Green Korea 2011

Estimation of GHG Mitigation Potential using MARKAL in Korea

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. Introduction020

; 30% reduction of GHG vs. BAU

- Framework Act on Low Carbon, Green Growth('09.12)

; transform voluntary to (domestically) binding actions

- effective strategy to reduce GHG emission

; cost-effective GHG reduction for green growth

- GHG mitigation potential in energy sectors in 2020

; technological potential using MARKAL with 2005 price

Introduction

- **voluntary mitigation target by 2020**
  ; 30% reduction of GHG vs. BAU

- **Framework Act on Low Carbon, Green Growth('09.12)**
  ; transform voluntary to (domestically) binding actions

- **effective strategy to reduce GHG emission**
  ; cost-effective GHG reduction for green growth

- **GHG mitigation potential in energy sectors in 2020**
  ; technological potential using MARKAL
  ; 2005 constant price and 5.5% discount rate

Model
- MARKAL

- MARKAL(MARKet Allocation)
  ; least-cost solution with constraints
  ; technology-rich/bottom-up optimization model

- structure of MARKAL
  ; objective function of cost
    - annualized cost of investment/management for technologies
  ; constraints of energy and environment
  ; decision variables of technology(investment, activity, etc.), energy supply, etc.

Energy System

- primary and conversion sector

- **primary energy supply→**
- **conversion→**
- **final energy consumption**

primary energy	dom. production	nuclear, renewables
	import	coal, oil(crude, products), LNG
	export	oil products
	bunkering	aviation and maritime
conversion	power	hydro, fossil(coal, LNG, oil), nuclear, renewable
	oil refining	AD, VD, hydro-cracking/treating, reforming, MTBE, etc
	city gas	import of LNG, manufacturing of city gas
	district heating	CHP with B-C, LNG
	hydrogen	IGCC, LNG, nuclear, renewable

Energy System

- final consumption sector

final consump-tion	industry	agri./fish	classified in other manufacturing
		mining	mining
		manufacturing	automobile, cement, petrochemical, paper, iron & steel
		other manuf.	other manufacturing
		construction	construction
	transport	railroad	passenger, freight, subway, KTX
		land	passenger car, bus, truck with private and commercial
		water	passenger, freight
		air	passenger, freight
	residential	5 usages	cooking, heating, cooling, lighting, electric appliances
	commercial	5 usages	cooking, heating, cooling, lighting, power
	public	energy	oil, LNG(city gas), electricity, renewable, heat, etc.

RES

- reference energy system

- RES(Reference Energy System) : network diagram of energy and material flow

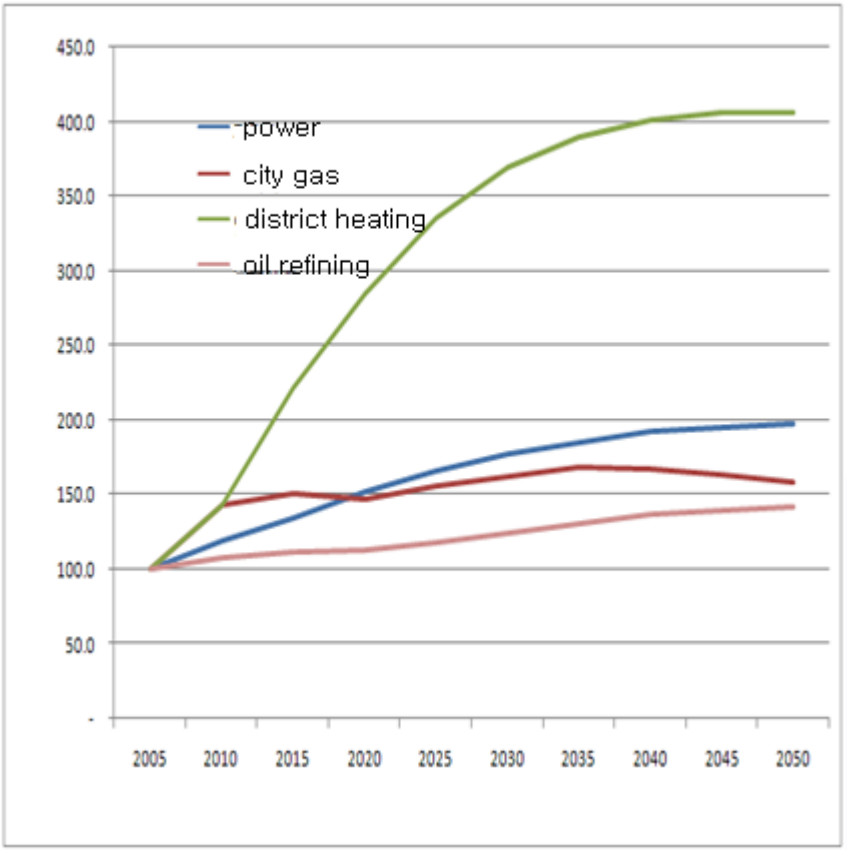
components		final demand for sectors
commodities	energy	crude oil, gasoline, steam coal, electricity, etc.
	material	materials as cement, limestone, etc.
	emissions	CO_2, CH_4, etc.
energy sources	domestic production	solar, wind, etc.
	import	crude oil, coking coal, etc.
technologies	resource technology	import process
	conversion technology	fossil fuel electricity technology, district heating, oil ref. technology, etc.
	transformation technology	-
	process technology	cement kiln, naphtha cracker, etc
	demand technology	electricity appliances, etc
sinks		export of energies, forestry, etc

Final Demand

- conversion

- **conversion sector : production of energy in final sectors**
  ; demand for heat is increasing with high rate by 2050

conversion	power	power consumption
	oil refining	production of oil products
	city gas	domestic gas consumption
	district heating	production of heat
	hydrogen	production of hydrogen energy



Final Demand

- industry

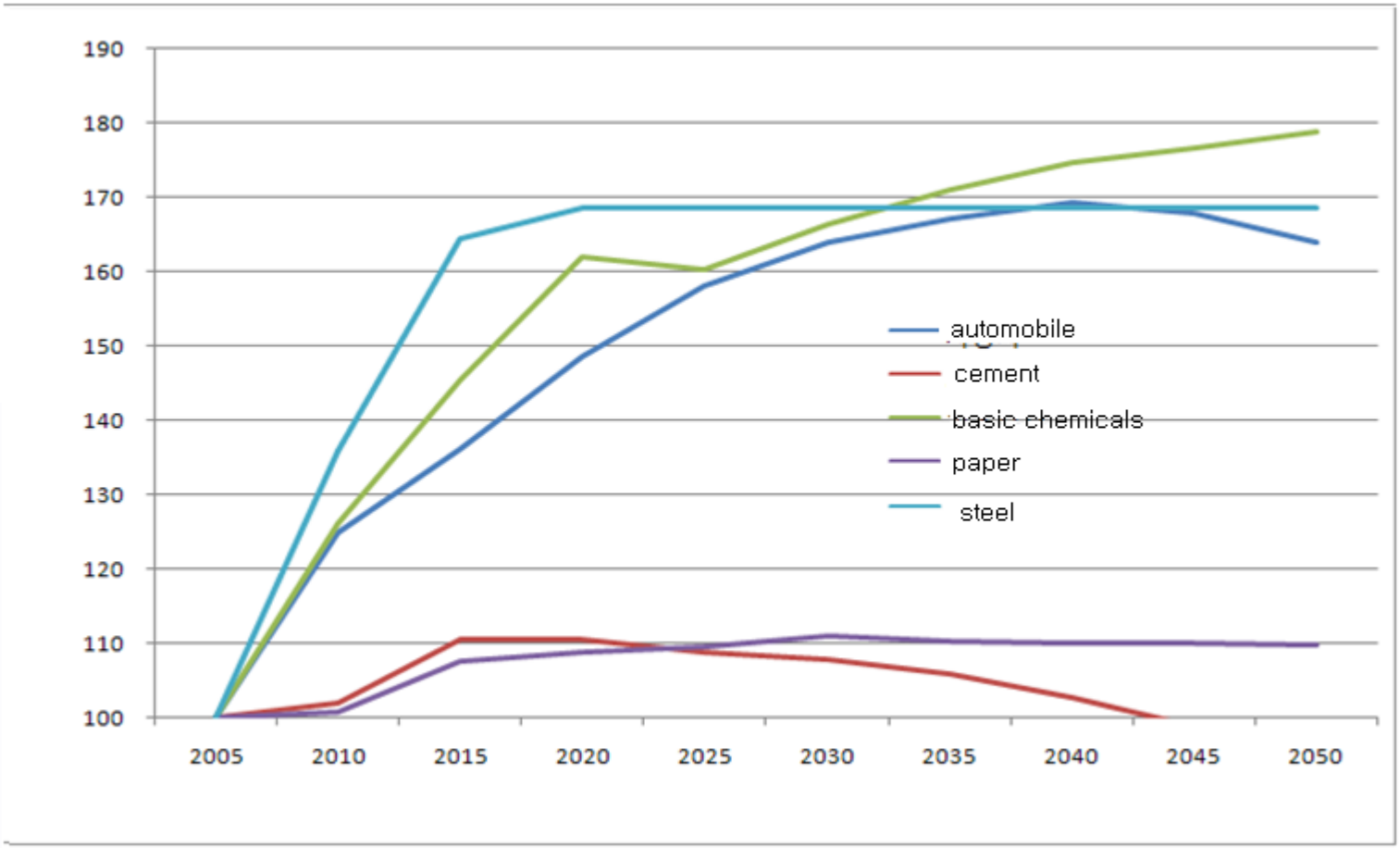
- demand of industry : production of products for each sector

industry	agri/fish.		demand for other energy
	mining		demand for other energy
	manufacturing	foods, tobacco	demand for other energy
		textile & apparel	demand for other energy
		wood & prodc	production of papers
		pulp.publication	
		petrochemical	production of basic material(naphtha cracking)
		non-metallic	production of cement
		iron & steel	production of iron from furnace
			production of iron from electric-arc
		non-ferrous	demand for other energy
		fabricated material	production of cars
		other manufacturing	demand for other energy
		other energy	demand for other energy
	construction		demand for other energy
	others		demand for other energy

Final Demand

- industry

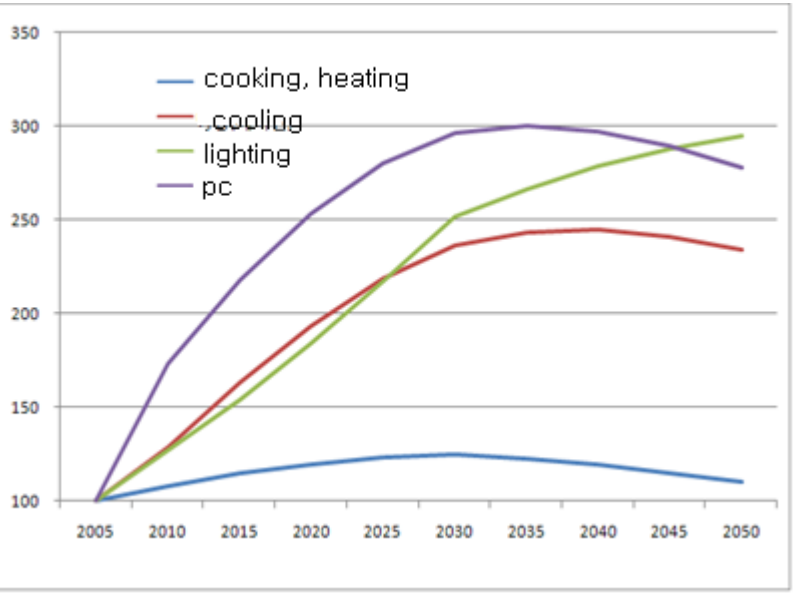
- demand of industry : increase except cement and paper



Final Demand
- residential

- **residential sector : energy consumption for usage**
  ; rapid increase except PC

residential	cooking	energy consumption per household for cooking
	heating	energy consumption per household for heating
	cooling	energy consumption per household for cooling
	lighting	energy consumption per household for lighting
	appliance	energy consumption per appliance



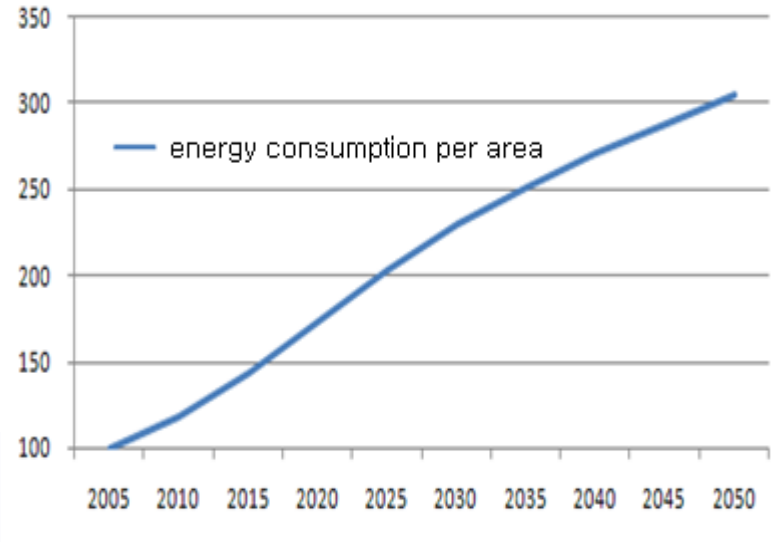
	2005	2010	2020	2030	2040	2050
households (mn)	15.887	17.152	19.012	19.871	19.294	17.629

Final Demand

- commercial

- commercial sector : energy consumption per area

commercial	cooking	energy consumption per area for cooking
	heating	energy consumption per area for heating
	cooling	energy consumption per area for cooling
	lighting	energy consumption per area for lighting
	power	energy consumption per area for power



	2005	2010	2020	2030	2040	2050
area (mn m3)	316.095	376.334	550.285	726.667	858.012	965.114

Final Demand
- transport

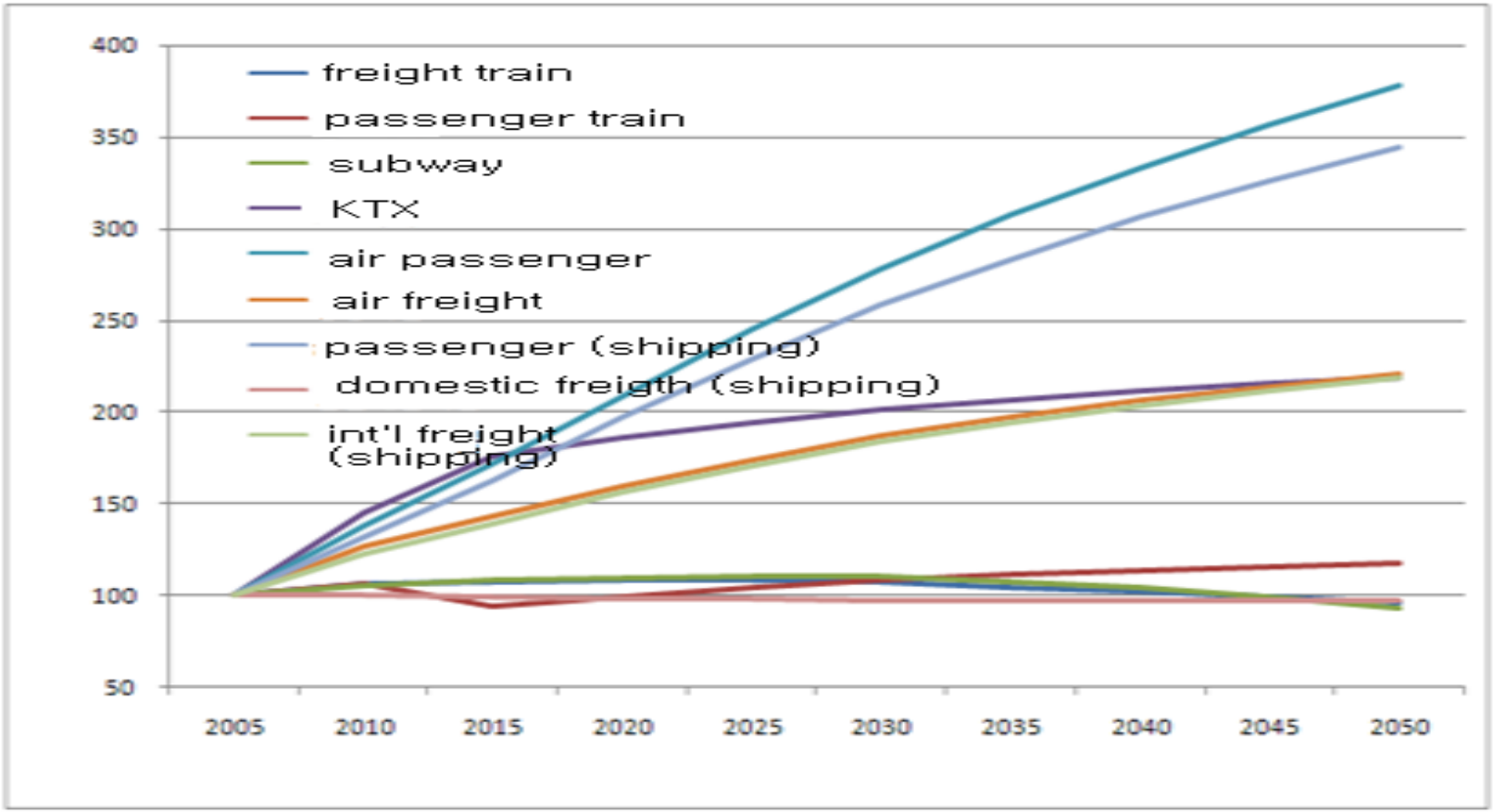
- transport : final demand for transport mode

transport	land	pass. Car	registered car
		prirvate bus	registered car
		private truck	registered car
		taxi	registered car
		commercial bus	registered car
		commercial truck	registered car
	railroad	passenger	passenger transported
		freight	freighted transported
		subway	passenger transported
		KTX	passenger transported
	water	passenger	passenger transported
		domestic freight	freighted transported
		int'l freight	freighted transported
	air	domestic passenger	passenger transported
		int'l passenger	passenger transported

Final Demand

- transport

- passenger car and aviation demand increase



Energy Prices
- emission factor

- calorific value : net-calorific value
- energy prices : price spread vs. crude oil
- emission factor : IPCC factor

		2005	2010	2020	2030	2040	2050
crude oil	($/bl)	50.53	85.63	72.03	83.70	104.57	115.70
coking coal	($/ton)	109.88	128.78	108.33	125.88	157.27	174.00
steam coal	($/ton)	56.11	83.64	70.36	81.77	102.15	113.02
LNG	($/mmbtu)	6.81	12.26	11.35	14.99	18.72	20.71
gasoline	($/liter)	0.32	1.58	1.33	1.54	1.93	2.13
diesel	($/liter)	0.41	1.21	1.02	1.18	1.48	1.64

Mitigation Options
- conversion

- technological options in power and oil refining
  ; new process/technology, fuel switch, CHP, renewable, fuel cell, CCS(10%, 5% for bituminous, gas fueled power capacity in 2020, respectively)

	power	oil ref.	city gas	hydrogen
new process		O		
fuel switch		O		
raw material switch				
CHP		O		
renewable				
CCS	O			
fuel cell	O			O
loss in transmission				

Mitigation Options

- conversion

- new process/technology : compete with current tech.

power	district heating	oil refining	city gas	hydrogen
-	-	3 technologies at 2 process	-	-

- fuel switch : sub. B-C/coal by LNG

power	district heating	oil refining	city gas	hydrogen
-	-	20% of B-C by 2015, 50% after 2015	-	-

Mitigation Options
- conversion

- CHP : sub. purchased elec./heat by CHP

power	district heating	oil refining	city gas	hydrogen
-	-	20MW by 2015, 30MW after 2015	-	-

- CCS(apply to coal and gas power plant) and fuel-cell power

CCS	Fuel cell				
	2015	2020	2030	3040	2050
10% by 2020, 100% of coal by 2030, 5% by 2020 to 50% by 2050 for gas	2.5	45	1,364	9,457	9,783

Mitigation Options
- industry

- technological options in industry
  ; new process, fuel switch, raw material switch, CHP, renewable, CCS

	automobile	cement	petrochemical	paper	iron & steel
new process	O	O	O	O	O
fuel switch		O	O	O	O
raw material switch		O			
CHP	O	O	O	O	
renewable	O				
CCS		O	O		O

Mitigation Options

- industry

- new process/technology : compete with current tech.

automobile	cement	petrochemical	paper	steel & iron
28 tech.	4 tech.	5 tech.	8 tech.	6 tech.

- fuel switch : sub. B-C/coal by LNG

automobile	cement	petrochemical	paper	steel & iron
-	5% of coal by waste-plastic by 2015	100% of B-C by 2020	100% of B-C by 2015	100% of B-C by 2015

Mitigation Options

- industry

- raw material switch : sub. Slag cement

automobile	cement	petrochemical	paper	steel & iron
-	6 million ton of slag by 2015			

- renewable : solar power

automobile	cement	petrochemical	paper	steel
15MW by 2015	-	-	-	-

Mitigation Options

- industry

- CHP : sub. purchased elec./heat by CHP

automobile	cement	petrochemical	paper	steel
20MW by 2015	20MW by 2015, 45MW by 2020	60MW by 2015, 60MW by 2020, 60MW by 2025	12.5% of electricity consumption by 2030	-

- CCS : cement, petrochemical, steel

automobile	cement	petrochemical	paper	steel
-	30% by 2030, 50% of kiln by 2050	10% by 2025, 50% of NCC by 2050		10% by 2025, 50% of furnace by 2050

Mitigation Options

- residential

- technological options in residential sector
  ; efficient process/technology for heating, cooling, lighting, appliance, fuel cell

heating	vacuum insulation
cooling	motor control, efficient motor
lighting	efficient light(LED, etc.)
appliances	LCD+standby power for TV, efficient inverter for refrigerator
fuel cell	13.8MW in 2020

Mitigation Options

- residential

- heating : penetration rate of vacuum insulation

2010	2020	2030	2040	2050
10%	30%	50%	70%	90%

- cooling : penetration rate of efficient system

2010	2020	2030	2040	2050
20%	40%	60%	80%	100%

- lighting : penetration rate of efficient system

2010	2020	2030	2040	2050
20%	60%	100%	100%	100%

Mitigation Options

- residential

- appliance : penetration rate of vacuum insulation

2010	2020	2030	2040	2050
20%	40%	60%	80%	90%

- fuel cell : introduction MW

2015	2020	2030	2040	2050
0.9	13.8	302.8	3,329.3	8,013.3

Mitigation Options
- commercial

- technological options in commercial sector
  ; efficient heating, cooling, lighting, fuel cell

heating	vacuum insulation
cooling	efficient cooling(absorber)
lighting	efficient CFL
Fuel cell	23.9MW in 2020

Mitigation Options

- commercial

- heating : penetration rate of vacuum insulation

2010	2020	2030	2040	2050
10%	30%	50%	70%	90%

- cooling : penetration rate of efficient system

2010	2020	2030	2040	2050
20%	40%	60%	80%	100%

Mitigation Options

- commercial

- lighting : penetration rate of efficient system

2010	2020	2030	2040	2050
20%	60%	100%	100%	100%

- fuel cell : introduction MW

2015	2020	2030	2040	2050
1.3	23.9	798.5	7,957.5	11,830.3

Mitigation Options
- transport

- technological options in land transport mode
  ; increasing share of hybrid, electric and fuel cell car for passenger car/bus/truck
  ; biodiesel for bus and truck

land	
- passenger car	hybrid→electric→fuel cell car
- bus	fuel cell car
- truck	fuel cell car
railroad	-
water	-
air	-
bio-diesel	10% in 2020, 20% in 2030

Mitigation Options

- transport

- share of private car

	2005	2010	2020	2030	2040	2050
current car(gas, diesel)	1.00	0.95	0.50	0.36	0.18	0.05
hybrid	-	0.05	0.30	0.10	-	-
electrical car	-	-	0.20	0.50	0.40	0.10
fuel cell car	-	-	-	0.04	0.42	0.85

Mitigation Options

- transport

- share of taxi by fuel-type

	2005	2010	2020	2030	2040	2050
current fuel(butane)	1.00	1.0	0.50	0.36	0.25	0.10
hybrid	-	-	0.30	0.10	-	-
electrical car	-	-	0.20	0.50	0.30	-
fuel cell car	-	-	0.01	0.04	0.45	0.90

Mitigation Options

- transport

- share of private bus

	2010	2015	2020	2025	2030-
Bio-diesel share	1%	5%	10%	15%	20%

	2005	2010	2020	2030	2040	2050
current car(gas, diesel)	1.00	0.95	0.90	0.78	0.70	0.63
bio-diesel	-	0.05	0.10	0.20	0.20	0.20
fuel cell car	-	-	-	0.02	0.10	0.17

Mitigation Options

- transport

- share of commercial bus

	2005	2010	2020	2030	2040	2050
current car	1.00	1.00	1.00	0.92	0.09	-
fuel cell car	-	-	-	0.08	0.91	1.0

- share of private truck

	2005	2010	2020	2030	2040	2050
current car	1.00	1.00	0.90	0.74	0.03	-
Bio-diesel			0.10	0.20	0.20	
fuel cell car	-	-	-	0.06	0.67	1.0

- share of commercial truck

	2005	2010	2020	2030	2040	2050
current car	1.00	1.00	0.90	0.67	0.40	-
Bio-diesel			0.10	0.20	0.20	0.20
fuel cell car	-	-	-	0.13	0.40	0.80

CO2 Emission

- base case

- emissions increases 0.6% annually by 2050

; high for commercial/conversion, low for industry(1,000 tCO_2)

	2005	2010	2020	2030	2040	2050	'05-'50
(conversion)	186,073	239,474	266,915	308,312	337,860	342,624	1.4%
industry	235,694	271,352	298,993	292,834	280,194	262,346	0.2%
- manuf.	168,536	201,207	239,109	239,796	234,186	226,413	0.7%
- const.	4,150	4,679	2,686	2,900	3,153	3,423	-0.4%
commercial	57,904	70,088	86,165	101,160	116,511	127,863	1.8%
public	14,492	17,298	17,772	18,689	19,579	19,240	0.6%
residential	71,478	76,749	82,862	83,814	80,429	71,616	0.0%
transport	101,109	116,001	143,379	153,904	154,937	151,242	0.9%
CO2	480,677	551,488	629,171	650,401	651,649	632,307	0.6%

Mitigation Potential

- conversion(1,000tCO$_2$, $1,000/tCO$_2$)

- technological potential is 32.8% of GHG emission of conversion sector in 2020
  ; CCS has the highest potential(99.4% of potential)

sector	options	potential		potential vs. emission	
		option	cum.	nat'l	sector
power	fuel cell	-299	-299	0.0%	-0.1%
	CCS	-86,689	-86,989	-13.8%	-37.5%
	trans.		-86,989	-13.8%	-37.5%
oil ref.	CHP	-137	-137	0.0%	-1.1%
	LNG	-416	-553	-0.1%	-4.4%
	new proc.		-553	-0.1%	-4.4%
sub-total			-87,542	-13.9%	-32.8%

Mitigation Potential

- conversion(1,000tCO$_2$, $1,000/tCO$_2$)

- fuel switch(LNG) is the most expensive option

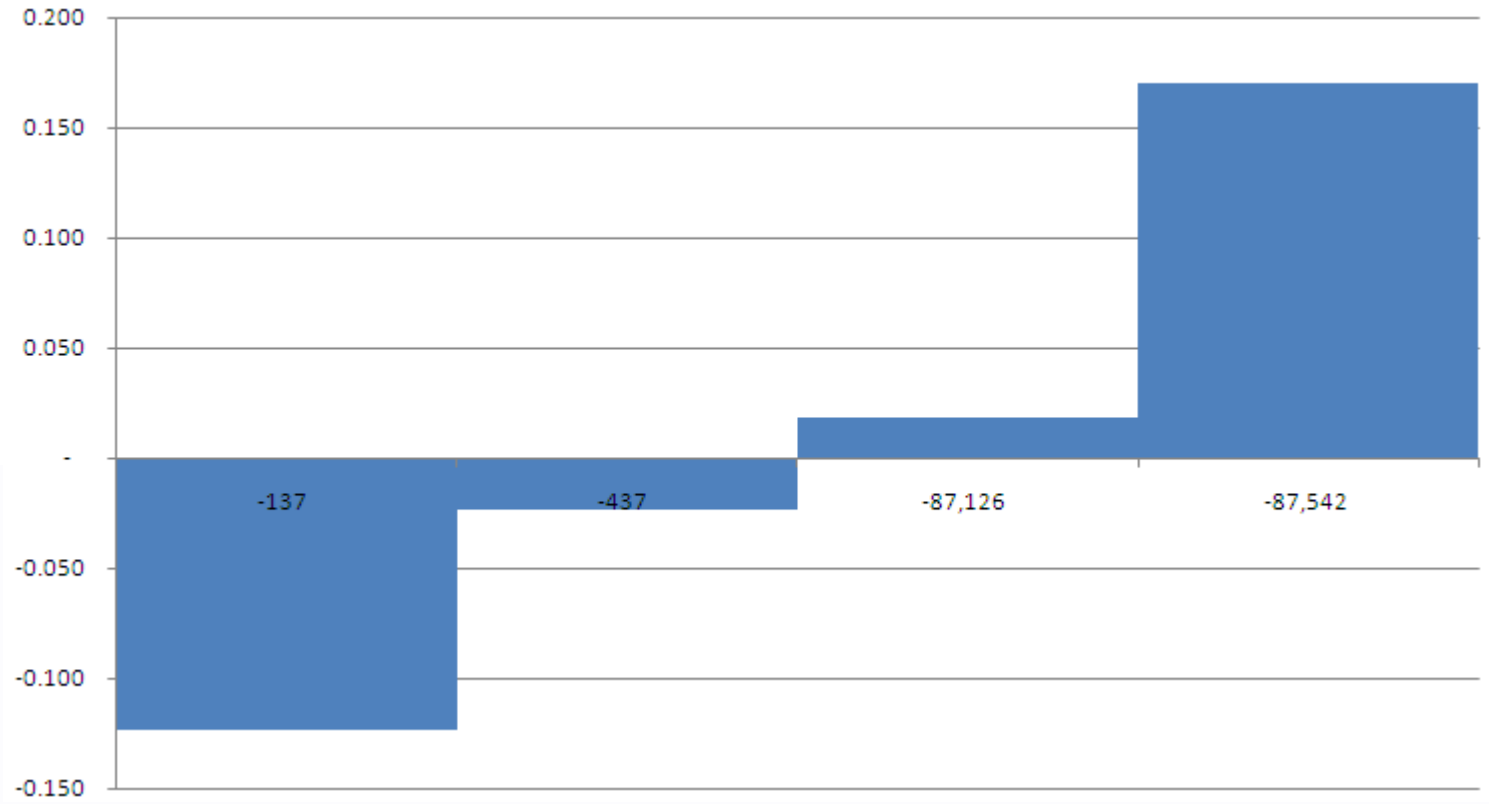
  ; fuel cell and CHP are negative cost options

sector	options	potential	cum.potential	marginal cost	average cost
power	fuel cell	-299	-299	-0.024	-0.024
	CCS	-86,689	-86,989	0.019	0.019
	loss in tr.		-86,989	-	0.019
oil ref.	CHP	-137	-137	-0.123	-0.123
	LNG	-416	-553	0.170	0.097
	new proc.		-553	-	0.097
sub-total			-87,542	0.170	0.019

Mitigation Potential

- conversion(1,000tCO$_2$, $1,000/tCO$_2$)

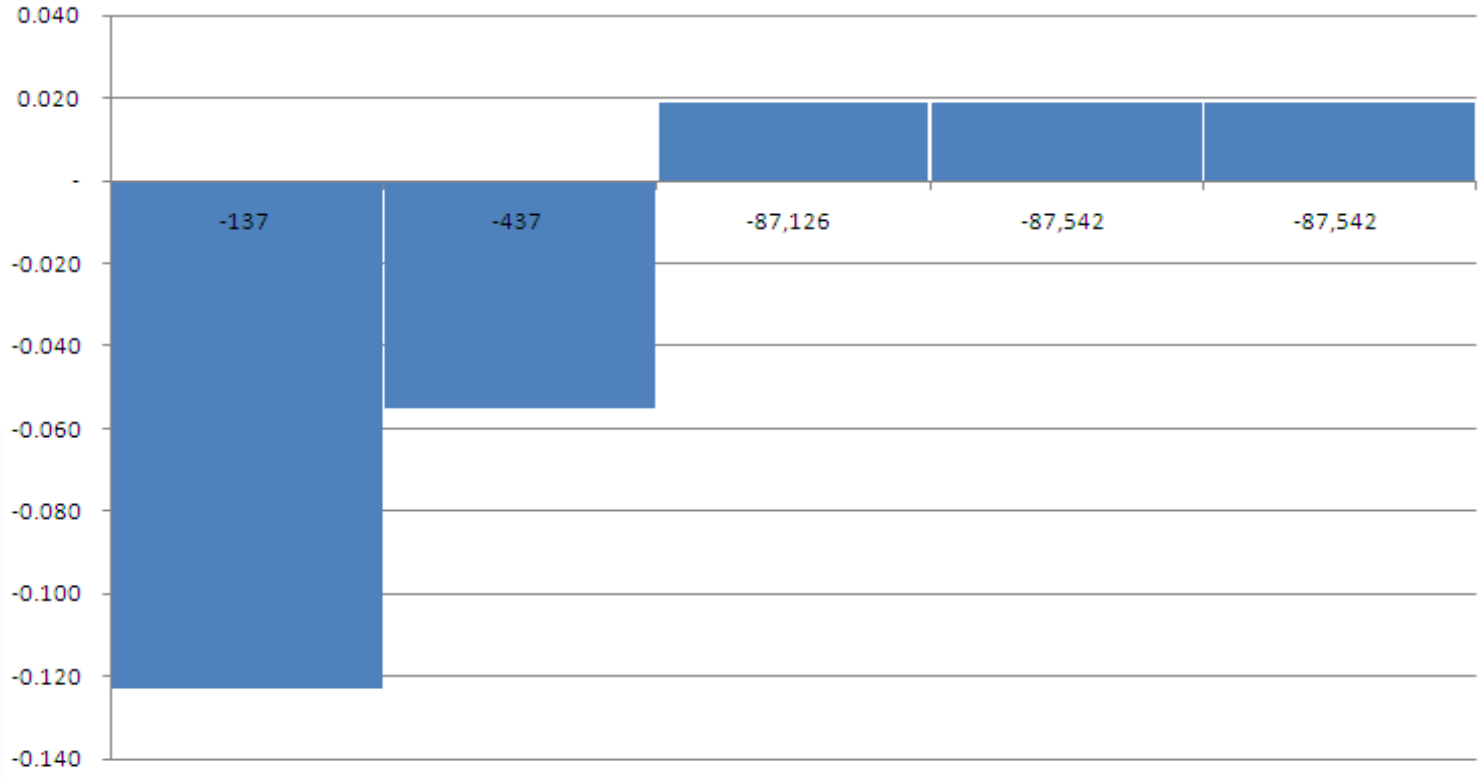
- marginal abatement cost($170/tCO$_2$)



Mitigation Potential

- conversion(1,000tCO$_2$, $1,000/tCO$_2$)

- low average cost($19/tCO$_2$) due to CCS
- high potential with low cost(cost-effective)



Mitigation Potential

- industry(1,000tCO_2, \$1,000/tCO_2)

- mitigation potential in industry is 1.8% of GHG emission in 2020

  ; cement(slag) has half of the potential

  ; small potential due to high efficiency

  ; CCS has potential after 2010

Mitigation Potential

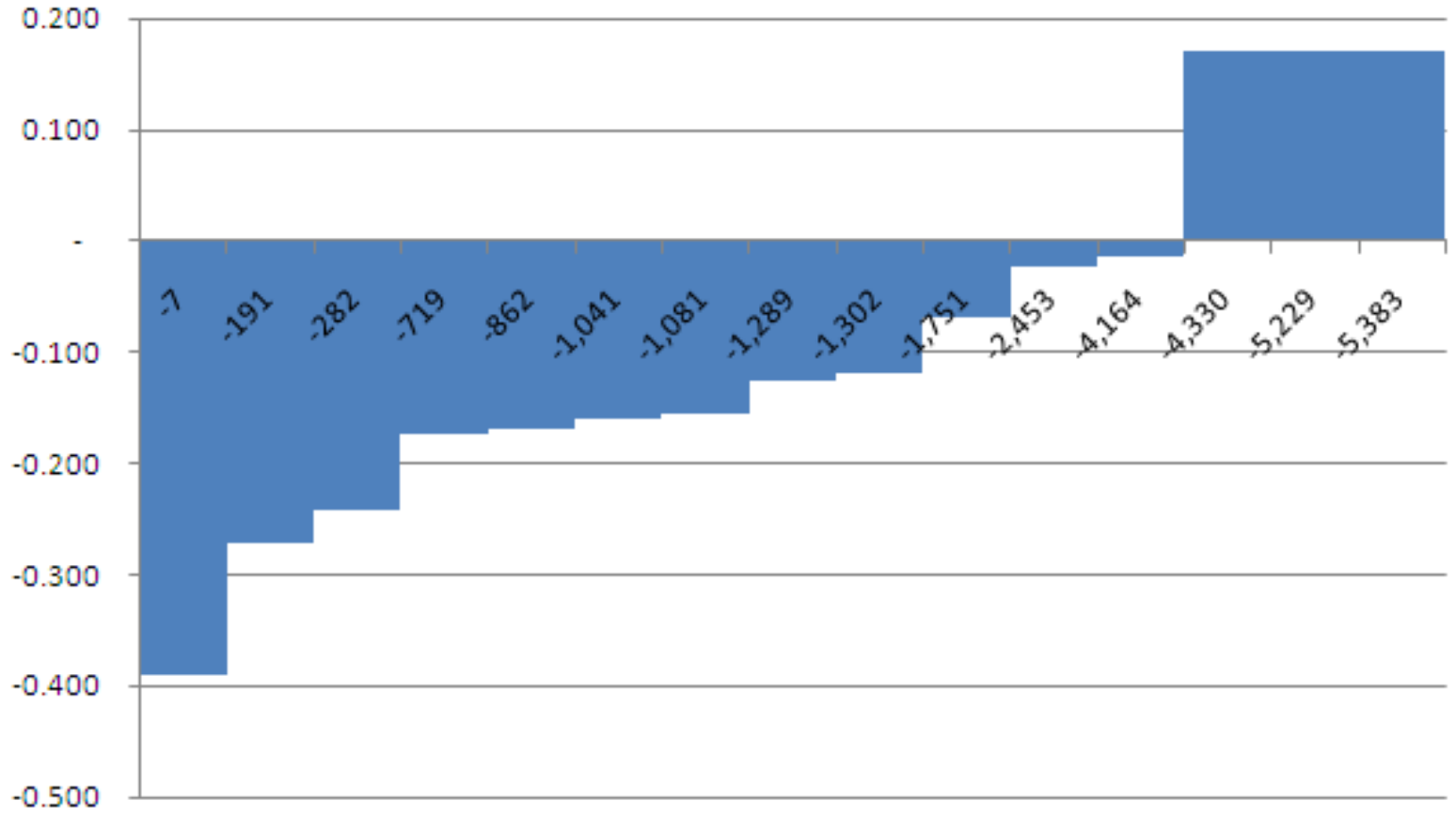
- industry(1,000tCO$_2$, $1,000/tCO$_2$)

sector	option	potential	cum.	potential vs. emis.	
				nat'l	sector
petrochemical	new proc.	-7	-7	0.0%	0.0%
	CHP	-184	-191	0.0%	-0.3%
	LNG	-899	-1,091	-0.2%	-1.9%
	CCS		-1,091	-0.2%	-1.9%
cement	CHP	-179	-179	0.0%	-1.1%
	plastic	-702	-881	-0.1%	-5.4%
	slag	-1,711	-2,592	-0.4%	-16.0%
	CCS		-2,592	-0.4%	-16.0%
	new proc.		-2,592	-0.4%	-16.0%
automobile	new proc.	-143	-143	0.0%	-4.0%
	PV	-40	-183	0.0%	-5.1%
	CHP	-13	-196	0.0%	-5.5%
paper	CHP	-209	-209	0.0%	-3.2%
	new proc.	-449	-657	-0.1%	-10.0%
	LNG	-154	-811	-0.1%	-12.3%
steel	new proc.	-90	-90	0.0%	-0.1%
	CHP	-437	-528	-0.1%	-0.4%
	LNG	-166	-693	-0.1%	-0.6%
	CCS		-693	-0.1%	-0.6%
sub-total			-5,383	-0.9%	-1.8%

Mitigation Potential

- industry(1,000tCO_2, \$1,000/tCO_2)

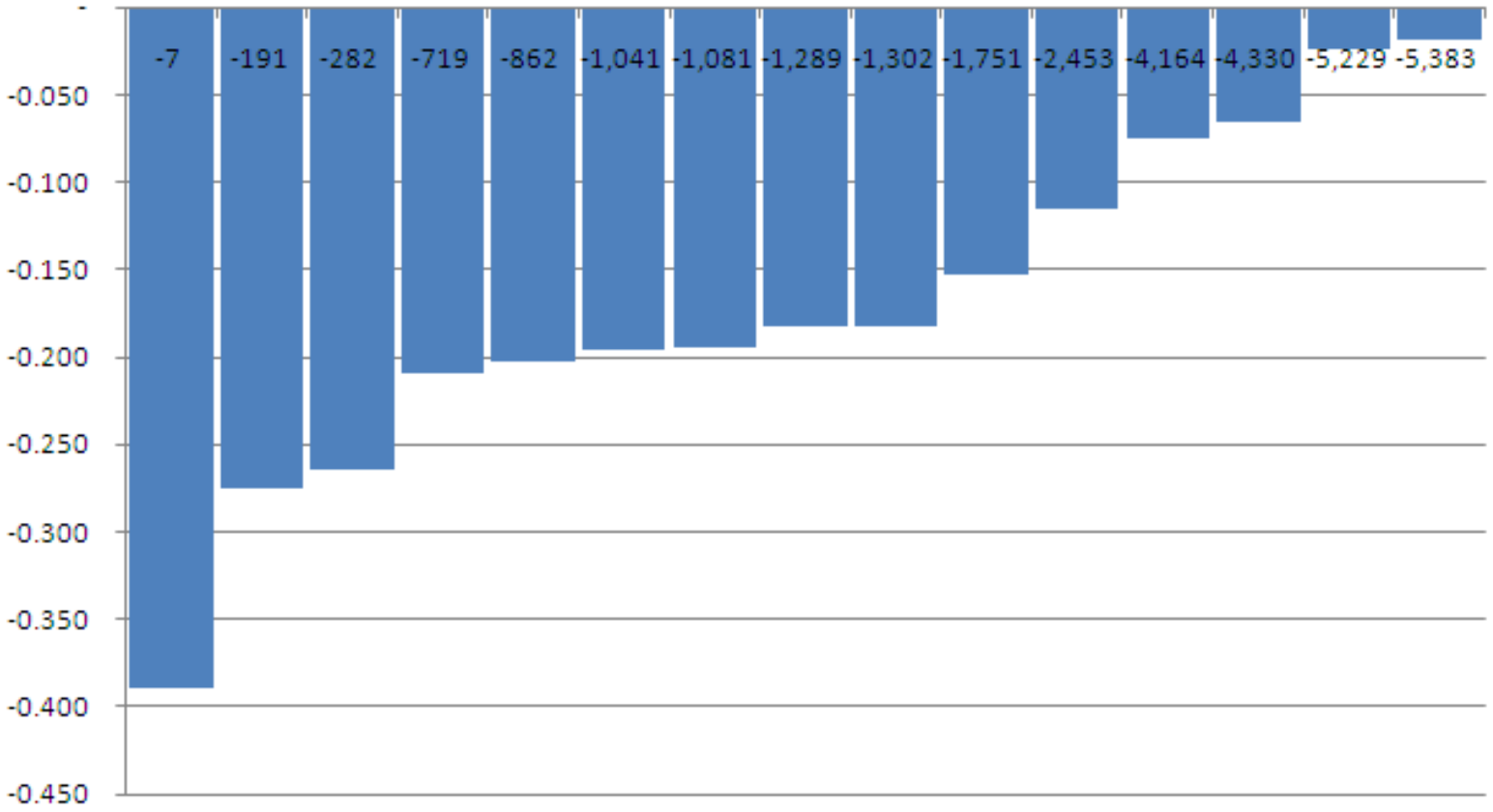
- marginal abatement cost(\$190/tCO_2)



Mitigation Potential

- industry(1,000tCO$_2$, $1,000/tCO$_2$)

- cumulated average cost is negative(-$19/tCO$_2$)
  ; low potential with low cost



Mitigation Potential

- commercial(1,000tCO$_2$, $1,000/tCO$_2$)

- mitigation potential is 34.1% of emission in 2020 (4.7% of nat'l emission)
; high potential for lighting

sector	options	potential		potential vs. emission	
		potential	cum.	nat'l	sector
commercial	fuel cell	-87	-87	0.0%	-0.1%
	heating	-9,116	-9,203	-1.5%	-10.7%
	cooling	-7,040	-16,243	-2.6%	-18.9%
	lighting	-13,166	-29,409	-4.7%	-34.1%
sub-total			-29,409	-4.7%	-34.1%

Mitigation Potential

- commercial(1,000tCO$_2$, $1,000/tCO$_2$)

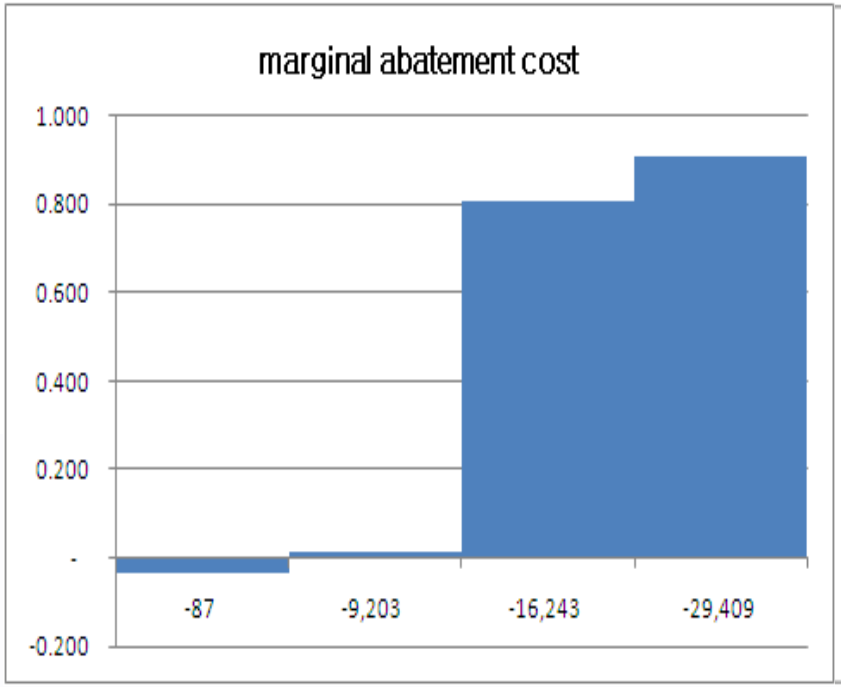
- high marginal cost($906/tCO$_2$) and average cost($603/tCO$_2$)

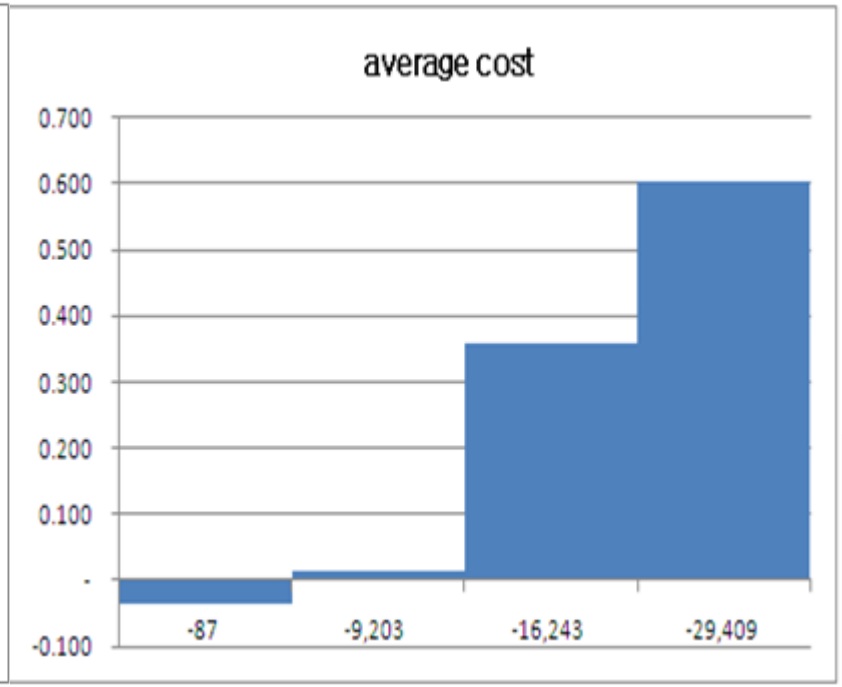
sector	options	potential	cum. potential	marginal cost	average cost
commercial	fuel cell	-87	-87	-0.036	-0.036
	heating	-9,116	-9,203	0.015	0.014
	cooling	-7,040	-16,243	0.806	0.358
	lighting	-13,166	-29,409	0.906	0.603

Mitigation Potential

- commercial(1,000tCO$_2$, $1,000/tCO$_2$)

- high technological potential with high cost





Mitigation Potential

- residential(1,000tCO_2, $1,000/t$CO_2$)

- mitigation potential is 13.1% in 2020

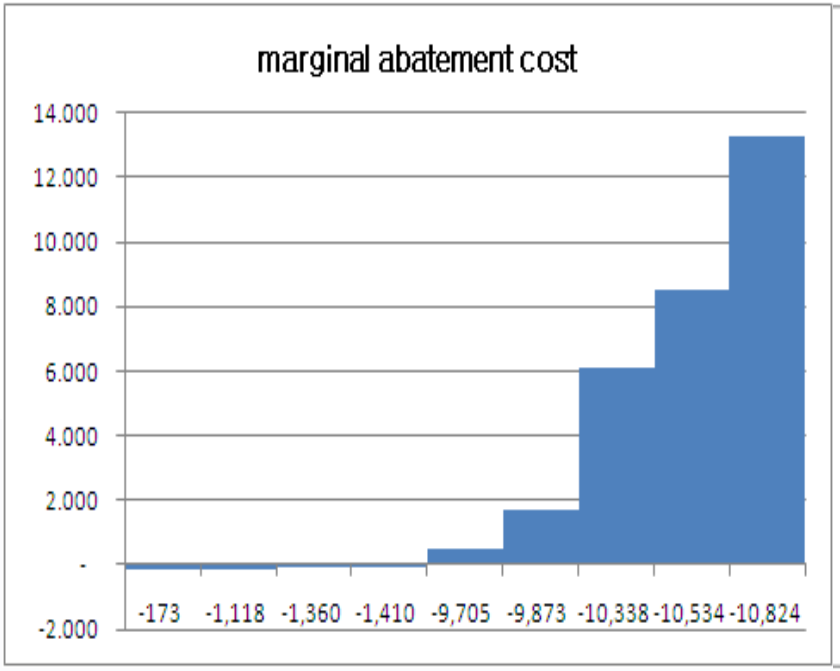
  ; heating(vacuum insulation) has the biggest potential

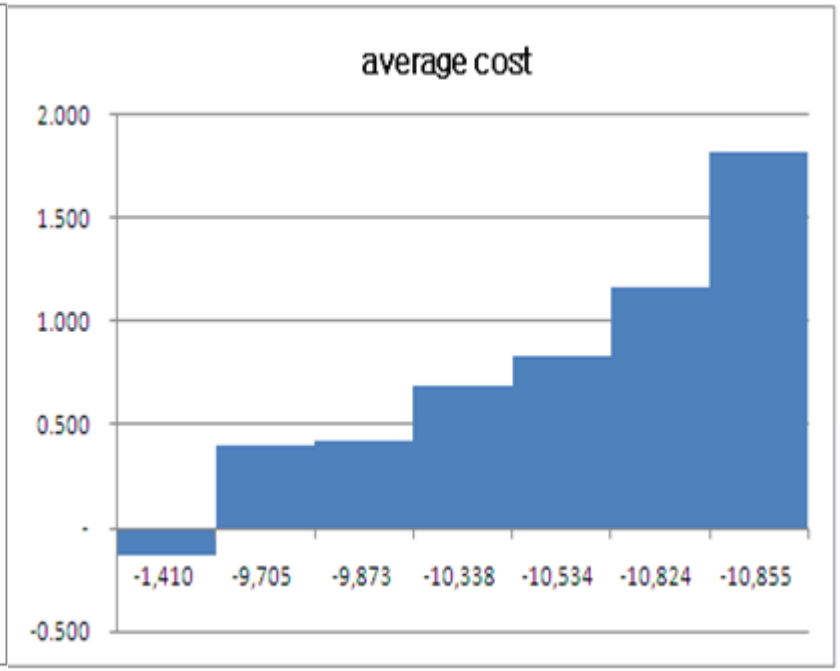
sector	options	potential		Potential vs. emission	
		potential	cum.	nat'l	sector
residential	CFL	-173	-173	0.0%	-0.2%
	fluorescent	-946	-1,118	-0.2%	-1.3%
	white ramp	-241	-1,360	-0.2%	-1.6%
	fuel cell	-50	-1,410	-0.2%	-1.7%
	heating	-8,295	-9,705	-1.5%	-11.7%
	air cond.	-168	-9,873	-1.6%	-11.9%
	refrigerator	-465	-10,338	-1.6%	-12.5%
	washing	-196	-10,534	-1.7%	-12.7%
	TV	-290	-10,824	-1.7%	-13.1%
	elec. fan	-31	-10,855	-1.7%	-13.1%
sub			-10,855	-1.7%	-13.1%

Mitigation Potential

- residential(1,000tCO_2, \$1,000/tCO_2)

- high cost with low potential
  ; high marginal cost and high average cost





Mitigation Potential

- transport(1,000tCO$_2$, $1,000/tCO$_2$)

- mitigation potential is 7.5% of emission in 2020
  ; passenger car has the biggest potential

sector	options	potential		poten. vs. emission	
		potential	cum.	nat'l	sector
transport	private bus	-602	-602	-0.1%	-0.4%
	comm. bus	-14	-616	-0.1%	-0.4%
	private truck	-1,928	-2,544	-0.4%	-1.8%
	comm. truck	-1,191	-3,735	-0.6%	-2.6%
	taxi	-609	-4,344	-0.7%	-3.0%
	passenger car	-6,367	-10,711	-1.7%	-7.5%
sub			-10,711	-1.7%	-7.5%

Mitigation Potential

- transport(1,000tCO$_2$, $1,000/tCO$_2$)

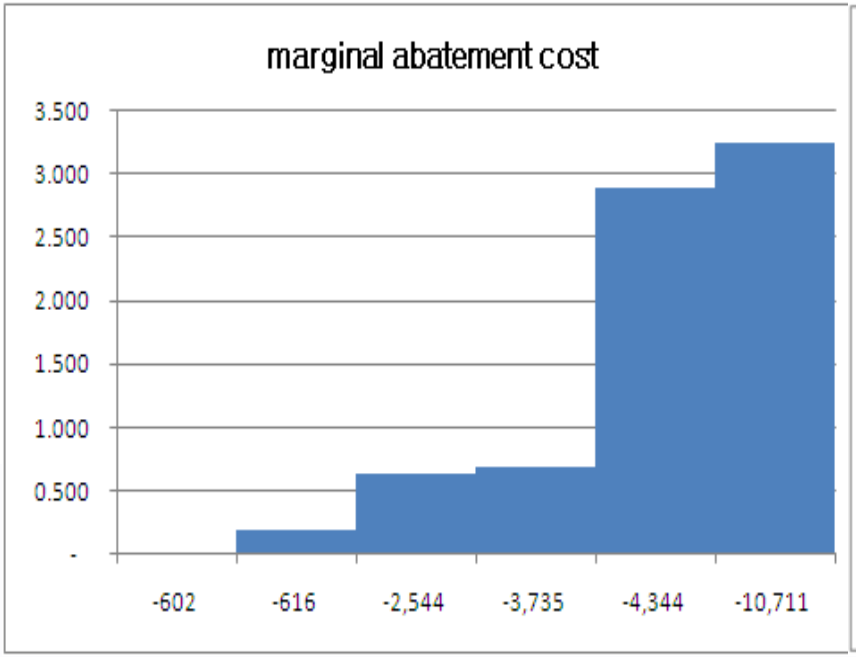
- high marginal/average cost($3,237, $2,281/tCO$_2$)

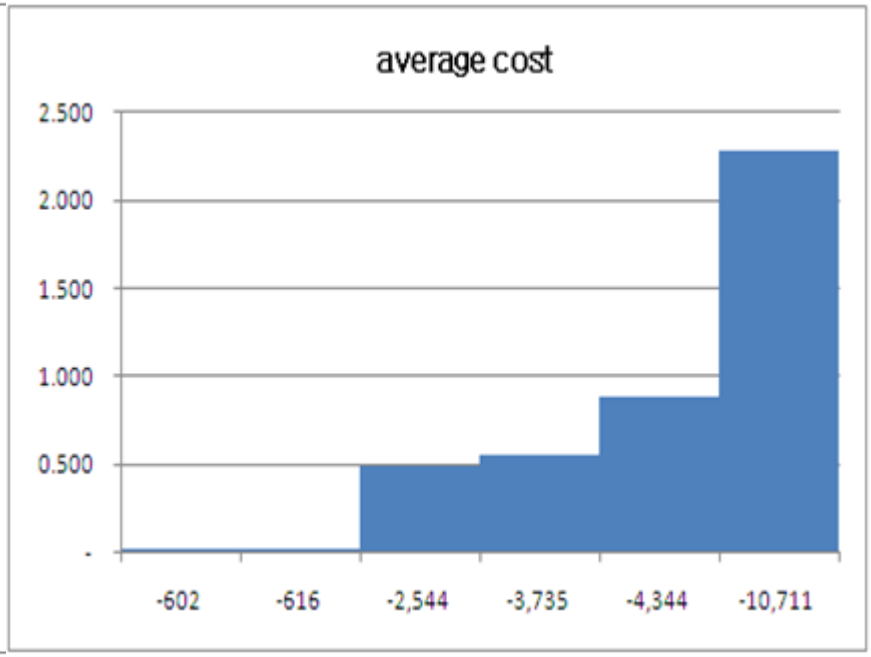
sector	options	potential	cum. potential	marg. cost	aver. cost
transport	private bus	-602	-602	0.018	0.018
	comm. bus	-14	-616	0.181	0.021
	private truck	-1,928	-2,544	0.634	0.486
	comm. truck	-1,191	-3,735	0.693	0.552
	taxi	-609	-4,344	2.891	0.880
	passenger car	-6,367	-10,711	3.237	2.281
sub-total			-10,711	3.237	2.281

Mitigation Potential

- transport(1,000tCO$_2$, $1,000/tCO$_2$)

- high marginal/average cost





Mitigation Potential

- national potential(1,000tCO_2, $1,000/t$CO_2$)

- technological potential is 22.9% of emission in 2020

; conversion(60.8%), commercial(20.4%), residential(7.5%), transport(7.4%), industry(3.7%)

sector	potential	potential vs. emission		share of potential
	cum.	nat'l	sector	nat'l
conversion	87,542	-13.9%	-32.8%	-60.8%
- power	86,989	-13.8%	-37.5%	-60.5%
- oil ref.	553	-0.1%	-4.4%	-0.4%
industry	5,383	-0.9%	-1.8%	-3.7%
- pet.chem	1,091	-0.2%	-1.9%	-0.8%
- cement	2,592	-0.4%	-16.0%	-1.8%
- automobile	196	0.0%	-5.5%	-0.1%
- paper	811	-0.1%	-12.3%	-0.6%
- iron & steel	693	-0.1%	-0.6%	-0.5%
residential	10,855	-1.7%	-13.1%	-7.5%
commercial	29,409	-4.7%	-34.1%	-20.4%
transport	10,711	-1.7%	-7.5%	-7.4%
total	143,900	-22.9%		-100%

Mitigation Potential

- national(1,000tCO$_2$, $1,000/tCO$_2$)

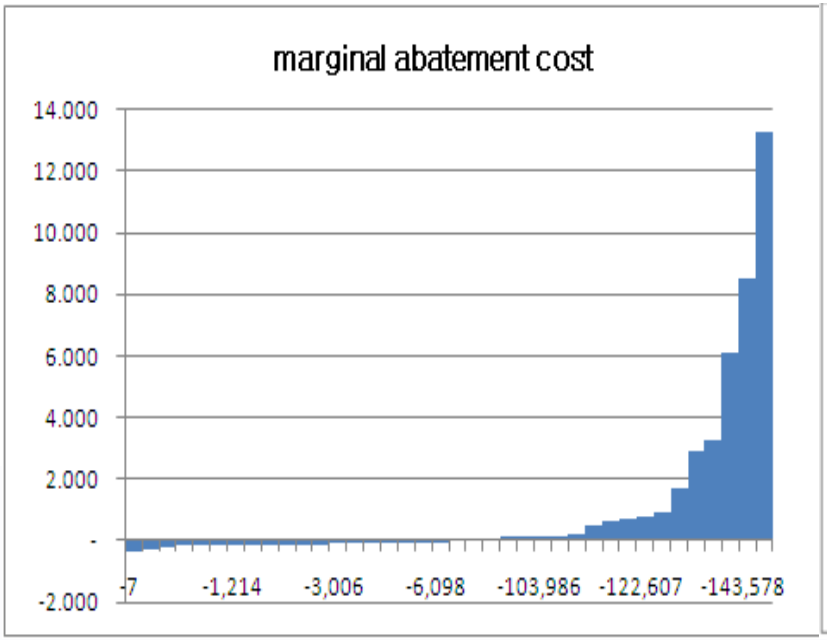
- high marginal/average cost

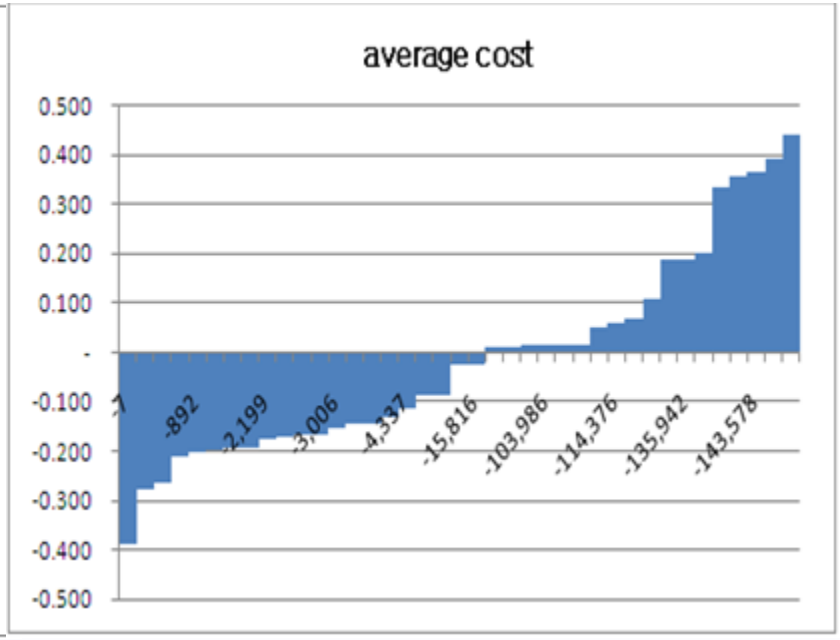
sector	cum. potential	marg. cost	aver. cost
conversion	-87,542		0.019
- power	-86,989		0.019
- oil ref.	-553		0.097
industry	-5,383		-0.019
- petro.chem	-1,091		0.092
- cement	-2,592		-0.027
- automobile	-196		-0.163
- paper	-811		-0.038
- iron & steel	-693		-0.101
residential	-10,855		1.818
commercial	-29,409		0.603
transport	-10,711		2.281
total	-143,900	228.418	0.441

Mitigation Potential

- total(1,000tCO$_2$, $1,000/tCO$_2$)

- low technological potential with high cost





Mitigation Potential

- total(1,000tCO$_2$, $1,000/tCO$_2$)

- reduction of 16.3% of emission under current carbon price($20-30/tCO$_2$)

cum. potential (1,000tCO$_2$)	(%)	marg. cost ($1,000/tCO$_2$)	aver. cost ($1,000/tCO$_2$)
-6,098	-1.0%	-0.010	-0.086
-15,213	-2.4%	0.015	-0.026
-15,816	-2.5%	0.018	-0.024
-102,505	-16.3%	0.019	0.012
-104,153	-16.6%	0.181	0.015
-112,448	-17.9%	0.496	0.050
-143,900	-22.9%	228.418	0.441

Conclusion

- maximum technological mitigation potential is 22.9% of GHG emission in 2020

; 16.3% under current carbon price($20-30/tCO2)

; not sufficient for nat'l target of 30% reduction vs. BAU in 2020

- cost-effective mitigation with more R&D for technology development

; achieve Green Growth with GDP and GHG reduction

Thank you

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