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Greenhous Gas Emissions and Electricity Generation Technologies: Some Emerging Trends

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Abstract – *This paper develops – for a select, yet significant group of countries – a panoramic overview of the changes in the electricity generation technology-fuel-mix, in the backdrop of emerging concerns about global warming and the contribution of the electricity industry to such warming. This overview is based on extended case studies developed by individual country experts, as part of a research project undertaken under the aegis of the International Atomic Energy Agency (United Nations). Each case study essentially employs a technological optimization model (for example, MESSAGE), driven by a range of scenarios that reflect the technological, economic and policy positions under consideration by various countries. The results of such studies are then contextualized in this paper, and supplemented with additional analyses, in order to draw broader inferences. The analyses suggests that over the next twenty years or so, there is likely to be a significant transformation in the electricity technology (fuel) landscapes across all countries, especially the BRIC group of countries. Broad contours of such a transformation are likely to include continuing dominance by thermal electricity especially coal; increased gas-based capacity, yet lower than expected share of gas-based electricity due mainly to its appropriateness as a peaking fuel - thus raising questions about the 'dash-for-gas' argument; small yet noticeable decline in the share of hydro-electricity, suggesting continuing influence of environmental considerations of large hydro-electric projects and the conflicts between the use of water resources for irrigation and electricity generation; rapid increase of nuclear-based capacity and generation, reflecting its appropriateness as a reliable base-load source of electricity in a carbon constrained world; and the lower than expected contribution from small-scale renewable technologies, due to the intermittency of their availability, and the historic institutional biases. The analysis also foreshadows the challenges faced by the policy makers in terms of establishing, in a timely manner, the necessary institutional and regulatory mechanisms that are capable of accommodating such technological transformation.*

Keywords – CO_2 mitigation, electricity generation technologies, emerging trends comparisons.

1. INTRODUCTION

Global warming is currently a major environmental challenge for humanity. Carbon dioxide (CO_2) is the dominant greenhouse gas (GHG), contributing more than 70 percent to the global GHG emissions. Electricity production is the single largest source of CO_2 emissions, responsible for nearly 40 percent of the total CO_2 emissions. This is primarily due to the overwhelming reliance by the electricity sector on fossil fuels, especially coal. For example, currently coal accounts for approximately 30 percent of the world's electricity generation capacity and 40 percent of electricity generation [1].

In the absence of any significant transformation in the electricity technology-fuel-mix in the coming years, coal is expected to continue to occupy a central place in the electricity-economy complex. For example, the share of coal-based electricity is expected to increase to 44 percent by 2030, as the world contemplates an addition of nearly 4800GW of additional capacity in order to meeting an expected 76 percent growth in electricity demand over this period [2]. Further, by the year 2030, CO_2 emissions are expected to increase by 40 percent, with electricity contributing more than 60 percent to this increase [3].

Notwithstanding some uncertainties and discord that surround the global warming debate, there is a wide consensus on the enormity of the GHG challenge, and hence the unsustainability of such high levels of CO_2 emissions from the electricity sector. Any reduction in CO_2 emissions from the electricity sector will however require substantial shifts in the electricity technology and fuel choices by nations. This is likely to be a challenging task as such choices are inextricably intertwined with a complex web of local and global imperatives and agendas of sovereign nations, often entailing complex socio-political and geo-strategic tradeoffs.

Against this backdrop, the International Atomic Energy Agency (IAEA) implemented a three year (2006-2009) project, with participation from a select group of IAEA-member states – Australia, Argentina, Brazil, Bulgaria, China, Cuba, Korea, Germany, India, Lithuania, Pakistan, Romania, Russia and Syria. This project aimed to assess the shifts in electricity technology-fuel-mix being contemplated by these countries in the context of global climate change debate. An express objective of this project was to encourage

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the member states to undertake policy-useful analysis that could assist them to make informed decisions on technological choices for evolving their electricity systems.

This paper provides a summarized overview of the above noted assessments carried out by individual countries. A particular emphasis is placed in this paper on developing a panoramic profile of the broad contours of the changes in the technological landscape envisioned by these countries. While much of the analyses in this paper have been drawn directly from individual country studies, they have been supplemented with additional information for the purposes of completeness and global contextualization.

2. THE CASE STUDY CONTEXT

As contextual backdrop, this section of the paper provides a brief overview of the key lineaments of each country study - its economic-electricity-environmental settings, focus and scope, scenarios, and analytical methodologies (models) employed for analyses.

2.1 Economy-Energy-Environmental Settings

Select economic, energy and environmental features of the countries considered in this paper are provided in Table 1. These features are also provided for the OECD and non-OECD countries and the World at large, in Table 2 - in order to facilitate international comparisons and enhance appreciation for the arguments presented in this paper. A review of these tables, supplemented with additional information, suggests that these countries represent a considerably wide range of attributes in terms of:

- economic advancement, for example, Germany with a per capital income, in 2005 prices, of $50K as compared with Korea ($20K), Bulgaria ($8K), and India ($3K);
- resource endowments, for example, resource-rich Russia and generally resource-deficient China and India;
- industrialization, for example, newly industrialized (Korea) in contrast with fast industrializing (Pakistan);
- population, for example, China and India with over one third of the world population, and Lithuania, with a small fraction;
- CO_2 emissions – China and India as large emitters as compared with Argentina – a relatively benign emitter;
- geographic-historic backdrop, for example, Syria with its middle-eastern alignment to a non-aligned India;
- per capita electricity consumption, for example, 0.6MWh for India, and 2.1MWh for China, as compared with the World (2.6MWh) and OECD (8.4MWh);
- fossil-fuel dependence, from an overwhelming dependence (China and India), to a modest dependence (Brazil); and
- institutional structures and governance arrangements, from an institutionally robust, market-attuned Germany, to institutionally evolving, mixed economy (China), to a centralized economy (Cuba).

Clearly, the countries included in this paper differ considerably in their demographic, economic, energy and environmental backgrounds. Collectively however they constitute a perceptibly representative group. For example, these countries account for nearly 40 percent of the world population; 28 and 75 percent of the world and non-OECD electricity generation capacity; and 34 and 27 percent of the world GHG and CO_2 emissions, respectively (see Table 2). A comparative analysis of technological trends in these countries in a carbon constrained world should therefore be instructive, not least from the point of view of understanding the relative positions taken by these countries in the international dialogues on policy strategies to redressing the climate change challenge.

2.2 Scope, Focus and Scenarios

The salient features of the scope and focus of each study is presented in Table 3. A review of this table suggests that while there are apparent differences in the time-frame for analysis, sectoral coverage and the focus across the case studies, each study essentially analyses the likely long-term (extending typically to the year 2030) impact on GHG emissions of alternative energy supply options, in particular electricity generation options.

In contrast, the differences in the scenarios across the countries are rather stark, due mainly to the differences in the underlying assumptions about economic growth, energy demand, energy supply options, and the nature, and the extent and pace of technological transformation envisaged in the electricity sector. These assumptions essentially reflect individual country perspectives on economic growth, enormity of environmental challenge, international commitments, and policy options and strategies to deal with the environmental challenge – moderated by the considerations of energy security, resource endowments, domestic imperatives and geo-strategy. For example (see Table 4 for details):

Table1. Select economic, energy and environmental features of the IAEA-CRP countries (2005).

	Argentina	Brazil	Bulgaria	China	Cuba	Germany	India	Korea	Lithuania	Pakistan	Romania	Russia	Syria
Per capita Income [a] (US$000)	11	9	9	4	7	30	2	23	14	2	9	12	4
Per capita Electricity (MWh)	2.7	2.6	5.5	2.1	1.4	7.1	0.6	8.1	4.6	0.6	2.7	6.5	1.8
Electricity Capacity (GW)	28	106	12	443	4	119	137	72	5	19	20	217	8
GHG Emissions (Gt)	0.3	1.9	0.06	7.5	0.05	0.85	2.4	0.6	0.2	0.33	0.13	2.2	0.07
CO_2 Emissions (Gt)	0.07	0.4	0.05	5.4	0.03	0.79	1.2	0.49	0.01	0.15	0.09	1.5	0.05

Notes: 1.[a] at 2005 constant prices
Sources: Various, including [4] to [17]

Table 2. Economic, energy and environmental settings: a global overview (2005).

	World	OECD	Non-OECD	Countries IAEA-CRP		
				Range	% of World	% of Non-OECD
Per capita Income [a] (US'000)	8.5	26.1	4.6	2-20	-	-
Electricity/ capita (MWh)	2.6	8.4	1.3	0.4-7.8	-	-
Electricity capacity (GW)	3800	2400	1400	1202	28	75
GHG Emissions (Gt)	43	17	26	16	37	61
CO_2 Emissions (Gt)	32	13	18	11	34	61
Electricity Consumption (10^3TWh)	23.2	12.86	10.34	6.26	27	60

Notes: 1.[a] at 2005 constant prices
Sources: Various, including [1], [2],[3],[17], Table 1(above)

Table 3. Scope and focus of country case studies: salient features.

Country	Time frame	Sectoral coverage	Focus
Argentina	2006-2025	Electricity, Transport sector	Impact of GHG mitigation under alternative energy supply mix, electricity generation, and transport constraints
Brazil	2010-2030	Electricity sector	Strategies to mitigate GHG emissions in the power sector under a ‘carbon tax’ scheme and ‘energy compensation mechanism’
Bulgaria	2007-2050	Energy, Electricity, Transport sector	Impact of plausible post -Kyoto approaches on energy, electricity and transport sectors
China	2006-2030	Energy sector	Assessment of energy policies and energy options under climate change strategies
Cuba	2006-2030	Energy sector	Assessment of GHG mitigation, energy options, and climate change costs for Cuba
Germany	2010-2030	Energy, Electricity sector	Impact of energy supply, electricity supply, and GHG emissions under climate change restrictions and the phase-out of nuclear power
India	2005-2035	Electricity sector	Estimation of energy demand and supply under specified GHG constraints
Korea	2008-2030	Electricity sector	Impact of GHG mitigation in the electricity sector under a set of plant specification scenarios
Lithuania	2005-2020-2050	Energy sector	Analyse GHG emission projections under various emission reduction sectors (‘with measures’ and ‘without measures’) in Lithuania
Pakistan	2007-2030	Energy sector	Assess energy options for alternative GHG mitigation strategies
Romania	2008-2020	Electricity sector	Estimation of electricity production and CO_2 emissions under the Romanian ‘Laws and Directives’ and environmental constraints
Russia	1990-2020	Electricity sector	Role of nuclear power as GHG mitigation options
Syria	1999-2030	Energy demand, Electricity sector	Analyse energy demand and identify optimal expansion plan for the supply of energy and electricity under environmental constraints

Sources: Various, including [4] to [16]

Table 4. Country scenarios: salient features.

Country	Scenario Parameters
Argentina (2005-2025)	BAU - 5% annual increase in electricity demand - 5.4% share of renewable energy by 2016 - 7% (750 MW) share of nuclear power by 2025 - hydro power dominating (~1700-2500MW, or 30% share) electricity capacity expansion Mitigation - Reduced annual increase in electricity demand (4.1%), achieved through rational use of electricity - higher penetration of hydro (2800MW or 33% of total capacity), nuclear (10%) and renewables (7%) share)
Brazil (2005-2030)	BAU - annual growths: GDP (4%), population (1.1%) - renewables (4%), underpinned by increased share of hydro, from 74% in 2010 to 78% in 2030 - increase in nuclear capacity, from 1.96 to 3.31GW - improved carbon intensity, from 110 to 104 gCO_2 eq./KWh) Alternative - annual growths: GDP (4%), population (1.09%), electricity demand (2.7% to 2020, 2% to 2040, and 1% thereafter), resulting in a 80% share of hydro - 83% (191GW) of total hydro potential tapped - ANGRA III Nuclear commissioned in 2014 and also 2 more 1000MW nuclear plants, raising nuclear capacity in 2030 to 4.31GW - shares of small hydro, wind and biomass increase annually by 4%, reaching 12% by 2030, with small hydro (4.2%), biomass (5.8%), and wind (2%) - carbon intensity in 2030 ~ 78gCO_2 eq./KWh - introduction of a carbon tax (~$26/MWh) as a GHG penalty
Bulgaria (2006-2030)	BAU - No CO_2 restrictions Absolute Binding Target (ABT) - Absolute binding targets of 20% and 30% reduction of GHG from 1988-levels by 2020 and 2030, respectively - Emission prices 10-60 Euro/ton to buy and 8-57 Euro/ton to sell Dual Target (DT) - Ranges for CO_2 reductions of 5-15% and 15-25% from 1988-level by 2020 and 2030, respectively - Emission prices 30 Euro/ton to buy and 28 Euro/ton to sell Price Cap (PC) - Binding targets of 20% and 30% reduction of GHG from 1988-levels by 2020 and 2030, respectively - Price cap ranges between 20-40 Euro/ton Carbon Taxes - Carbon tax ranges between 10-30 Euro/ton
China (2006-2030)	BAU - no major new policy - high rate of increase in energy demand - electricity capacity by 2030: nuclear (40GW, by 2020 and 60GW by 2030), wind (50GW), large-scale hydro (270 GW) and small-scale hydro (75GW) - promotion of energy conservation, solar energy, clean-coal technologies, and - development of highly efficient supercritical and ultra-supercritical coal-fired power technologies, and termination of small-scale coal-fired power units Alternative Policy Scenario (APS) - Diversify energy resources, improve efficiency and move economy away from high energy intensive activities - higher shares of renewable and nuclear energy as compared to BAU - electricity capacity by 2030: nuclear power (100GW), wind (80GW), large-scale hydro (300GW) and small-scale hydro (100GW) Emission Restricted Scenario (ERS) - restrict carbon emission factor to the world average level (134 and 110 g-c/Kwh, by 2020 and 2030, respectively)
Cuba (2006-2030)	BAU - Addition, by 2010, of 5MW of windpower and 295MW of gas turbines and combined cycle plants - closure of 460MW of existing fossil fuel units (small and large) by 2010 - promotion of bagasse for electricity production (target ~ 10.5 million tonnes of bagasse) Mitigation 1 (Increased Renewable) - increased emphasis on improving bagasse plant efficiency - introduction of biomass gasification and solar energy - utilization of entire wind (1200MW) and hydro potential (360MW) Mitigation 2 (Increased Nuclear and Low-carbon fuel)

Table 4. Country scenarios: salient features.

Country	Scenario Parameters
	- improved efficiency of gas-fired electricity generation - 220MW of nuclear power by 2020 - 85 to 95% reduction in CO_2 emissions from carbon capture and storage
Germany (2005-2030)	Reference - No specific GHG mitigation policies - Phase-out of nuclear power Preference Renewable Energy (PEE) - emission reduction targets of 21, 40 and 50% by 2010, 2020 and 2030, respectively - 30% share of renewable in electricity generation mix by 2030 - phase-out of nuclear power - no CCS Low Coal Use (CKN) - PEE emission reduction targets - introduction of CCS to reduce CO_2 emissions phase-out of nuclear energy Efficient Resource Use (ER) - PEE emission reduction targets - cost-efficient achievement of reduction goals ER: Extended Nuclear (ER-L) - ER with lifetime extension of nuclear plants ER: New Nuclear (ER-N) - ER with new nuclear plants
India (2005-2030)	BAU - 8% GDP growth per annum - 20 GW of nuclear and 45 GW of renewables Low Growth - 6% GDP growth per annum - BAU parameters High Growth - 10% GDP growth per annum - BAU parameters High Nuclear - BAU GDP growth 8% per annum - Increased penetration by nuclear: 6.8, 14, 55 and 63GW by the years 2012, 2017, 2027 and 2032, respectively High Renewables - high penetration of renewables: wind(45GW), small-hydro (10GW), solar (8GW) and biomass (8GW) – by the year 2035
Korea (2005-2030)	BAU - 2.3% annual increase in GHG emissions to the year 2030 - LNG, combined-cycle, coal-fired, and nuclear – major future technologies BAU- 20 - BAU with a $20 carbon tax IGCC/MEA - IGCC power plants with MEA IGCC/MEA-20 - IGCC/MEA with a $20 carbon tax
Lithuania (2005-2020)	ZK1 - new nuclear capacity: upto 500MW by 2015 and upto 1000MW thereafter - average growth in energy demand ZK2 - ZK1's share of nuclear - faster growth in energy demand and average growth in fuel prices ZK3 – Minimal - new nuclear capacity: 500MW in 2015, and 1000MW in 2018 - average growth in energy demand ZK4 - ZK3's share of nuclear - faster growth in energy demand ZK5 - no new nuclear capacity - replacement of natural gas with oil - faster growth in energy demand AK1 - new nuclear capacity: same as for ZK3

Table 4. Country scenarios: salient features.

Country	Scenario Parameters
	- average growth in energy demand but high fuel prices AK2 - new nuclear capacity: same as ZK3 - faster growth in energy demand and high fuel prices AK3 - Maximal - no new nuclear capacity - faster growth in energy demand and high fuel prices
Pakistan (2005-2030)	Baseline - no GHG emission limits - high coal, (imported) natural gas and hydro; medium nuclear Contraction and Convergence (CAC) - high coal, (imported) natural gas and hydro; medium nuclear - all developing countries participate in quantified Kyoto targets - per capita emissions to converge to 2 tonne CO_2-e consistent with 450-ppmv of GHG by 2050 - all UNFCCC members to adopt this approach after 2012 (post-Kyoto period) - high coal, (imported) natural gas and hydro; medium nuclear GHG Intensity Target (GIT) - high coal, (imported) natural gas and hydro; medium nuclear - 2 to 4% per annum reduction in GHG intensity (GHG/GDP) for all UNFCCC members after 2012 GHG Intensity With High Nuclear (GIT-N) - GIT, with increased in nuclear capacity (4,000MW) between 2010 and 2030; hydro, coal and natural gas – as for the baseline scenario - reduction in GHG intensity - as for the GIT scenario
Romania (2005-2020)	Reference - Business as usual Nuclear - increased contribution by nuclear capacity after 2015 Wind Power - 3GW of wind power by 2015 Hydro - 1.23GWof hydro power by 2020
Russia (2005-2030)	Scenario 1 - 6% growth in GDP per annum - 4% reduction in energy intensity per annum - 1.2% increase in energy consumption per annum Scenario 2 - 4.2% growth in GDP per annum - 3% reduction in energy intensity per annum - 1.2% increase in energy consumption per annum Scenario 3 - 6.4% growth in GDP per annum - 4.4% reduction in energy intensity per annum - 2% increase in energy consumption per annum
Syria (2005-2030)	Reference - no CO_2 constraint and no carbon tax - increased contribution by nuclear after 2020 – nearly one nuclear plant every 5 years - a minimum 15% reserve margin in electricity generation Alternative Renewable Supply - increased share of renewable sources in electricity generation mix - 1% by 2010, and 10% in 2030, with solar contributing 10% by 2030 - increase emphasis on hydro and wind – as substitutes for oil and natural gas

Sources: Various, including [4] to [16]

- The Argentinian case study envisages CO_2 emissions reductions primarily from the electricity and road transport sectors. Two scenarios are considered, namely, Business-as-Usual (BAU) and Mitigation. For the electricity sector, the BAU Scenario assumes a 5 percent annual increase in electricity demand to the year 2025, a 55 percent share for thermal (predominantly, natural gas-based) electricity, a 5.4 percent share for renewable electricity by 2016, and 7 percent nuclear electricity by 2025, and domination by hydro (~ 1700-2500MW or 30 percent share) in the electricity capacity expansion programme. The Mitigation Scenario, on the other hand, assumes a reduced growth in electricity demand (4.1 percent annually) achieved mainly through rational use of energy, and increased penetration by hydro (2800MW or 33 percent share – mainly at the expense of coal and oil), nuclear (10 percent), and renewable (7 percent). For the transport sector, this scenario envisions significant modal shifts in road transport.
- Two scenarios are considered for Brazil, namely, BAU and Alternative. The BAU Scenario assumes no specific mitigation policy or measures to reduce CO_2 emissions whereas the Alternative Scenario considers a carbon tax of $26/MWh, increased share of hydro (from 74 percent in 2010, to 78 percent in 2030), and an appreciable reduction in carbon intensity (from 110 to 78 gCO_2 eq./KWh).
- The Bulgarian case study considers five scenarios, differentiated by targets for CO_2 emissions (ranging between 20 and 30 percent of 1988 levels), achieved essentially through a combination of emission prices (10 to 60 Euros/ton), price caps (20 to 40 Euros/ton), and a carbon tax (10 to 30 Euros/ton).
- In the case of China, the BAU, Alternative Policy Scenario (APS), and Emissions Restricted Scenario (ERS) seek CO_2 emissions reduction through increased shares of nuclear, wind and hydropower; introduction of clean-coal technologies; and restriction (in ERS) of carbon emission factor to the world standards (~ 134 and 110 g-c/KWh, by 2020 and 2030, respectively).
- The Cuban case study, underpinned by an expected annual economic growth of 5.9 percent to the year 2030, envisions – for the BAU - an additional capacity of 5MW of windpower, 295MW of gas and combined-cycle plants, a closure of 460MW of existing small and large fossil-fuel plants, and substantially increased use of bagasse for electricity production. The Mitigation (Increased Renewable) Scenario emphasizes improved efficiency for bagasse-based electricity production, introduction of biomass gasification and solar energy, and the utilization of the country's entire wind and hydro power potential. The Mitigation (Nuclear and Low-carbon fuel) Scenario proposes an addition of 220MW of nuclear power by 2020, and 85 to 95 percent reduction in CO_2 emissions from CO_2 capture and storage.
- The BAU Scenario for Germany represents no specific GHG mitigation policies and a continuation of the existing policy of a phase-out of nuclear power. The Preference Renewable Energy (PEE) Scenario sets CO_2 emission reduction targets at 21, 40 and 50 percent by 2010, 2020 and 2030, respectively – proposed to be achieved mainly through an increased share (30 percent) of renewables in electricity generation-mix. It also assumes a phase-out of nuclear capacity and no carbon capture and storage is planned. In the Low Coal Use (CKN) Scenario, while CO_2 emission targets and nuclear phase out policy is the same as in the PEE Scenario, CO_2 emission reductions are achieved through recourse to carbon capture and storage. The Efficient Resource (ER) Scenario proposes to reduce CO_2 emissions through extension of the lifetimes of existing nuclear plants (in the ER-L Scenario), and addition of new nuclear plants (in the ER-N Scenario).
- The BUA Scenario for India assumes an annual GDP growth of 8 percent the year 2035, and 20GW of nuclear and 45GW of renewable energy by that year. The Low-Growth and High-Growth scenarios assume 6 and 10 percent annual GDP growth rates, respectively. And, the High Nuclear Scenario visualizes 63GW of nuclear capacity by 2032, and the High Renewable Scenario – 71GW of renewable capacity by 2035, comprising wind (45GW), small-hydro (10GW), solar (8GW), and biomass (8GW).
- The BAU Scenario for Korea considers a 2.3 percent annual increase in GHG emissions to the year 2030. LNG Combined Cycle, nuclear and renewable (5 percent of total electricity by 2011, and 9 percent by 2030) are contemplated as the major technologies for reducing CO_2 reduction in the long-term. The other scenarios include: BAU-20 (BAU, with a $20 carbon tax), IGCC/MEA (IGCC power plants with MEA), IGCC/MEA-20 (IGCC/MEA technology, with a $20 carbon tax).
- The Lithuanian case study essentially focuses on analyzing the role of nuclear energy in alternative conceptions of post-Kyoto mitigation architectures, namely, Continuing Kyoto (acceptance of binding emission reduction targets), Multi-stage Approach, Multi-Sector Convergence Approach (involving binding emission reduction targets and convergence, over specified time, to equal per-capita emissions), Triptych Multi-Sector Approach (sharing, by country groupings, of emission allowances based on sectoral considerations, e.g., power sector, energy-intensive industries), Brazilian Proposal (sharing of emission reductions in accordance with historic contributions, and impacts on surface temperature changes), and Commitment to Human Development with Low Emissions (underpinned by distinction between

basic and luxury goods and associated emissions). Various scenarios considered in this case study include varying levels of growth in energy demand (average or fast), prices (average or high) and the share of nuclear (new capacity or no new capacity), for example, the ZK1 Scenario assumes average growth in electricity demand, and the addition of upto 500 and 1000MW of new nuclear capacity by 2015 and subsequently, respectively. Similarly, the AK3 Scenario envisages a fast growth in energy demand but no further additions to nuclear capacity.

- The Baseline Scenario for Pakistan assumes high contributions from hydro, coal, and (imported) natural gas-based electricity capacities; a medium contribution by nuclear capacity; and no specific GHG emission limits. The Contraction and Convergence (CAC) Scenario, with the same reliance on electricity technologies as the Baseline Scenario, expects that all developing countries will participate in quantified Kyoto targets, and that per capita emissions will converge to 2 tonnes of CO_2-e (consistent with 450-ppmv of GHG) by 2050, and that all UNFCCC members will adopt this approach after 2012 (post-Kyoto period). The GHG Intensity (GIT) and GHG Intensity With High Nuclear (GIT-N) scenarios envisage a 2 to 4 percent reduction in GHG intensity (i.e., GHG per unit of GDP) with a medium contribution by nuclear (in the GIT Scenario) and a high contribution (~4GW) in the GIT-N Scenario.
- The Romanian Reference Scenario assumes no specific GHG reduction limits or policies, and the preservation of the existing status quo in terms of the shares of various electricity generation technologies. The Nuclear Scenario however assumes increased contribution by nuclear after the year 2015. The Wind scenario assumes 3GW of wind capacity by 2015. A 1.23GW of hydro capacity, by 2020, is considered for the Hydro Scenario.
- The three Russian scenarios assume 6, 4.2 and 6.4 percent annual economic growth rates; 4, 3 and 4.4 percent annual reduction in energy intensities; and 1.2, 1.2, and 2 percent increase in annual energy consumption, respectively.

The Reference Scenario for Syria considers no CO_2 constraints or tax, and an addition of one nuclear plant every five years after 2020, while ensuring a minimum reserve margin of 15 percent of electrical capacity. The Alternative Renewable Supply Scenario assumes increased share of renewables – 1 percent by 2010, and 10 percent by 2030, supported by a 10 percent share of solar energy in the overall thermal energy-mix. The other priority renewable technologies include hydro and wind – primarily as replacements for oil and natural gas.

2.3 Modelling Approaches

Table 5 provides an overview of the main modeling approaches employed in various case studies. A review of the table suggests that the IAEA's MESSAGE model is the core modeling approach adopted by various countries in order to determine the respective shares of various electricity generation technologies and fuels. The MESSAGE model belongs to a group of models that provide a complete representation of the entire energy system in a country (or region) in terms of its interdependencies and interrelationships. It associates each end-use energy type to a primary energy resource through a system of intermediate processes, for example, distribution, conversion, transport, extraction, etc. It requires the specification of technologies associated with these processes in terms of their technical, economic and environmental characteristics. The model is driven by exogenously specified end-use energy demands and it seeks to determine, through a process of typically linear-programming-based optimization algorithm, the most efficient combination of technologies and fuels to satisfy end-use demands – subject to a set of pre-specified policy and technological constraints generally embedded in the case study scenarios (as discussed in the previous section).

Table 5 shows that all countries (expect Germany, Korea and Romania) have based their analysis on MESSAGE-based modelling approaches. The German case study employed MARKAL-TIMES – another model that belongs to the same genre of (network models) as MESSAGE. The Korean and Romanian case studies are based on the application of WASP model. This model focuses exclusively on the analysis of the electricity systems (i.e., it ignores a detailed consideration of the links between electricity and energy system) and determines the minimum cost manner of meeting electricity needs in the short, medium and longer terms.

Further, all countries in this paper (except Argentina, Cuba and Syria) have assumed energy (electricity) demand to be exogenously given. Argentina, Cuba and Syria have instead used the MAED model to specifically forecast energy demand. The Argentinean case study has additionally employed the Kaya Identity to analyze CO_2 emission trends over the period 1970-2025. (The Kaya Identity relates CO_2 emissions to carbon intensity, energy intensity, GDP/capita and population).

Table 5. Modelling approaches: an overview.

	Argentina	Brazil	Bulgaria	China	Cuba	Germany	India	Korea	Pakistan	Romania	Russia	Syria
Energy demand analysis	MAED				MAED				MAED			MAED
Primary energy supply mix	MESSAGE			MESSAGE	MESSAGE	TIMES-D	MESSAGE		MESSAGE			MESSAGE
Capacity additional mix		MESSAGE	MESSAGE		MESSAGE			WASP-IV	MESSAGE	WASP		MESSAGE
Electricity generation mix	MESSAGE		MESSAGE	MESSAGE	MESSAGE	TIMES-D	MESSAGE	WASP-IV	MESSAGE	WASP		MESSAGE
GHG emissions	Laspeyres			MESSAGE	MESSAGE	TIMES-D			MESSAGE			MESSAGE
Climate change cost					FUND							

Sources: Various, including [4] to [16]

Table 6. Summary of total generating capacity in the IAEA-CRP countries.

		Capacity (GW)								
		Total	TH		H		N		Oth	
		(GW)	(GW)	(%)	(GW)	(%)	(GW)	(%)	(GW)	(%)
Argentina	2005	28	16	56	10	36	1	5	1	4
	BAU	49	25	52	16	32	5	10	3	6
	ALT	46	21	46	18	39	4	9	3	7
Brazil	2005	106	17	16	79	75	2	2	7	7
	BAU	219	29	13	169	77	4	2	18	8
	ALT	221	24	11	175	79	4	2	19	8
Bulgaria	2005	12	7	55	2	21	3	24	0	0
	BAU	14	10	69	1	10	3	20	0	1
	ALT	11	4	38	1	10	6	52	0	0
China	2005	443	328	74	106	24	9	2	0	0
	BAU	1607	1148	71	290	18	89	6	80	5
	ALT	1621	844	52	362	22	216	13	200	12
Cuba	2005	4	4	99	0	1	0	0	0	0
	BAU	6	5	91	1	9	0	0	0	0
	ALT	6	4	67	2	33	0	0	0	0
Germany	2005	119	70	59	13	11	20	17	16	13
	BAU	151	104	69	10	7	0	0	37	25
	ALT	129	63	49	10	8	19	15	37	28
India	2005	137	100	73	31	23	3	2	4	3
	BAU	650	553	85	52	8	20	3	26	4
	ALT	645	527	82	52	8	35	5	31	5
Korea	2005	72	49	69	4	6	18	25	0	0
	BAU	102	75	74	4	4	22	22	0	0
	ALT	97	62	64	5	5	29	30	1	1
Lithuania	2005	5	2	36	1	21	1	26	1	17
	BAU	6	3	50	1	17	1	17	1	17
	ALT	6	3	50	1	17	1	17	1	17
Pakistan	2005	19	12	64	7	33	0	3	0	0
	BAU	55	24	44	23	42	8	15	0	0
	ALT	64	9	13	25	39	9	15	21	33
Romania	2005	20	13	64	6	33	1	3	0	0
	BAU	25	18	73	0	1	7	26	0	0
	ALT	26	16	64	1	3	6	25	2	9
Russia	2005	217	148	68	46	21	24	11	0	0
	BAU	300	195	65	60	20	45	15	0	0
	ALT	334	136	41	68	20	96	29	35	10
Syria	2005	8	6	76	2	24	0	0	0	0
	BAU	19	14	76	0	0	2	8	3	16
	ALT	24	13	54	0	0	2	8	9	38
TOTAL	2005	1190	772	65	307	26	82	7	29	2
	BAU	3203	2203	69	627	20	206	6	168	5
	ALT	3229	1725	53	719	22	427	13	358	11
	BAU (%)*	169	185		104		151		479	
	ALT (%)*	171	123		134		421		1134	

Sources: Various, including [4] to [16]

Table 7. Summary of generating capacity in the BRIC group of countries.

		Capacity (GW)								
		Total	TH		H		N		Oth	
		(GW	(GW)	(%)	(GW)	(%)	(GW)	(%)	(GW)	(%)
Brazil	2005	106	17	16	79	75	2	2	7	7
	BAU	219	29	13	169	77	4	2	18	8
	ALT	221	24	11	175	79	4	2	19	8
	BAU (%)*	107	71		114		100		157	
	ALT (%)*	108	41		122		75		164	
China	2005	443	328	74	106	24	9	2	0	0
	BAU	1607	1148	71	290	18	89	6	80	5
	ALT	1621	844	52	362	22	216	13	200	12
	BAU (%)*	263	250		174		889			
	ALT (%)*	266	157		241		2300			
India	2005	137	100	73	31	23	3	2	4	3
	BAU	650	553	85	52	8	20	3	26	4
	ALT	645	527	82	52	8	35	5	31	5
	BAU (%)*	374	453		68		567		550	
	ALT (%)*	371	427		66		1080		675	
Russia	2005	217	148	68	46	21	24	11	0	0
	BAU	300	195	65	60	20	45	15	0	0
	ALT	334	136	41	68	20	96	29	35	10
	BAU (%)*	38	32		30		88			
	ALT (%)*	54	-8		48		300			
BRIC	2005	903	593	66	262	29	38	4	11	1
	BAU	2776	1925	69	571	21	158	6	124	5
	ALT	2821	1530	54	656	23	351	12	284	10
	BAU (%)*	207	225		118		316		1027	
	ALT (%)*	212	158		150		823		2479	
TOTAL#	2005	1190	772	65	307	26	82	7	29	2
	BAU	3203	2203	69	627	20	206	6	168	5
	ALT	3229	1725	53	719	22	427	13	358	11
	BAU (%)*	169	185		104		151		479	
	ALT (%)*	171	123		134		421		1134	

Source: Various, including [5], [7], [10], [15]

Table 8. Summary of total electricity generation in the IAEA-CRP countries.

		Generation (TWh)												
		Total	C		O		G		H		N		Oth	
		(TWh)	(TWh)	(%)	(TWh)	(%)	(TWh)	(%)	(TWh)	(%)	(TWh)	(%)	(TWh)	(%)
Argentina	2005	106		0	4	4	41	39	45	43	11	10	4	4
	BAU	262	47	18	34	13	56	21	64	24	34	13	26	10
	ALT	219	0	0	24	11	68	31	72	33	32	15	24	11
Brazil	2005	491	16	3	2	0	78	16	351	71	13	3	31	6
	BAU	1075	22	2	9	1	180	17	746	69	22	2	97	9
	ALT	1071	16	1	8	1	134	13	783	73	28	3	102	10
Bulgaria	2005	44	19	49	1	1	2	8	4	5	18	36	0	1
	BAU	51	24	47	1	2	4	8	3	6	18	35	1	2
	ALT	51	9	17	0	0	4	8	3	6	35	69	1	2
China	2005	2800	2200	79	50	2	100	4	400	14	50	2	0	0
	BAU	7700	5200	68	0	0	600	8	1200	16	500	6	200	3
	ALT	6987	3298	47	48	1	603	9	1297	19	1133	16	608	9
Cuba	2005	15	0	0	14	96	0	0	0	1	0	0	1	4
	BAU	51	0	0	50	99	0	0	1	1	0	0	0	0
	ALT	50	0	0	42	84	0	0	7	14	1	2	0	0
Germany	2005	580	270	47	5	1	60	10	40	7	155	27	50	9
	BAU	645	500	78	0	0	0	0	29	4	0	0	116	18
	ALT	594	271	46	0	0	32	5	31	5	146	25	114	19
India	2005	699	482	69	28	4	63	9	105	15	14	2	7	1
	BAU	4334	2687	62	173	4	823	19	347	8	130	3	173	4
	ALT	4398	2593	59	176	4	835	19	352	8	232	5	210	5
Korea	2005	388	147	38	25	6	63	16	5	1	147	38	0	0
	BAU	530	285	54	10	2	50	9	10	2	175	33	0	0
	ALT	530	218	41	10	2	75	14	7	1	214	40	6	1
Lithuania	2005	14	0	0	2	15	3	24	0	1	8	60	0	0
	BAU	20	0	0	4	18	5	23	0	0	12	59	0	0
	ALT	20	0	0	4	20	5	25	0	0	12	60	0	0
Pakistan	2005	98	0	0	28	29	35	36	32	33	2	2	0	0
	BAU	356	139	39	0	0	15	4	137	38	57	16	9	3
	ALT	356	14	4	0	0	2	0	146	41	66	19	129	36
Romania	2005	59	24	40	1	2	11	19	17	29	5	8	1	2
	BAU	78	41	53		C,O,G			17	22	20	26	0	0
	ALT	78	38	49		C,O,G			17	22	20	26	2	3
Russia	2005	931	161	17	20	2	428	46	170	18	151	16	0	0
	BAU	1540	302	20	26	2	658	43	231	15	323	21	0	0
	ALT	1715	210	12	19	1	458	27	262	15	689	40	78	5
Syria	2005	35	0	0	19	53	13	37	4	10	0	0	0	0
	BAU	105	0	0	70	67	20	19	5	5	10	10	0	0
	ALT	105	0	0	59	56	20	19	2	2	9	9	15	14
TOTAL	2005	6260	3319	53	199	3	897	14	1173	19	574	9	94	2
	BAU	16747	9247	55	377	2	2411	14	2790	17	1301	8	622	4
	ALT	16173	6666	41	389	2	2236	14	2979	18	2618	16	1288	8
	BAU (%)*	168	179		89		169		138		127		562	
	ALT (%)*	158	101		96		149		154		356		1270	

Note: *Percentage increase in total electricity generation from 2005-2020

Sources: Various, including [4] to [16]

3. KEY RESULTS AND ANALYSIS

This section of the paper provides a summarized overview of the broad contours of the evolving technological landscape in the electricity sectors of various countries considered in this study – in the backdrop of emerging concerns about global warming (as noted earlier in this paper). Various arguments in this overview are based on the results of country case studies – as summarized in Tables 6 and 7. While Table 6 presents key results of all countries considered in this paper, Table 7 presents results for countries popularly known as BRIC (Brazil, Russian, India and China) countries - a group of countries that is currently attracting increasing attention in view of their sheer size, anticipated economic prospects, energy requirements and associated environmental ramifications. A review of Tables 6 to 10 suggests that:

- Over the period 2005-2030, nearly 2100GW[1] of electricity generation capacity is expected to be added in the countries included in this paper. An overwhelming proportion (~92 percent) of these additions is likely to take place in the BRIC countries. Within the BRIC group, China and India alone will be responsible for nearly 89 percent of total capacity additions. Over this period, China is expected to expand its electricity generation capacity 2.6 times, and India - 3.7 times (Tables 6 and 7). Deeper insights into the technological trends in the electricity generation in these two countries will therefore be of particular interest from the perspective of developing strategies to address the global warming challenge.
- Of the 2100GW of capacity additions, thermal capacity will account for between 45 and 68 percent (or 953GW and 1431GW) of new capacity in the ALT and BAU scenarios, respectively. These additions will consequently raise the share of thermal capacity (in total capacity) from 65 percent (772GW) in 2005, to nearly 69 percent (2203GW) in 2030 – in the BAU Scenario. In the ALT Scenario this share will however decline to 53 percent (1725GW) in 2030 (Tables 6 and 7).
- Further, with the exception of Brazil, Lithuania, and Pakistan (especially in the ALT Scenario), thermal power will continue to be the mainstay of the electricity systems in all countries, accounting for between one-half and three-quarters of total capacity - in both the BAU and ALT scenarios. Particularly noteworthy are the trends in thermal capacity in China, India and Russia – there members of the BRIC group. In the BAU Scenario, the share of thermal capacity for India is likely to increase from 73 percent (100GW) in 2005, to 85 percent (553GW) in 2030. The corresponding shares for China are 74 percent (328GW) in 2005 and 71 percent (1148GW) in 2030. And, for Russia, 68 percent (148GW) and 65 percent (195GW) in 2005 and 2030, respectively. In the ALT Scenario, the share of thermal capacity, by 2030, is expected to reduce considerably for Russia and China – to 41 percent (136GW) and 52 percent (844GW), respectively. This share in the case of India is however expected to stay inordinately high – 82 percent (527GW).
- Although the average overall share of hydro-electric capacity, by 2030, will decline from 25.8 percent in 2005, to 19.6 and 22.3 percent in the BUA and ALT scenarios, respectively, hydro will still play an important role in the electricity systems in most countries included in this study. For example, the electricity capacity is expected to more than double over the period 2005-2030, from 307GW in 2005, to 627 and 719GW in 2030 in the BAU and ALT scenarios, respectively. A significant proportion of this increase is likely to take place in China where hydro-capacity will increase from 106GW in 2006, to 362GW in 2030. The corresponding increase in Brazil will be 94GW. For the other countries in this study, the share of hydro-electricity capacity is either likely to remain the same as in 2005, or change only modestly (see Tables 6 and 7). The environmental impacts of hydro-electric capacity, its social impacts (rehabilitation of displaced people), and issues arising from the nexus between water, energy, and food security are some of the issues cited by various countries as the likely reasons for less-than-significant change in its share – notwithstanding its attractiveness as base-load capacity with near negligible greenhouse gas emissions.
- There is likely to be an upsurge in the uptake of nuclear power in the countries included in this study. For example, in the ALT scenario, the nuclear capacity is expected to more than quadruple over the period 2005-2030, from 82GW in 2005, to 427GW in 2030. This, in percentage terms, implies an increase in the overall share of nuclear from 6.9 percent in 2005, to 13.2 percent in 2030. Even in the BAU Scenario, the nuclear capacity is expected to more than double, from 82GW is 2005, to 206GW in 2030. Further, an overwhelming proportion of this increase is likely to take place in three members of the BRIC group, namely, China, India and Russia. They collectively will account for 304GW of the total increase of 345GW over the period 2005-2030, with China alone expecting to add 207GW of the increase. Korea, India, and Russia expect to add 11, 32, and 72GW of nuclear capacity over the period. Pakistan plans to increase the share of its nuclear capacity from 3 percent in 2005, to 15 percent by 2030. Other countries in the study, notably, Argentina, Brazil, Bulgaria, Lithuania, and Romania – while not planning to add substantial amounts to their existing nuclear capacities, do however plan to maintain a nuclear presence, with a steady increase in their nuclear capacities. The case of Germany is rather interesting, showing

[1] A significant amount, especially when viewed alongside the fact that the world's total electricity capacity in the year 2005 was 3800GW.

either a cessation of nuclear activity (in the BAU scenario) or a revival of its nuclear industry in the years to come. Syria appears to be progressing its ambition to develop nuclear power, expecting to add 2GW of capacity by 2030 (Tables 6 and 7).

- There is expected to be a rapid increase in the role of 'other' (mainly small-scale renewable) technologies/fuel over the period 2005-2030. The current capacity of 29GW (2.4 percent share) is expected to increase to 168GW (5.2 percent share) in the BAU scenario, and 358GW (11.1 percent share) in the ALT scenario. An overwhelming proportion of this increase is likely to take place in China which alone plans to add nearly 200GW of 'other' technologies. Other countries with ambitious plans to increase the role of 'other' technologies include Germany, India, Russia and Brazil (Tables 6 and 7).
- It is interesting to note that much of the increase in the role of nuclear and 'other' technologies comes at the expense of thermal power in all countries except India where thermal power continues to play a domineering role. Overall, in the ALT Scenario, the share of thermal capacity decreases from 64.9 percent in 2005, to 53.4 percent in 2030, the share of nuclear increases, from 6.9 percent to 13.2 percent, and that of 'other' technologies, from 2.4 percent in 2005, to 11.1 percent in 2030.
- The trends in electricity generation (expressed in TWh in this paper) are broadly consonant with those of electricity capacity (as discussed above) (see Tables 7 and 8). For example, the share of thermal capacity is expected to decline from 71.7 percent in 2005, to 57.4 percent in 2030 in the BAU scenario (the correcting capacity shares were 64.9 and 53.4 percent, respectively). Within the thermal generation, while the share of coal-based generation declines from 53 percent in 2005, to 41.2 percent in 2030, the share of natural gas-based generation stays more-or-less steady, at approximately 14 percent. This appears to belie the 'dash-for-gas' argument that underpin current professional discourse on this topic. A more penetrating look into the inter-fuel dynamics, in particular for the BRIC group of countries, should provide some explanation for this apparent anomaly. For example, while the use of gas for electricity generation increases rapidly for India, China, Brazil, and stays at high levels for Russia, coal-based electricity still constitutes the bulk of the base-load capacity in these countries (with the exception of Brazil), thus resulting in a relatively lower share of gas-based generation and a less than-balanced increase in gas-based capacity and gas-based generation.
- In the year 2005, the overall shares of hydro-electric capacity and hydro-electric generation were 25.8 and 18.7 percent respectively. By 2030, in the BAU scenario, these shares are expected to decline marginally, to 22.3 and 18.4 percent, respectively. Clearly, the reliability of hydro-electricity as a source of dependable base-load capacity is likely to increasingly come under close scrutiny in the coming years, as the environmental concerns associated with large scale projects, and the inevitable conflicts between the use of water for irrigation and power generation, become obvious.
- The case for nuclear as dependable base-load capacity, in the countries in this paper, appears rather credible if one takes not of the fact that, in 2005, its share of total electricity generation (9.2 percent) exceeded its share of installed capacity (6.9 percent). These shares, in 2030, in the BAU scenario are expected to be 16.2 and 13.2 percent respectively. This strengthens the potential role that nuclear technology can play in climate policy responses aimed at mitigating the growth of CO_2 emissions from the electricity sector.
- The share of 'other' (mainly small-scale renewable) technologies in the countries is expected to increase significantly, from 2.4 percent in 2005 to 5.2 and 11.1 percent in BAU and ALT scenarios. Their share of electricity generation will however generally lag their capacity-share. For example, their share of electricity generation increases from 1.5 percent in 2005, to 3.7 and 8 percent in 2030 in BAU and ALT scenarios. This is mainly due to the intermittent nature of their availability and possibly the impact of historical institutional biases in favour of large, especially, thermal technologies. The contribution therefore of renewable technologies in mitigating GHG emissions, though increasing, is likely to be relatively modest.
- It is noticed that even in the most environmentally-optimistic scenario (namely, the ALT Scenario), the CO_2 emissions in all countries considered in this paper (with the exception of Germany) are likely to increase. Such an increase will be rather substantial in the case of BRIC group of countries, most notably China and India whose emissions are likely to increase from 5429 and 1154mn tons in 2005, to 8204 and 2000mn tons in 2030 – in the ALT scenarios. Further, although the contribution of electricity sector to total CO2 emissions, over the period 2005-2030, is likely to decline for all countries in the study, the electricity sector will remain as a substantial contributor to global warming overall (Table 10) - thus prompting a significant transformation in electricity technology-fuel-mix in the years to come.

Table 9. Summary of total electricity generation in the BRIC group of countries.

		Generation (TWh)												
		Total	C		O		G		H		N		Oth	
		(TWh)	(TWh)	(%)	(TWh)	(%)	(TWh)	(%)	(TWh)	(%)	(TWh)	(%)	(TWh)	(%)
Brazil	2005	491	16	3	2	0	78	16	351	71	13	3	31	6
	BAU	1075	22	2	9	1	180	17	746	69	22	2	97	9
	ALT	1071	16	1	8	1	134	13	783	73	28	3	102	10
	BAU (%)*	119	38		350		131		113		69		213	
	ALT (%)*	118	0		300		72		123		115		229	
China	2005	2800	2200	79	50	2	100	4	400	14	50	2	0	0
	BAU	7700	5200	68	0	0	600	8	1200	16	500	6	200	3
	ALT	6600	2640	47	66	1	594	9	1386	19	1188	16	726	9
	BAU (%)*	175	136		-100		500		200		900			
	ALT (%)*	136	20		32		494		247		2276			
India	2005	699	482	69	28	4	63	9	105	15	14	2	7	1
	BAU	4334	2687	62	173	4	823	19	347	8	130	3	173	4
	ALT	4207	2386	59	168	4	799	19	337	8	293	5	224	5
	BAU (%)*	520	457		518		1206		230		829		2371	
	ALT (%)*	502	395		501		1169		221		1993		3105	
Russia	2005	931	161	17	20	2	428	46	170	18	151	16	0	0
	BAU	1540	302	20	26	2	658	43	231	15	323	21	0	0
	ALT	1715	210	12	19	1	458	27	262	15	689	40	78	5
	BAU (%)*	65	88		30		54		36		114			
	ALT (%)*	84	30		-8		7		54		356			
BRIC	2005	4921	2859	58	100	2	669	14	1026	21	228	5	38	1
	BAU	14649	8211	56	208	1	2261	15	2524	17	975	7	470	3
	ALT	13593	5252	39	261	2	1985	15	2768	20	2198	16	1130	8
	BAU (%)*	198	187		108		238		146		328		1137	
	ALT (%)*	176	84		161		197		170		864		2873	
TOTAL#	2005	6260	3319	53	199	3	897	14	1173	19	574	9	94	2
	BAU	16747	9247	55	377	2	2411	14	2790	17	1301	8	622	4
	ALT	16173	6666	41	389	2	2236	14	2979	18	2618	16	1288	8
	BAU (%)*	168	179		89		169		138		127		562	
	ALT (%)*	158	101		96		149		154		356		1270	

Source: Various, including [5] ,[7], [10], [15]
Note: # For all countries in the IAEA-CRP; *Percentage increase in total electricity generation from 2005-2020

Table 10. Summary of the key results of country case studies.

Country	Scenario	Year	Demography: Per capita GDP [a] (US$'000)	Demography: Per capita Elec. (kWh)	Electricity: Capacity Total (GW)	Capacity Th (%)	Capacity H (%)	Capacity N (%)	Capacity Oth (%)	Generation Total (TWh)	Generation C (%)	Generation O (%)	Generation G (%)	Generation H (%)	Generation N (%)	Generation Oth (%)	Emissions: CO_2 (Mtons)	Emissions: Elec [b] (%)
Argentina	BAU	2005-2025	10.8-24.8	2705-5413	28-49	56-52	36-32	5-10	4-6	106-262	0-18	4-13	39-21	43-25	11-13	4-10	67-138	42-57
	ALT	2025			47	46	40	8	7	219	0	11	31	33	15	11	97	42
Brazil	BAU	2005-2030	8.6-21.8	2638-4555	106-219	16-13	75-77	2-2	7-8	491-1075	3-2	0-1	16-17	71-69	3-2	6-9	366-891	15-13
	ALT	2030			219-223	9-12	77-81	2	8-9	1071	1	1	13	73	3	9	891	9
Bulgaria	BAU	2006-2030	9.3-21.0	5500-7567	12-14	55-69	21-10	24-20	0-1	44-51	42-50	1-1	4-8	10-5	42-36	0-1	50-64	40-38
	ALT	2030			11	34-40	13	46-51	1	51	15-20	0	8	5	65-71	1	48-53	
China	BAU	2006-2030	4.1-19.5	2133-5281	443-1607	74-71	24-18	2-6	0-5	2800-7700	79-68	2-0	4-8	14-16	2-6	0-3	5429-11730	49-49
	ALT	2030			1461-1732	44-65	19-26	6-17	1-20	6684-7676	40-57	0-1	8-9	17-21	9-21	7-11	8204	46
Cuba	BAU	2006-2030	7.0-26.6	1391-4250	4-6.4	99-99	1-9	0-0	0-0	15-51	0-0	96-99	0-0	1-1	0-0	4-0	27-86	58-62
	ALT	2030			6	62	37	2	0	50	0	84	0	14	2	0	71-73	
Germany	BAU	2005-2030	30.5-52.8	7073-8134	119-151	59-69	11-6	17-0	13-25	580-645	47-78	1-0	10-0	7-5	27-0	9-18	795-771	39-51
	ALT	2030			107-140	28-67	7-9	0-51	11-48	535-640	22-72	0	1-14	5-6	27-66	6-39	489	27-40
India	BAU	2005-2030	2.1-7.7	616-1859	137-650	73-85	23-8	2-3	3-4	699-2800	69-62	4-4	9-19	15-8	2-3	1-4	1154-2100	56-53
	ALT	2030			420-850	77-83	8	3-9	4-6	1750-4774	54-60	4	19	8	3-9	4-6	1800-2000	
Korea	BAU	2005-2030	22.7-54.8	8083-10896	72-102	69-74	6-4	25-22	0-0	388-530	38-54	6-2	16-9	1-2	38-33	0-0	497-680	40-38
	ALT	2030			95-99	57-71	4-6	24-35	0-2	530	32-52	2	13-15	1-2	33-47	0-3	680	28-38
Lithuania	BAU	2005-2020	14.2-32.9	4667-6667	5	36	20	26	17	14	0	15	24	1	60	0	14-17	21
	ALT	2020															15-21	
Pakistan	BAU	2005-2030	2.2-5.7	629-1559	19-55	64-44	34-42	2-14	0-0	98-356	0-39	29-0	36-4	33-39	2-16	0-2	149-290	30-41
	ALT	2030			61-67	11-16	38-41	12-18	30-37	356	0-11	0	0-1	41	16-24	30-43	219-242	0-14
Romania	BAU	2005-2020	9.4-13.7	2682-3916	20-25	64-73	33-1	3-26	0-0	59-78		61-52		29-22	9-26	1-0	92-95	40-33
	ALT	2020			25-28	56-73	1-10	17-26	0-26	78		45-52		22-24	26	0-7		31-33
Russia	BAU	2005-2030	11.8-22.1	6508-11774	217-300	68-65	21-20	11-15	0-0	931-1540	17-20	2-2	46-53	18-15	16-21	0-0	1531-2100	34
	ALT	2030															1800-2000	
Syria	BAU	2005-2030	4.1-8.4	1842-3178	8-19	76-76	24-0	0-8	0-16	35-105	0-0	53-67	37-19	10-5	0-10	0-0	48-61	41-33
	ALT	2030			24	56	0	7	37	105	0	56	19	2	9	14	54	33

Source: Various, including [1] to [16]

Notes: [a] GDP as measured in terms of Purchasing Power Parity (2005US$); [b] Contribution of electricity to total CO_2 emissions;

C – Coal; O – Oil; G – Gas; H – Hydro; Th – Thermal; N – Nuclear; Oth – Others;

BAU – Business – as – Usual Scenario;

ALT – refers to the range (minimum and maximum) of values for various scenarios considered for a particular country. The range therefore does not compare to a specific score.

4. SUMMARY AND CONCLUSIONS

This paper develops – for a select, yet significant group of countries – a panoramic overview of the changes in the electricity generation technology-fuel-mix, in the backdrop of emerging concerns about global warming and the contribution of the electricity industry to such warming. This overview is based on extended case studies developed by individual country experts, as part of a research project undertaken under the aegis of the International Atomic Energy Agency (United Nations). Each case study essentially employs a technological optimization model (for example, MESSAGE), driven by a range of scenarios that reflect the technological, economic and policy positions under consideration by various countries. The results of such studies are then contextualized in this paper, and supplemented with additional analyses, in order to draw broader inferences. The analyses suggests that over the next twenty years or so, there is likely to be a significant transformation in the electricity technology (fuel) landscapes across all countries, especially the BRIC group of countries. Broad contours of such a transformation are likely to include continuing dominance by thermal electricity especially coal; increased gas-based capacity, yet lower than expected share of gas-based electricity due mainly to its appropriateness as a peaking fuel - thus raising questions about the 'dash-for-gas' argument; small yet noticeable decline in the share of hydro-electricity, suggesting continuing influence of environmental considerations of large hydro-electric projects and the conflicts between the use of water resources for irrigation and electricity generation; rapid increase of nuclear-based capacity and generation, reflecting its appropriateness as a reliable base-load source of electricity in a carbon constrained world; and the lower than expected contribution from small-scale renewable technologies, due to the intermittency of their availability, and the historic institutional biases. The analysis also foreshadows the challenges faced by the policy makers in terms of establishing, in a timely manner, the necessary institutional and regulatory mechanisms that are capable of accommodating such technological transformation.

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