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Assessment of Energy Options for Development of Greenhouse Gas Mitigation Strategies in Pakistan

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Objective of the Research Study

International Atomic Energy Agency initiated a research project on "Greenhouse Gas Mitigation Strategies and Energy Options" in 2007. Pakistan is participating in this project.

Background Information of Pakistan

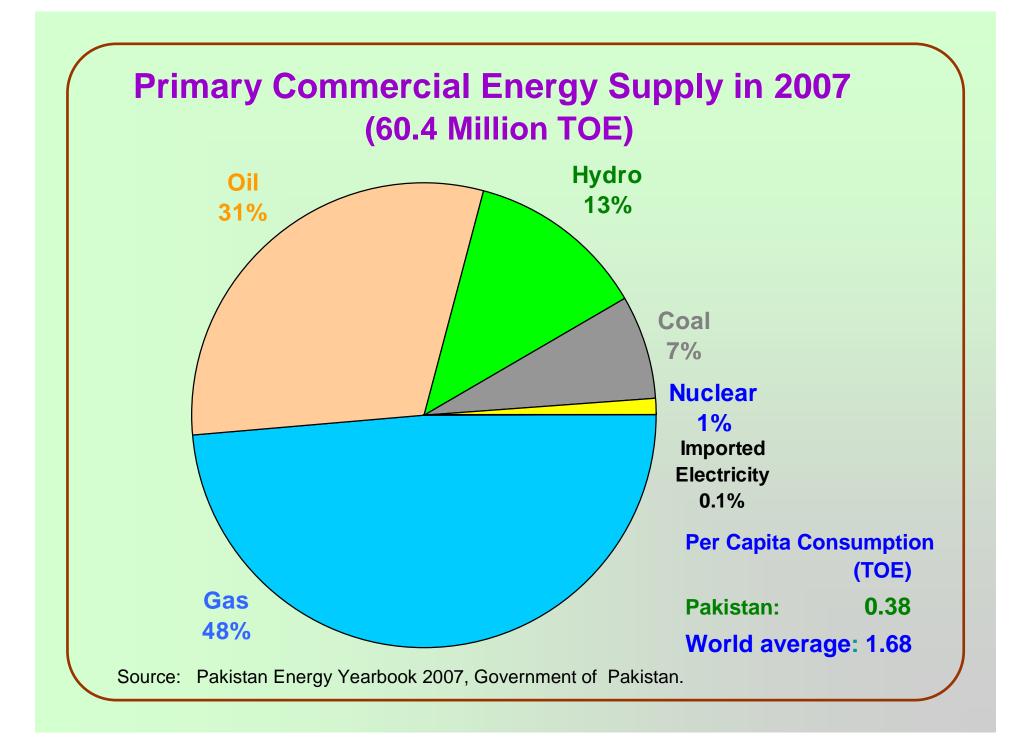
Population and Energy Consumption Population in Year 2007: 158 million (urban share: 34%) Per capita GDP (2007) : US \$ 925 Per capita primary commercial energy consumption (2007): 0.38 TOE (World average: 1.68 TOE/capita) Per capita electricity consumption: 460 kWh (World average: 2752 kWh/capita)

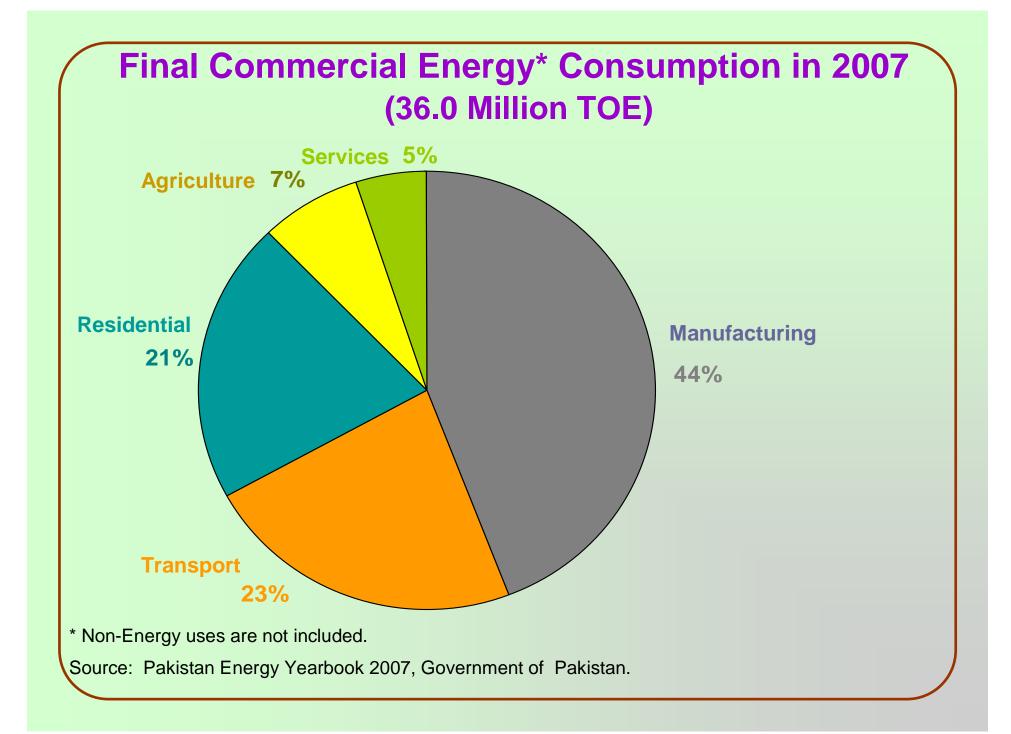
Sources: i) Pakistan Economic Survey 2007-08, Government of Pakistan. ii) Pakistan Energy Yearbook 2007, Government of Pakistan. iii) Key World Energy Statistics 2009, International Energy Agency.

Sectoral Gross Domestic Product

Year	1987	1997	2002	2007
Total GDP (billion Pak. Rupees* in 2007 prices)	3,157	5,056	5,956	8,257
(average annual growth rate)		4.8%	3.3%	6.8%
Agriculture (share)	26.6%	25.7%	24.1%	21.8%
(average annual growth rate)		4.5%	2.1%	4.6%
Industries (manufacturing construction & mining, etc.) (share)	17.0%	16.5%	15.9%	19.0%
(average annual growth rate)		4.5%	2.6%	10.6%
Services (share)	49.0%	49.5%	52.1%	52.1%
(average annual growth rate)		4.9%	4.4%	6.7%
Energy (share)	2.5%	4.0%	3.0%	2.1%
(average annual growth rate)		9.9%	-2.4%	-0.3%

* 1 US dollar = 60.63 Pak Rupees Source: Pakistan Economic Survey 2008-09, Government of Pakistan.





Fossil Fuel Reserves (million TOE) of Pakistan in 2007

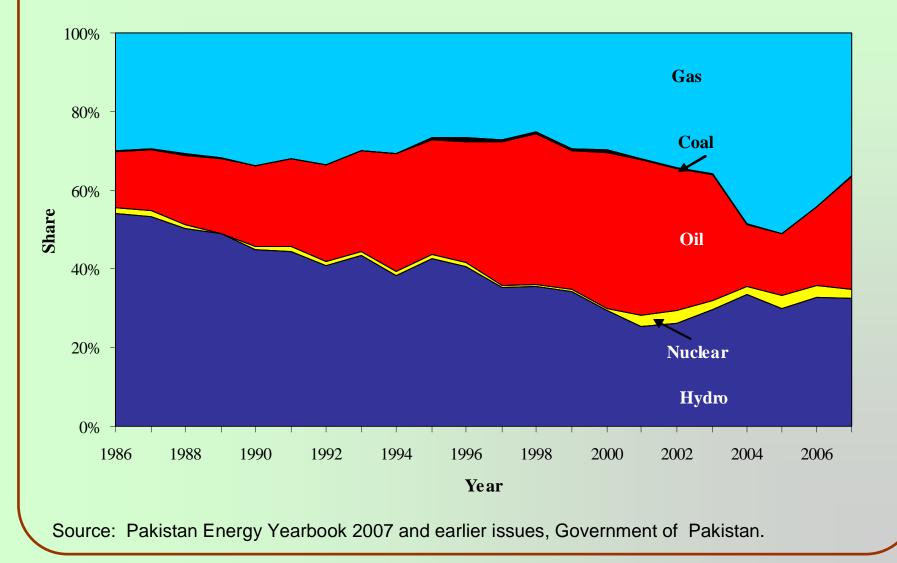
	Paki	stan	World		
Fossil Fuels	Million TOE	R/P ratio	Million TOE	R/P ratio (2006)	
Oil	47	14	168,600	42	
Gas	605	21	162,847	63	
Coal*	1,527*	937	426,128	147	
Total	2189		757,575		
TOE/capita	13.8		114.4		

* Total resources = 185 billion tonnes

Sources: i) Pakistan Energy Yearbook 2007, Government of Pakistan.

ii) BP Statistical Review of World Energy, June 2008.

Electricity Generation Mix of Pakistan (98.2 billion kWh during 2007)



Electricity Installed Capacity in 2008

	MW	Shares
Hydel	6,480	33.4%
Gas/Oil	12,328	63.4%
Coal	150	0.8%
Nuclear	462	2.4%
Total	19,420	100.0%

Source: Pakistan Energy Yearbook 2008, Government of Pakistan.

Research Work



GHG Inventory for 2007 was estimated using:

- The national statistics of different activities leading to GHG emissions,
- 2006 IPCC Guidelines for National Greenhouse Gas Inventories, and
- UNFCCC's Non-Annex I National Greenhouse Gas Inventory Software, Version 1.3.2, 2005-06

Activities Considered for GHG Inventory (1/2)

Energy and Non-Energy related activities

- I. Energy Related GHG Emissions
 - Energy Industries
 - Manufacturing and Construction sectors
 - Transport sector
 - Commercial, Residential and Agriculture sectors
- II. Non- Energy Related Emissions a) Industrial Process
 - Cement production
 - Steel production

Activities Considered for GHG Inventory (2/2)

- Soda ash production
- Urea fertilizer production and use
- Asphalt use in construction industry
- **b)** Agriculture Sector
 - Animals related:
 - (i) Enteric fermentation and
 - (ii) Manure management
 - Rice cultivation
 - Crop residues burning

Greenhouse Gas Inventory in 2007 (thousand tonnes)

Sector	CO2	CH ₄	N ₂ O	СО	NMVOC	Total CO ₂ eq
Energy Sector	132,208	154	3	183	105	137,653
i). Energy Related (fuel combustion)	132,208	12	3	183	105	134,100
Power Sector	43,813	1	0.2	12	5	43,948
Manufacturing	42,963	2	0.4	11	22	43,224
Transport	30,151	7	2.3	156	76	31,572
Other sectors	15,282	2	0.1	4	3	15,357
ii). Fugitive Emissions		142	0	0	0	3,553
Non-Energy Related	17,309	3,592	35	163	147	118,457
i). Industrial Processes	17,309		35	0	147	28,322
ii). Agriculture		3,592	0	163	0	90,135
Total	149,518	3,746	38	346	252	256,110

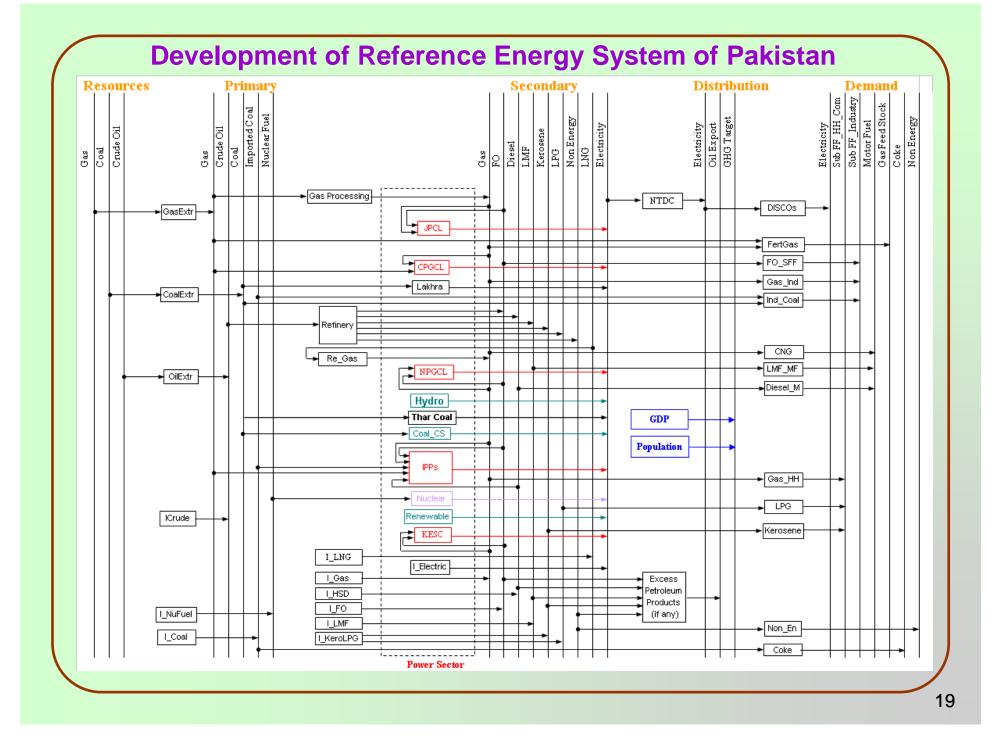
Global warming potentials for CH₄, N₂O, CO and NMVOC are taken as 25, 298, 1.9 and 3.4 respectively (IPCC 4th Assessment Report).

Grow	th of Green	house Gase	S		
	CO ₂ eq of GHG Emissions (Thousand tonnes)				
	1994* 2007		Growth rate (%)		
A. Energy Sector	85,816	137,653	3.7%		
1. Fuel Combustion	78,898	134,100	4.2%		
Power sector	21,651	43,948	5.6%		
Manufacturing	25,113	43,224	4.3%		
Transport	19,848	31,572	3.6%		
Other sectors	12,286	15,357	1.7%		
2. Fugitive Emissions	6,918	3,553	-5.0%		
B. Non-Energy Sector	84,929	118,457	2.6%		
1. Industrial processes	13,297	28,322	6.0%		
2. Agriculture	71,632	90,135	1.8%		
Total	170,745	256,110	3.2%		

* Pakistan's Initial National Communication on Climate Change to UNFCCC, November 2003.

Methodology

IAEA's Model for Energy Supply Strategy Alternatives and their General Environmental Impacts (MESSAGE) was used in the study for modeling the energy system of Pakistan and two post-Kyoto climate protection approaches.



Assumptions for the MESSAGE Model

Planning Horizon: 2007 to 2030
Discount Rate: 10%
Division of the Year: Six seasons and four parts of the day
Load Curve: for Electricity Demand
Seasonal Availability Factor: for Hydro Power

	In Physical Units	US \$/million BTU	US \$/TOE	
Imported Crude Oil	US \$ 75/bbl (FOB)	14.2	595	
Domestic Crude Oil	US \$ 67.8/bbl (85% of imported)	12.1	505	
Furnace Oil	US \$ 503 tonne	11.7	489	
HSD	US \$ 835/ tonne	20.9	877	
Gasoline	US \$ 705/ tonne	17.9	750	
Kerosene	US \$ 830/ tonne	20.4	856	
Domestic Natural Gas	US \$ 5306/million CFT#	5.6	234	
Imported Natural Gas	US \$ 5760/million CFT#	6.1	254	
LNG	-	8.7	364	
Thar Coal	US \$ 60/ tonne	3.15	132	
Imported Coal	US \$ 80/ tonne	2.90	121	

Calorific value of 950 BTU/CFT

	Overnight	Variable	Fixed	Plant	Construct.	Efficiency
Plant Type	Investment Cost (\$/kW)	O & M Cost (\$/kWyr)	O & M Cost (\$/kWyr)	Factor (fraction)	Period (Year)	(%)
Furnace Oil, (Steam)	1100	4.78	11.75	0.75	4	40.0
Combined Cycle	877	17.5	11.7	0.75	3	55.0
Combustion Turbine	604	27.2	10.5	0.25	2	35.0
Coal (Steam)	1923	39.4	27.5	0.75	4	38.0
Coal CCS*	2872	56.3	35.0	0.75	4	34.0
Nuclear, PWR	2700	4.2	66.0	0.80	6 , 5	33.0
Hydro	1500-2500	0	11.2	0.50	4-8	
Wind	1797	11	30.3	0.28	3	
Solar Thermal	5750	0	11.7	0.35	3	

* with carbon capture and storage

Load Curve Data for Electricity Demand

		Total			
Season	Night	Morning	Daytime	Evening	TOLAT
Winter1 (Jan-Feb)	3.62%	2.21%	5.09%	2.75%	13.66%
Spring (Mar-Apr)	4.38%	2.40%	5.58%	2.88%	15.24%
Dry Summer (May-Jun)	6.00%	3.14%	7.76%	3.52%	20.42%
Wet Summer (Jul-Aug)	5.96%	3.03%	7.49%	3.54%	20.02%
Autumn (Sep-Oct)	5.05%	2.58%	6.12%	3.26%	17.01%
Winter2 (Nov-Dec)	3.59%	2.18%	5.03%	2.85%	13.64%

Hydro Electricity Availability

	Winter1	Spring	Dry Summer	Wet Summer	Autumn	Winter2
%	7.7	8.4	20.6	28.3	23.3	11.5

Final Commercial Energy Demand of Pakistan

	200)7	2020		2030	
	MWyr	(000 TOE)	MWyr	(000 TOE)	MWyr	(000 TOE)
Electricity	8,300	5,922	17,421	12,428	35,433	25,279
Industry Fossil Fuel	18,501	13,199	38,395	27,392	96,197	68,629
Residential and Services Fossil Fuel	8,037	5,734	15,286	10,905	24,882	17,752
Transport Motor Fuel	13,777	9,828	22,863	16,311	42,524	30,337
Transport CNG	1,851	1,321	4,716	3,365	9,337	6,661
Feed Stocks (gas)	4,191	2,990	5,385	3,842	7,992	5,702
Feed Stocks (coke)	286	204	1,697	1,211	4,376	3,122
Non-Energy Oil	839	599	1,398	997	2,069	1,476
Total Commercial	55,784	39,797	107,160	76,450	222,810	158,957

Final energy demand is based on 6.5% average economic growth rate during the study period.

Scenarios					
	Hydro	Coal	Import of Natural Gas	Nuclear	GHG Emission Limit
Baseline	High	High	High	Medium	No limit
CaC	Same as in Baseline scenario.			Medium	Equal per capita emission to keep GHG at 450 ppmv level by the year 2050.
GIT	Same as in Baseline scenario.			Medium	GHG intensity reduction by 2% per annum
GITN	Same as in Baseline scenario.			High	Same as in GIT scenario

- CaC: Contraction and Convergence scenario
- **GIT: GHG Intensity Target scenario**
- GITN: GIT with high Nuclear scenario

Approaches Modeled in MESSAGE

Contraction and Convergence	The safer level of stabilization of GHG concentration is 450 ppmv by the year 2050. Beyond 2010, all countries would adopt the global pathway of equal per capita emissions which will converge to the level of 2.0 t CO_2 - eq per capita by 2050. A 450 ppm CO_2 -eq stabilisation target would be extremely demanding, requiring emissions of greenhouse gases to peak within the next few years followed by annual reductions of 6% or more. Average annual per-capita CO_2 -eq emissions would need to fall to around 2 tonnes by 2050 (WEO, 2008).
Intensity Target	Targets are in terms of reduction in GHG emissions per unit of GDP. A 2% to 4% decrease in global emission intensity per year on average is required if it is applied to all countries to reach stringent environmental goals.

Contraction and Convergence

 $\sum_{i=1}^{N} T(i) \times E(i) - POPL \times PCE \leq 0$

where for a certain year,

- N = number of technologies,
- T(i) = activity of technology (MWyr) emitting GHG,
- E(i) = emission factor (thousand tonnes CO₂-eq /MWyr)

POPL = population, (thousands),

PCE = Per Capita Emission, (tonnes/capita),

GHG Intensity Target

 $\sum_{i=1}^{N} T(i) \times E(i) \quad \neg \quad GDP \times GHG \text{ int } \leq 0$

where for a certain year,

- *N* = number of technologies,
- T(i) = activity of technology (MWyr) emitting GHG,
- *E*(*i*) = emission factor (thousand tonnes CO2-eq /MWyr)
- *GDP* = gross domestic product, real, (million US \$),

GHGint = GHG intensity, (tonnes/thousand US \$),

GHG Data used for the Approaches

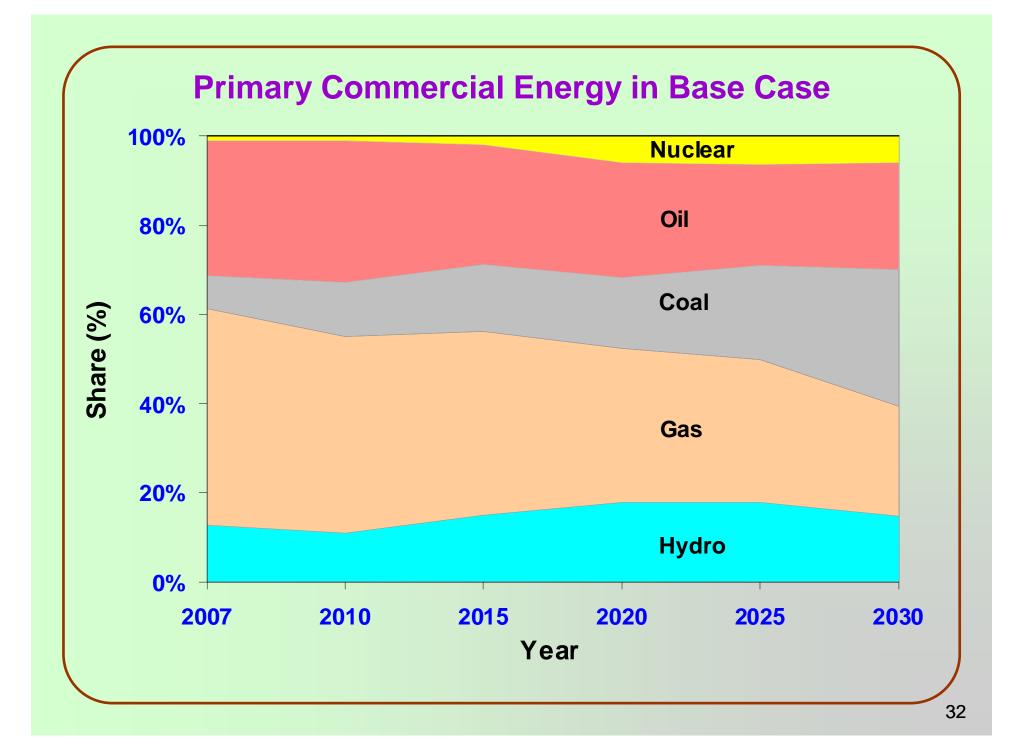
	Contra	ction and	d Converg	gence	GHG Intensity Targets					
			Path for Pakistan		(2% reduction per year)					
	Population				GDP (billion US \$)		GHG Intensity (Tonne of CO2-eq / thousand US \$)			
	(million)		Energy Related Emission (share)	Energy Sector (tonne/ capita)	Total	Excluding Agriculture	With Total GDP and Emissions	Excluding Non-energy emissions		
2007	158.2	5.32*	57.1%	3.04	136	106.5	1.8	1.33		
2010	166.1	5.32	57.4%	3.05	154	122.4	1.8	1.33		
2015	180.2	4.87	57.9%	2.82	202	163.3	1.7	1.23		
2020	195.4	4.00	58.4%	2.34	275	227.2	1.5	1.08		
2025	212.0	3.56	58.9%	2.10	390	329.0	1.4	0.93		
2030	230.0	3.17	59.4%	1.89	580	498.5	1.2	0.79		

* World data for the year 2004

Bounds on Additional Capacities for Electricity Generation (MW)

		2010	2015	2020	2025	2030	Total
Hydro	In all scenarios	265	4,549	8,758	5,732	6,103	25,407
Renewable (Wind)	In all scenarios	50	650	1,300	1,500	1,500	5,000
Renewable (Solar)	In all scenarios			20	30	100	150

Results of the MESSAGE Model



Energy Import Dependence

Share of energy imports in primary commercial energy would increase from the present 30% to about 35% in all the scenarios

New Installed Capacity in Base Case (MW)

	Hydro	Gas CC*	Coal	Nuclear	Ren. (Wind)	Total
2010	265	1,880	-	-	50	3,317
2015	4,548	285	1,200	600	-	6,633
2020	8,142	-	1,200	3,300	-	12,642
2025	6,348	-	4,956	2,000	-	13,305
2030	3,681	-	13,776	2,000	-	19,457
Total	22,984	2,165	21,133	7,900	50	55,354

* Combined Cycle

New Installed Capacity in Alternative Scenarios (MW)

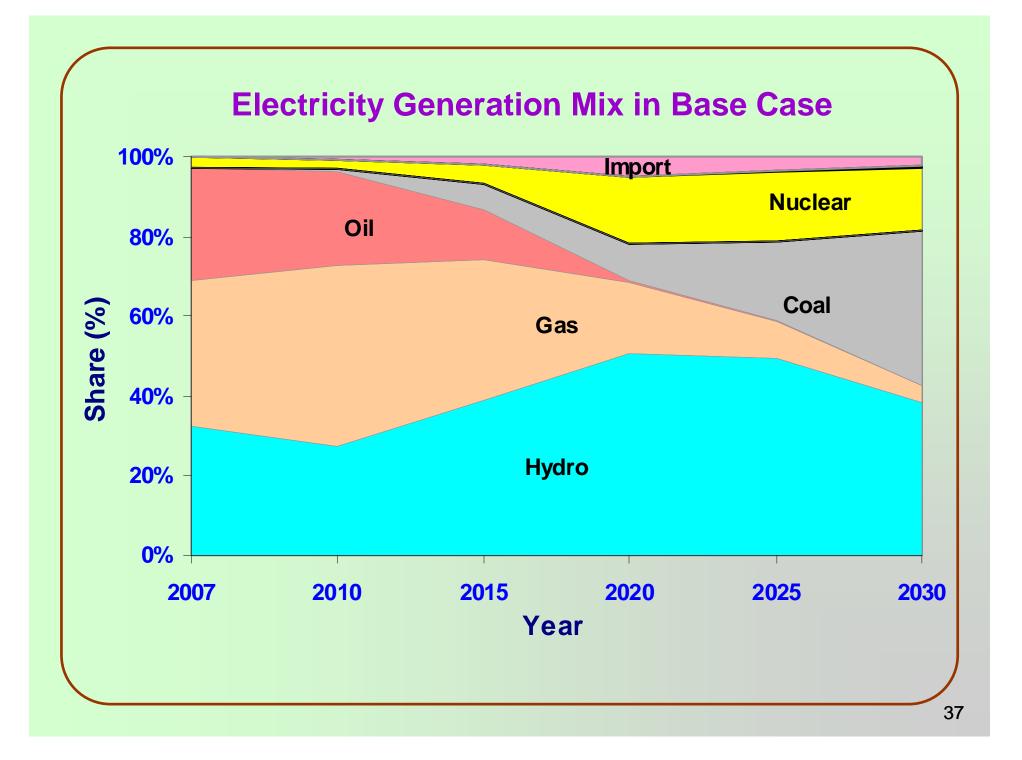
	0		Gas				Coal	Ren-	Tetel
	Scenario	Hydro	CC	Nuclear	Coal	Oil	CCS	ewable	Total
2010	Base	265	1880	0	0	1,122	0	50	3317
	CaC	265	1880	0	0	1,122	0	50	3317
	GIT	265	1880	0	0	1,122	0	50	3317
	GITN	265	1880	0	0	1,122	0	50	3317
2015	Base	4548	285	600	1200	0	0	0	6633
	CaC	4548	655	600	1200	0	0	0	7003
	GIT	4548	1961	600	1200	0	0	0	8309
	GITN	4548	1631	600	1200	0	0	0	7979
2020	Base	8142	0	3300	1200	0	0	0	12642
	CaC	7715	0	3300	1200	0	0	0	12215
	GIT	7595	0	3300	0	0	0	0	10895
	GITN	7595	0	3300	330	0	0	0	11225

(1/2)

New Installed Capacity in Alternative Scenarios (MW)

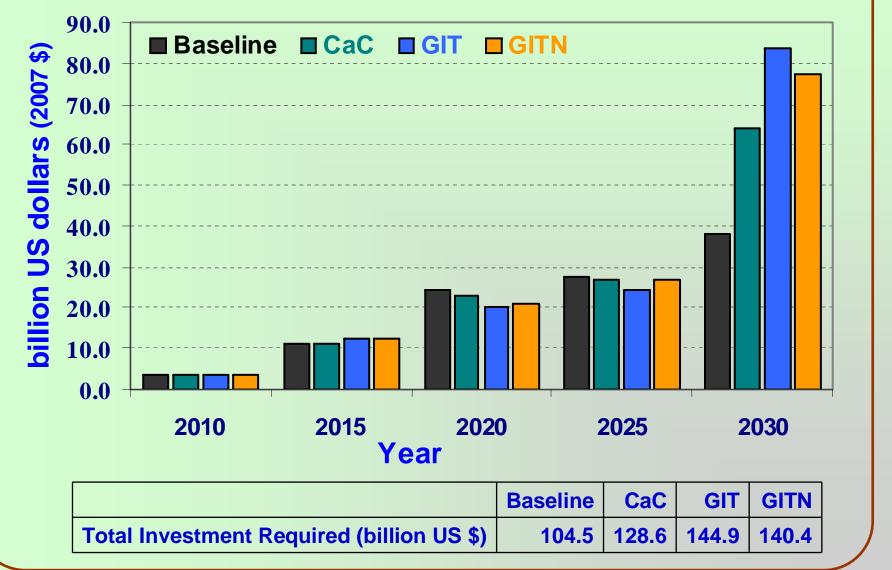
	Scenario	Hydro	Gas CC	Nuclear	Coal	Oil	Coal CCS	Ren- ewable	Total
2025	Base	6348	0	2000	4956	0	0	0	13305
	CaC	6775	0	2000	3813	0	0	0	12588
	GIT	6895	248	2000	2400	0	0	0	11543
	GITN	6895	0	4000	655	0	0	0	11550
2030	Base	3681	0	2000	13776	0	0	0	19457
	CaC	5853	0	2000	0	0	13148	4950	25951
	GIT	5853	0	2000	0	0	20101	4950	32904
	GITN	5853	0	4000	0	0	15834	4950	30637
Total	Base	22984	2165	7900	21133	1122	0	50	55354
	CaC	25156	2535	7900	6213	1122	13148	5000	61074
	GIT	25156	4089	7900	3600	1122	20101	5000	66968
	GITN	25156	3511	11900	2185	1122	15834	5000	64708

(2/2)



	Scenario	2007	2015	2025	2030
Hydro	Baseline	32.0	52.1	121.2	137.2
	CaC, GIT, GITN		52.1	121.2	137.2 146.1 14.2 4.9 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0
Gas	Baseline	35.8	47.6	22.5	14.2
	CaC		49.1	28.3	4.9
	GIT		55.5	43.9	0.0
	GITN		55.5	39.2	0.0
Oil	Baseline	28	16.6	0.6	0.0
	CaC		15.1	2.3	0.0
	GIT, GITN		8.7	3.9	0.0
Coal	Baseline	0.1	8.6	48.3	138.8
	CaC		8.6	40.8	40.8
	GIT		8.6	23.7	0.0
	GITN		8.6	14.4	0.0
Coal CCS	Baseline	0.0	0.0	0.0	0.0
	CaC		0.0	0.0	86.4
	GIT		0.0	0.0	132.1
	GITN		0.0	0.0	104.0
Nuclear	Baseline, CaC, GIT	2.3	6.7	43.2	57.2
	GITN		6.7	57.2	85.2
Renewable	Baseline	0.0	0.1	0.1	0.1
	CaC, GIT, GITN		0.1	0.1	12.3
Import	All	0.2	2.6	8.8	8.8
Total	All	98.4	134	245	356

Investment Cost in Power Sector



Investment Cost on Electricity Generation Technologies (billion US dollars of 2007)

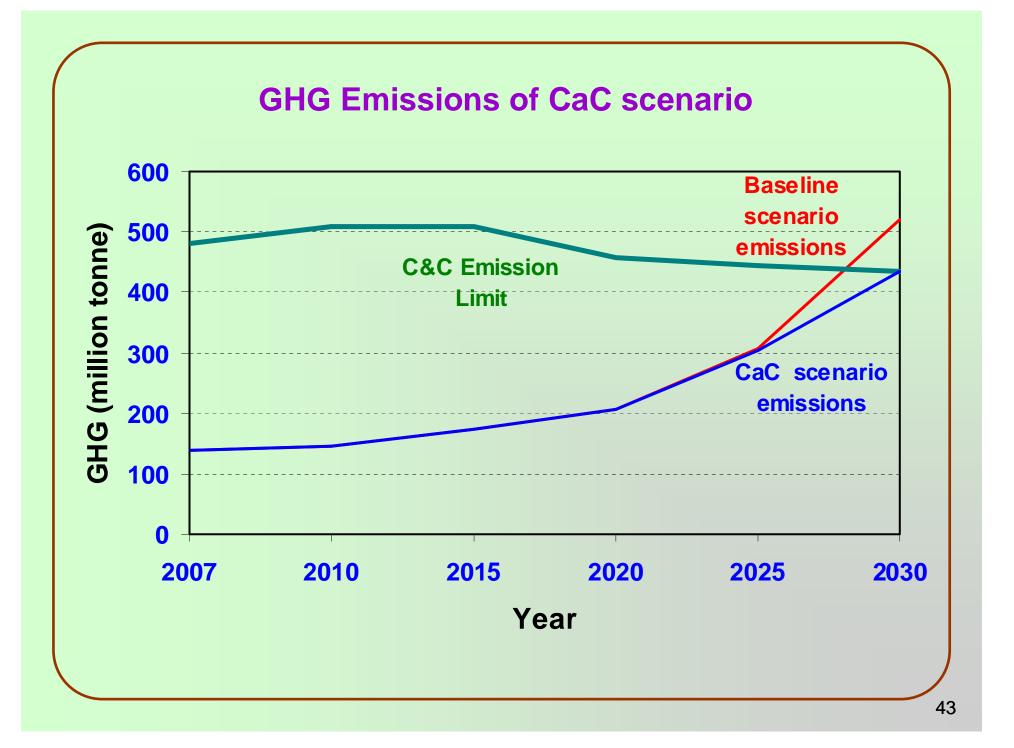
	GDP	Bas	eline	Ca	С	G	т	Gľ	TN
	(billion \$)	billion \$	GDP share	billion \$	GDP share	billion \$	GDP share	billion \$	GDP share
2010	154	3.6	0.8%	3.6	0.8%	3.6	0.8%	3.6	0.8%
2015	202	11.1	1.2%	11.4	1.3%	12.5	1.4%	12.2	1.4%
2020	275	24.3	2.0%	22.9	1.9%	20.3	1.7%	20.9	1.8%
2025	390	27.5	1.7%	26.8	1.6%	24.6	1.5%	26.6	1.6%
2030	580	38.0	1.6%	64.0	2.6%	84.0	3.5%	77.1	3.2%
Total		104.5		128.6		144.9		140.4	

GHG Intensity of Electricity Generation (grams of GHG /kWh)

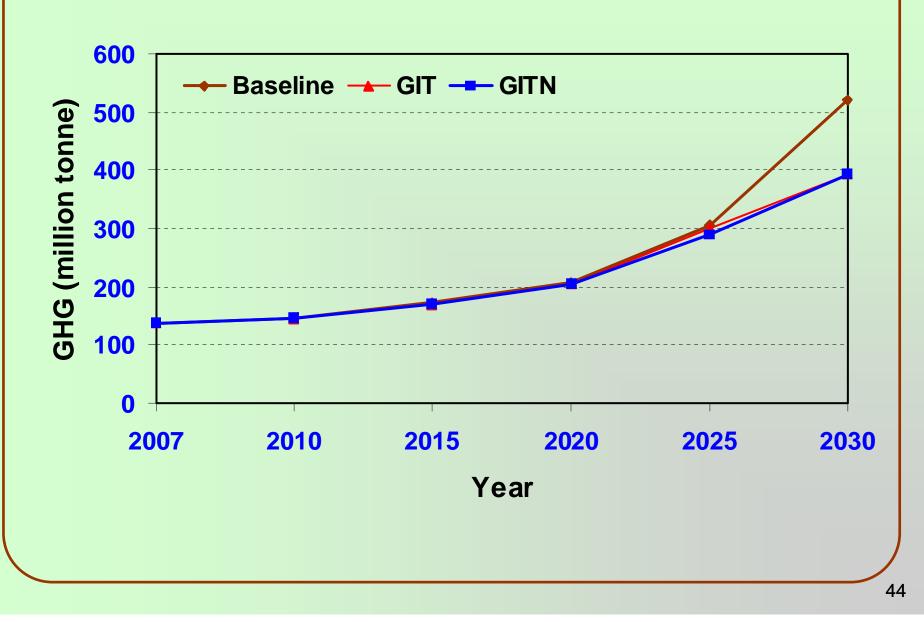
	Baseline	CaC	GIT	GITN
2007	450	450	450	450
2010	389	389	389	389
2015	307	304	291	292
2020	165	171	155	160
2025	205	194	168	130
2030	337	98	0	0

GHG Emissions from Energy Sector and GHG Intensity of Primary Energy

	Baseline		Ca	aC	G	IT	IT GI	
	GHG (million tonne)	Intensity (tonne/ TOE)	GHG (million tonne)	Intensity (tonne/ TOE)	GHG (million tonne)	Intensity (tonne/ TOE)	GHG (million tonne)	Intensity (tonne/ TOE)
2007	138	2.29	138	2.29	138	2.29	138	2.29
2010	145	2.22	145	2.22	145	2.22	145	2.22
2015	173	2.07	172	2.07	171	2.02	171	2.02
2020	206	1.73	207	1.74	205	1.72	205	1.73
2025	305	1.87	304	1.88	300	1.90	290	1.82
2030	521	2.31	435	1.90	394	1.73	394	1.73



GHG Emissions of CaC scenario



Electricity Generation Cost (cents/kWh) in Alternative Scenarios

	Baseline	CaC	GIT	GITN
2010	6.1	6.1	6.1	6.1
2015	5.3	5.2	5.1	5.1
2020	5.1	5.1	5.1	5.1
2025	5.7	5.7	5.6	5.6
2030	6.3	7.1	7.5	7.3

GHG Abatement Cost of Power Sector during 2025-30

	Baseline	CaC	GIT	GITN
Power sector emissions (million tonnes)	120	35	0	0
System generation cost (million US \$*)	22,067	24,840	26,192	25,293
GHG mitigated (million tonnes)		85	120	120
Additional generation cost (million US \$)		2,769	4,121	3,223
GHG abatement cost (US \$/tonne CO ₂)		32.5	34.3	26.9
Carbon abatement cost (US \$/tonne C)		119	126	98

* Dollar of 2007.

Conclusions and Recommendations (1/3)

➡ For the economic development of Pakistan at 6.5% per year, the expansion of energy and electricity system will require the maximum exploitation of indigenous energy resources i.e. hydro, oil, natural gas, coal and nuclear to keep import dependence at level of one-third of the total energy supply.

➡ The contraction and convergence (C&C) approach requires about 84% of the electricity generation capacity on carbon free or low carbon energy technologies (hydro, nuclear, wind, coal CCS) by 2030 to achieve the global objective of keeping GHG concentration at 450 ppmv by 2050. It will involve additional investments of US dollar 24.1 billion and increase annual electricity generation cost by US dollars 2.77 billion in 2030.

The GHG stabilization level at 550 ppmv by 2050 with C&C approach, will soften the limit of GHG emission for hardly a few years. In case of low to medium development of indigenous energy resources, utilization of wind and coal CCS technologies would be required during 2025-30.

Conclusions and Recommendations (2/3)

➡ GHG Intensity target approach with even 2% per annum reduction in GHG intensity needs whole of the electricity generation from carbon free or low carbon technologies by the year 2030.

- The total investment cost is increased by US dollars 40.4 billion for capacity additions on coal CCS and wind during the last period.
- ii. The annual electricity generation cost would be increased by US dollars 4.12 billion in 2030.
- iii. Additional 4,000 MWe nuclear capacity in the GHG intensity reduction approach, would save US dollars 4.5 billion in the total investments for power capacity additions and US dollars 0.9 billion in the annual cost for electricity generation by 2030.

Conclusions and Recommendations (3/3)

➡ Freezing of nuclear based capacity in the power generation system of Pakistan increases the GHG intensity of electricity generation in the range of 98 - 130 grams/kWh during the period of 2020-30 and annual generation cost of the system is increased by US dollars 0.31 billion annually by 2030.

➡ The carbon abatement costs of the two climate protection approaches is in the range of US dollars 32 - 34 per tonne of CO2 (US dollars 119 - 126/tC) in 2030.

In long term, GHG mitigation under these approaches can only be committed if the Annex-I Parties to UNFCCC support Pakistan financially and through effective transfer of clean technologies including the nuclear power plants.

Thank You