for each mitigation measure is assessed as the sum of investment, operational and maintenance cost of mitigation minus the economic benefits of mitigation per ton of avoided emissions.

The specific net cost option for each mitigation option where the cost and mitigation is the same throughout the time-period, is determined as follows (equation 1):

$$C_t = \frac{(\alpha C^{inv} + C_t^{O\&M} - B_t)}{R_t} \quad (1)$$

Where:

C_t = net costs of mitigation per year (Euro/tonne avoided)

C^{inv} = yearly additional investment costs (euro/year)

$C_t^{O\&M}$ = yearly operational and maintenance cost (euro/year)

α = annuity factor: $\frac{r}{1-(1+r)^T}$

r = discount rate

T = lifetime of the investment (i.e. depreciation period in years)

B_t = specific cost savings (benefits) of mitigation (Euro/ton avoided)

R_t = yearly avoided emissions of greenhouse gases (ton-avoided/year), measured in CO₂ eq.

The annuity factor, α distributes the investment cost to a uniform series to T , equal payments.

The specific net cost option for each mitigation option, where the cost and mitigation is uneven throughout the time-period, is determined as follows (equations 2 to 4):

$$C_t R_t = (\alpha C^{inv} + C_t^{O\&M} - B_t) \quad (2)$$

Equation 2, illustrates that the net cost of mitigation action equals total cost less the benefits of mitigation action. This statement must be true for the entire lifetime of the investment such that:

$$\sum_{t=1}^T \frac{C_t R_t}{(1+r)^t} = \sum_{t=1}^T \frac{(\alpha C^{inv} + C_t^{O\&M} - B_t)}{(1+r)^t} \quad (3)$$

Average net cost for the entire time-period can therefore be determined as:

$$C_t = C = \frac{\sum_{t=1}^T \frac{(\alpha C^{inv} + C_t^{O\&M} - B_t)}{(1+r)^t}}{\sum_{t=1}^T \frac{R_t}{(1+r)^t}} = \frac{C^{inv} + \sum_{t=1}^T \frac{(C_t^{O\&M} - B_t)}{(1+r)^t}}{\sum_{t=1}^T \frac{R_t}{(1+r)^t}} \quad (4)$$

Mitigation potential per measure and average net cost per mitigation action when put together creates a supply curve of mitigation measures.

Results

The results are presented in three sections. First, mitigation options are identified within each sector. Second, national mitigation possibilities are presented for all sectors simultaneously as derived from scenario analysis using tables and wedge diagrams and third the Icelandic mitigation supply curve is presented.

Sectoral mitigation measures

As described above, mitigation measures were identified and analyzed within the six sectors listed above, in addition to measures that fall under land-use, land use change and forestry (LULUCF).

Table 1 (below) lists all mitigation measures identified in this assessment (please see Brynhildur Davíðsdóttir et al., 2009, for in-depth discussion of all mitigation measures)

Table 1. All mitigation measures analyzed by sector

Sector	Mitigation measures
Energy production	Increased efficiency, carbon capture and sequestration using i) chemical weathering ii) production of synfuels iii) production of biomass.
Transportation	Walking, biking, strengthening public transportation, more efficient vehicles, diesel vehicles, blending bio-diesel to diesel oil, ethanol to gasoline, methanol to gasoline, new drive technology such as hybrid vehicles, flex fuel vehicles E-85, methane electric and hydrogen vehicles.
Industry and chemicals	
Aluminum production	More efficient production management, replacing fossil fuels with electricity, carbon free electrodes, chlorine processes, sulfide processes, carbon capture and sequestration.
Cement production	Low carbon fuels, reduced fraction of non-combustible chemicals.
Ferrous alloys production	Replacing oil with electricity, carbon capture and sequestration, use of wood-waste
Construction	Biodiesel
Chemical use	Better information is needed
Fisheries	Increased energy efficiency, lighter fishing gear, use of low carbon fuels such as vegetable oil, biodiesel, synthetic gas oil, DME, methane, hydrogen. Increased use of electricity in fleet at shore as well as in fishmeal plants.
Waste	Reducing waste creation, collection of methane from landfills, reducing landfilling of organic waste, increased recycling, composting and incineration with energy recovery.
Agriculture	Change feeds, storage management and use of manure as a fertilizer.
Land-use, land-use change and forestry (LULUCF)	Forestry, land-reclamation, wetland restoration.

Scenario assessment – national mitigation potential

When assessing national mitigation potential, selected mitigation measures are incorporated into two national scenarios; low growth and the high growth scenarios as described before. Table 2 presents the mitigation measures included in the presented scenario.

Table 2. Mitigation measures analyzed by sector in presented scenario

	Mitigation measures
Energy production	Increased efficiency, carbon capture and sequestration using i) production of synfuels ii) production of biomass.
Transportation	Walking, biking, strengthening public transportation, more efficient vehicles
Industry and chemicals	
Aluminum production	More efficient production management, replacing fossil fuels with electricity.
Cement production	Low carbon fuels, reduced fraction of non-combustable chemicals.
Ferrous alloys production	Replacing oil with electricity, use of wood-waste
Construction	Biodiesel
Chemical use	Not included due to lack of data
Fisheries	Increased energy efficiency, lighter fishing gear, use of low carbon fuels such as vegetable oil. Increased use of electricity in fleet at shore as well as in fishmeal plants.
Waste	Reducing waste creation, collection of methane from landfills, reducing landfilling of organic waste, increased recycling, composting and incineration with energy recovery.
Agriculture	Change feeds, storage management and use of manure as a fertilizer.
Land-use, land-use change and forestry (LULUCF)	Forestry, land-reclamation, wetland restoration.

The mitigation measures are selected based on what was determined by the authors to be the most likely combination of measures to be implemented before 2020. Measures such as e.g. carbon capture and sequestration in the energy industry and large scale use of hydrogen and electric vehicles e.g. were not included.

Table 3 presents results for sector specific mitigation potential compared to emission levels in 1990. Scenario 1 is based on the low growth case and scenario 2 is based on the high growth case.

Table 3. Mitigation potential by sector and in total compared to 1990 levels

Sector	Emissions 1990 (000 tons CO ₂ eq)	Emissions 2020 with MA (000 tons CO ₂ eq)		Mitigation activities (% change compared to 1990 in 2020)	
		Low growth	High growth	Low growth	High growth
Energy production- use of fuel	57	7	8	-88	-86
Geo-power plants	157	101	111	51	66
Aluminum	569	1253	2136	120	253
Cement	103	64	103	-37	0
Ferrous Alloys	205	390	628	90	208
Construction	136	217	229	59	68
Other industry	99	30	34	-70	-66
Agriculture	573	438	438	-24	-24
Fishing fleet	662	133	133	-80	-80
Fishmeal plants	127	0	0	-100	-100
Transportation	609	749	831	23	37
Chemical use	15	110	110	635	635
Waste	180	247	247	37	34
Total	3401	3739	5007	10	47
LULUCF, BAU		-773	-773		
Total with LULUCF BAU		2966	4234	-13	24
LULUCF beyond BAU		-726	-726		
Total with LULUCF beyond BAU		2240	3508	-34	3

The results in Table 3, assuming all selected mitigation methods are implemented, regardless of cost, illustrate that it is possible to reach 34% lower net greenhouse gas emissions compared to 1990 levels in 2020. Results for scenario 2 illustrate, if all selected mitigation methods are implemented, regardless of cost, that net emissions will remain higher than 1990 levels by 3%. The difficulty in reducing emissions beyond the BAU scenario stems from the relatively large share of emissions in the aluminum industry and insignificant mitigation options available before 2020. The most significant mitigation opportunities in both scenarios are in land-use land-use change and forestry (LULUCF), followed by the fishing industry both in the fishing fleet and in fishmeal plants.

Figures 3 and 4, below illustrate the final results in wedge diagrams, illustrating mitigation potential compared to BAU in 2020. The figures illustrate that it is possible to reduce net GHG emissions in Iceland 36% or 29% below BAU 2020 levels (for scenario 1 and 2 respectively) if all mitigation methods are accounted for and keeping LULUCF at current rates. However, if increasing the extent of LULUCF mitigation it is possible to reduce net GHG emissions 52 and 41% below BAU 2020 levels (for scenario 1 and 2, respectively).

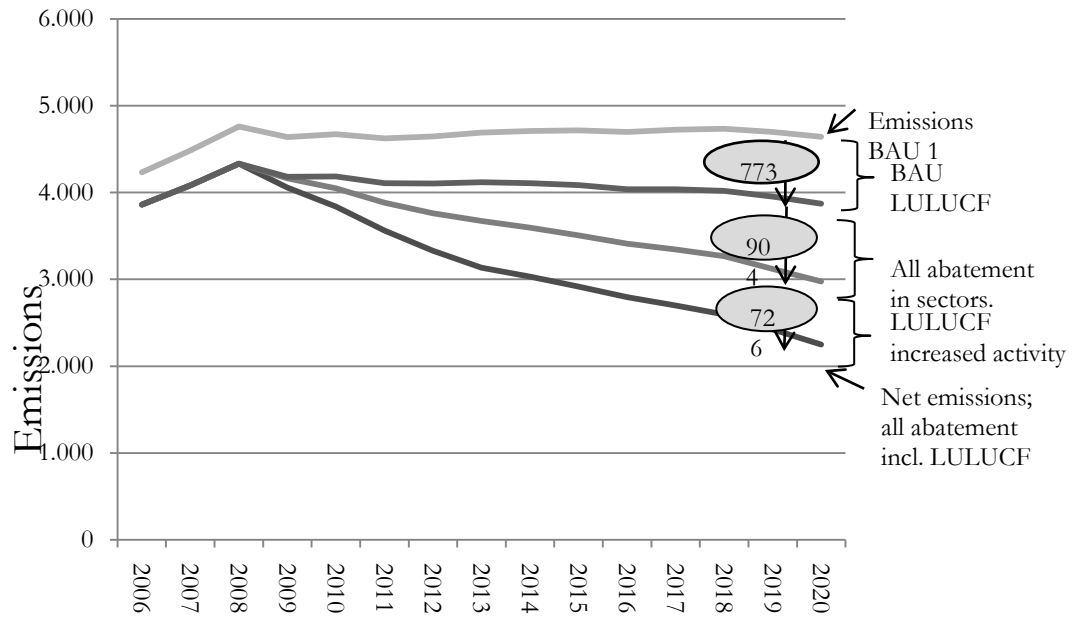


Figure 3. National wedges (scenario 1, low growth scenario)

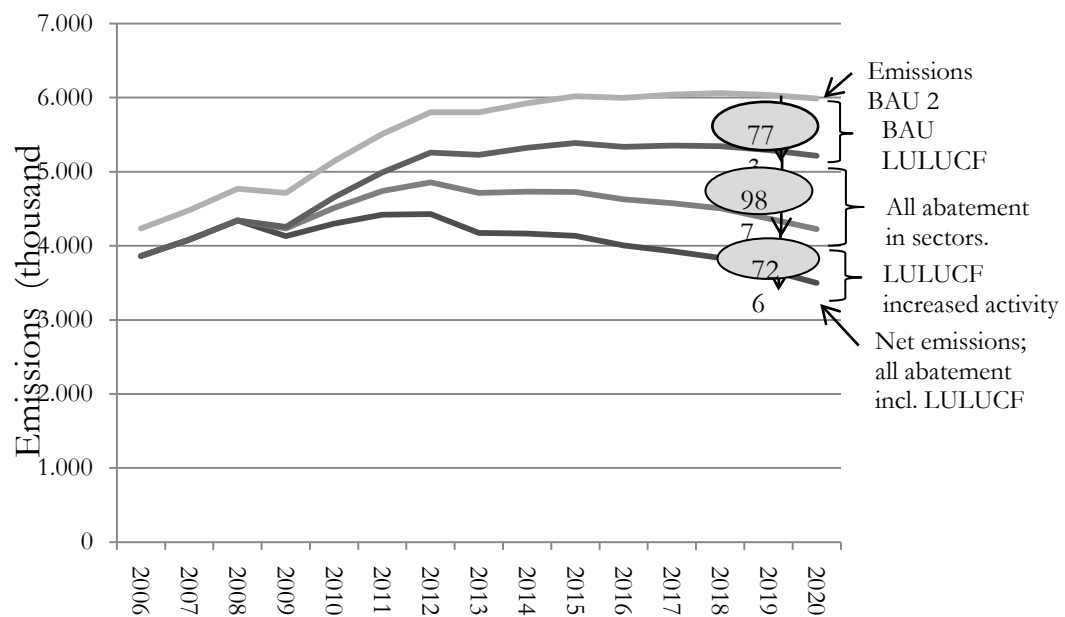


Figure 4. National wedges (scenario 2, high growth scenario).

The Icelandic mitigation supply curve

Using technology MAC, we assess the net cost for each mitigation method. Results are presented in Table 4. Please see Brynhildur Davidsdottir et al (2009) for more detailed information on individual results.

Table 4. Net cost of mitigation by mitigation method

Mitigation method	Net cost (Euros/ton CO ₂ eq.)
Fuel efficient vehicles	-1782
Walking and biking	-313
Increased efficiency fisheries	-206
Waste management	-64
Diesel vehicles	-116
Ferrous alloys - electricity replacing oil	-76
Fishmeal plants - oil replacement	-58
Improved utilization of manure	-21
CCS - production of biomass (A)	0
Aluminum - Efficiency improvements	0
Ferrous alloys - clean wastewood	0
Ferrous alloys - used wastewood	3
Improved storage of manure	3
Wetland restoration	7
Methane vehicles	8
Land reclamation	11
Forestry	12
Cement - low carbon fuels	16
Ethanol to gasoline - blend	27
Biodiesel to diesel oil - machinery	38
Change feeds - livestock	41
Biodiesel to diesel oil - vehicles	46
CCS - production of synfuels	46
CCS - production of biomass (B)	47
Vegetable oil replacing gasoil and crude - fishing fleet	48
Biodiesel replacing gasoil - fishing fleet	65
Methane instead of gasoil - fishing fleet	72
Synthetic gasoil instead of gasoil - fishing fleet	80
Methanol to gasoline - vehicles	86
Propeller - fishing fleet	99
DME replacing gasoil - fishing fleet	126
Hybrid vehicles	129
Smart bus system	206
Hydrogen for fishing fleet	250
Flex fuel vehicles (E85)	348
Electric vehicles	763
Light rail systems	1591
Hydrogen vehicles	2138

The results illustrate a wide range in cost, from large negative values (more efficient vehicles), to large positive values (hydrogen vehicles). Overall however, the majority of mitigation methods fall under 50 Euros per ton of CO₂ Eq. As stated before, cost

estimates based on technology MAC curves provide a narrow estimate of the associated cost and benefits of each mitigation option.

Creating technology MAC, we graph the net cost of selected mitigation methods against mitigation potential, providing an estimate of one potential supply curve of GHG mitigation.

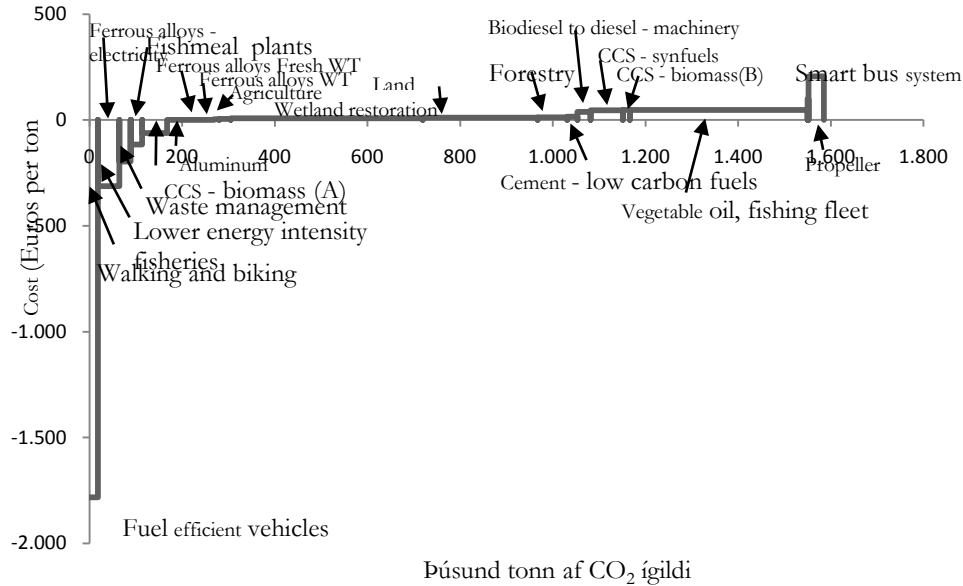


Figure 4. Supply curve of greenhouse gas mitigation options

Figure 4 illustrates three important features of the Icelandic mitigation cost curve, which as expected closely align with the specific features of the Icelandic emissions profile. First, mitigation at a net benefit can significantly contribute to lower GHG emissions or up to 4%. Second, the lack of low-cost measures for improving energy efficiency in buildings, available in most other countries. Three, the large cost-effective potential available in sequestration activities such as wetland restoration, land reclamation and forestry, which as stated before, accounts for over 60% of all mitigation potential in Iceland.

Discussion

This paper presents an analysis of GHG mitigation potentials in Iceland. Each mitigation method is evaluated based on cost, benefits and quantity abated using technology MSC. The results should therefore only be interpreted as an assessment of technical capabilities of reducing emissions. Whether those capabilities are realized depends on future cost, economic growth, development and the rate of technology diffusion in addition to government policy. As a result, substantial differences can occur between mitigation that technically can be realized and the mitigation that is realized in the end.

The results indicate that it is possible to significantly reduce net greenhouse gas emissions in Iceland, both compared to BAU emissions in 2020 and compared to 1990 emission levels. Compared to BAU scenario 1 and if all mitigation methods are implemented – regardless of cost – net emissions may be 52% lower in 2020 than in BAU scenario. This means 34% lower net emissions than in 1990. If wetland restoration is not included, net emissions in 2020 may reach 22% below 1990 levels.

Using BAU scenario 2, and if all mitigation methods are implemented regardless of cost, results indicate that net emissions will be 40% lower compared to emissions in the BAU scenario in 2020. This amounts to 3% higher net emissions than in 1990. If wetland restoration is not included, net emissions in 2020 will be 15% higher than in 1990. As a result, it is clear that the aim of the government to reduce domestic net emissions 25-40% below 1990 levels by 2020, in the case of high industrial growth is not feasible if only relying on changed technologies but not fundamental changes in economic structure and behavior, but easily feasible in the case of scenario 1.

Mitigation methods that are technically feasible before 2020, distribute unevenly between sectors. The largest mitigation potential, regardless of cost, is in the fisheries sector, near 100% reduction from fishmeal production plants by electrification of the plants, and 75% reduction from the fishing sector by improving energy efficiency and switching to biofuels. Technically it is possible to reduce emissions from energy production by 50% and agriculture by 12%. Diverse mitigation methods are possible in the transportation sector, such as increased use of biofuels, electrification, improved energy efficiency, increased use of public transportation and increased walking and cycling. Technical improvement in the aluminum industry such as the use of carbon-free electrodes would render the aluminum industry virtually emissions free but this is unlikely to happen before 2020. The results also clearly illustrate the significant carbon sequestration potential in Iceland. This potential however stems largely from poor land management in the past. Increased sequestration beyond BAU by increasing land reclamation, forestry and by wetland restoration, reduces net emissions by 32% in 2020 compared to scenario 1, and 25% compared to scenario 2.

The cost of mitigation differs substantially. Less expensive mitigation methods such as increased sequestration rates can significantly reduce net emissions. The cost ranges from mitigation that can be reached at a net benefit such as increased use of more efficient vehicles and increased walking and biking, to substantially more expensive methods, such as switching to electric vehicles or hydrogen based vehicles. The scenario analysis performed in this paper however did not include the more expensive options.

The policy implications of this study are at least fourfold:

1. Mitigation options are found in all sectors, and therefore when designing comprehensive climate change policy, all sectors should be included, including LULUCF. However, since policies must affect behavior in all sectors single policy measure will not be sufficient.
2. Large potential exists in the fisheries sector as well as in the transportation sector. Emissions in both of those sectors stem from the use of imported fossil fuels. The government should therefore move to rapidly transform the transportation and fisheries sector to rely on domestic fuels as possible, produced from low-carbon energy. Changing import duties and fuel cost to reflect differences in carbon content will go a long way to facilitate such a shift, and thus be a cross-cutting instrument between climate and energy policy.
3. Expanding the aluminum sector further from its current size will cancel-out mitigation efforts until alternative low-carbon electrodes are developed.
4. The government should emphasize sequestration options, in addition to options in ALL other sectors, since those options carry significant co-benefits. Care must be taken however when e.g. selecting tree species for sequestration to focus efforts on domestic species.

Further research includes the assessment of macroeconomic costs of mitigation measures and climate change policy.

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