ABSTRACT

Title of Document: TECHNOLOGY DIFFUSION IN CLIMATE MITIGATION MODELING AND IMPLICATIONS FOR MITIGATION TARGETS

Francisco Carlos de la Chesnaye, Doctor of Philosophy, 2014

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Global climate mitigation analyses have been used to evaluate the challenges of reducing greenhouse gases and to inform climate change policymaking for over 30 years. Studies traditionally focus on projections of greenhouse gases over the 21st century based on key drivers such as population growth, economic growth, and the rate of technological change especially in climate mitigation or energy technologies. Any one of these factors can have an appreciable impact on emissions levels and the cost of mitigation particularly in the face of stringent mitigation targets. One area that has not been sufficiently studied is the impact of different rates of technology diffusion of advanced energy technologies between high-income and low- and middle-income countries. This is the topic of this dissertation. The standard approach in climate economic modeling is to assume that all technologies are available at the same time and rate across countries with different incomes and technological capabilities. This study applies the literature related to economic and technological convergence to first develop new estimates of technology diffusion for energy-related sectors across 112 countries of varying income levels. Then new greenhouse gas scenarios are developed with the Global Change Assessment Model (GCAM) to test the importance of different assumptions on technology diffusion versus other key modeling assumptions. The modeling results from this research show that the cost of meeting the same climate target could be as high as 60% to 80% in marginal cost terms and about 30% greater in total policy costs when different assumptions on diffusion rates of climate mitigation technologies between countries are used. These results clearly point to the need for greater evaluation on the importance of technology diffusion in climate mitigation modeling and also in the consideration of these results for climate change policy decision making.

TECHNOLOGY DIFFUSION IN CLIMATE MITIGATION MODELING AND IMPLICATIONS FOR MITIGATION TARGETS

By

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Dissertation submitted to the Faculty of the Graduate School of the
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Dedication

To my family.

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Para mi familia.

Acknowledgements

There are many people to acknowledge given that it took almost eight years to complete this degree. First, I am grateful to the many professors and lecturers at the Maryland School of Public Policy (MSPP) for the lessons, instructions, and insights I gained from the many classes and seminars attended over the years.

Second, I would like to acknowledge the useful suggestions and comments from my professional colleagues in formulating my research questions on technically diffusion, in particular John Weyant at Stanford University, Nebojsa Nakicenovic at the International Institute for Applied Systems Analysis (IIASA), Geoff Blanford at the Electric Power Research Institute (EPRI), and others in the Stanford Energy Modeling Forum.

Third, I am especially thankful to the modeling team at the Joint Global Change Research Institute (JGCRI) for developing GCAM and making it available to other researchers. Thanks to Jae Edmonds and Leon Clarke for helping me think about how best to structure the analysis and deploy GCAM on the research questions. Special thanks to Kate Calvin who was very supportive during my intensive tutorials on learning GCAM; it would have taken a lot longer to learn how to utilize the model if it wasn't for Kate's extremely patient approach.

Fourth, I would also like to acknowledge the support from my employers, both motivational and financial, over these many years. At the beginning of my PhD studies it was the USEPA Climate Change Division, specifically Reid Harvey and Dina Kruger, then later the Electric Power Research Institute EPRI, specifically Rich Richels and Tom Wilson. Holding down a full-time job and working on a PhD part-time is not advisable and can only be done with the continued support of one's employer.

Fifth, I am especially indebted to my committee members for the questions and important issues raised in draft versions of the dissertation and subsequent comments. The interactions with the committee helped make the final version a more solid set of analyses and helped focused the key insights. Matthias Ruth at Northeastern University, as one of my co-chairs, deserves special recognition for sticking with me over these many years, providing direction, and keeping me on task. Anand Patwardhan at MSPP, my other co-chair, also deserves special recognition for his insights and support and especially for taking on the responsibilities as the UMD co-chair in the last stages of my dissertation.

Finally, none of this would have been possible without the support of my family. From my mother and sisters who served as inspiration to keep pushing ahead; my dad who always inquired how things were going. And of course my wife and children who allowed me the time and quite needed to get this done; it was very unselfish of them to do so. I am grateful to now have more time to spend with them in the evenings and weekends.

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1. Motivation for Research

1.1. Climate Change Scenarios

According to the latest full assessment of the Intergovernmental Panel on Climate Change (IPCC), “most of the observed increase in global average temperatures since the mid-20th century is very likely (over 90% probability) due to the observed increase in anthropogenic [greenhouse gas] GHG concentrations. It is likely (over 66% probability) that there has been significant anthropogenic warming over the past 50 years averaged over each continent (except Antarctica)” (IPCC, 2007a).

Figure 1-1 below illustrates important issues in climate change science and policy, two physical and one political. The temperature scale on the left is adjusted so that zero is benchmarked relative to 1990 which is also the year many climate negotiators use for settling on GHG reductions. The first physical issue that many people do understand is that if society does not dramatically reduce GHG emissions, global temperatures will increase. Depending on population and economic growth, energy efficiency, and technology change and diffusion, temperature growth from 1990 could be between 1.5ºC to 4 ºC (the top of the range could go as high as 6 ºC if the climate system is highly sensitive to increasing GHG emissions).

It is also worth noting that all of these trajectories are still increasing at the end of the century, i.e., they are not stabilization trajectories. However there is a second physical issue many people do not understand –including government officials: even if society were to completely stop all GHG emissions now, global temperature will continue to increase for the remainder of the century. This is illustrated by the lower orange line, which is the result of running climate models with today's GHG levels and shows continuing temperature increase due to positive feedback and inertia in the climate system, most notably from a warmer ocean.

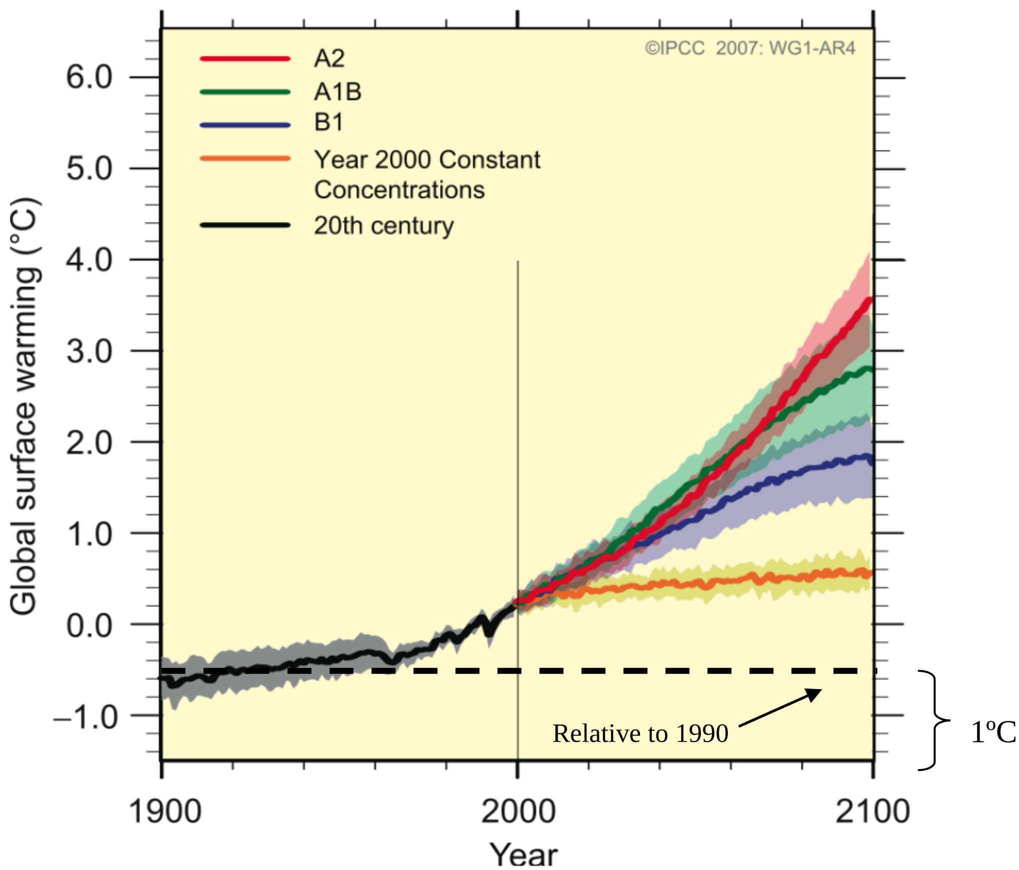

Figure 1-1: Projected global surface warming.

Solid lines are multi-model global averages of surface warming (relative to 1980–1999) for the scenarios A2, A1B and B1 which are various projections of how human society might develop over the 21st century from more to less greenhouse gas emitting. Shading denotes the ±1 standard deviation range of individual model annual averages. The orange line is for the experiment where concentrations were held constant at year 2000 values (IPCC, 2007a).

The political or public policy issue is the following: The European Union has stated that its official climate change target is “*to limit global warming to no more than 2°C above pre-industrial temperatures*.” (EC, 2007). To show what this target means on the above IPCC projections I’ve added a reference dashed line for pre-industrial temperatures which were about 0.5°C less than today. To today’s warmer world we can then add the warming that is in the system (barring any attempt at cooling the planet through geoengineering) and see that we are automatically headed for at least 1°C above pre-industrial temperatures without any action to reduce greenhouse gas emissions.

While the science of climate change enjoys a degree of consensus, the same is not the case for the economics of climate change. In this second field, there is quite a degree of nonconformity on the question of what the cost is to mitigate or reduce GHG emissions. The principle reason why there is this difference in consensus is that climate science is based on the natural sciences which count on many fundamental relationship in atmospheric chemistry and physics that can – by and large – be empirically tested. Climate economics, on the other hand, is primarily dealing with human socio-economic systems that are fundamentally more uncertain. In addition, the estimates of the cost of GHG mitigation are based on economic models of the world economic system which run scenarios out in the very long run, i.e., 50 to 100 years. Leading economic institutions attempt to harmonize the economic inputs, theory and methodology so that the resulting output and insights are not too divergent but at the same time there are many important assumptions about how the world operates, which technologies are implemented, and ultimately how societies respond.

Figure 1-2 illustrates the differences in economic cost of GHG mitigation from some of the most recent global analyses evaluated by the IPCC in its 2007 report (IPCC, 2007b). The graphs show the relationship between GHG concentration targets in terms of part per million (ppm) carbon dioxide equivalent (CO_2 eq) and related costs both in terms of a change in economic output (GDP) and a carbon price. As the GHG targets are made more stringent, the costs of achieving those targets increase slightly more than linearly. For example, for the often sought target of 450 ppm CO_2 eq, which is roughly consistent with the 2°C target mentioned above, GDP losses could be up to 4% of global output and the associated carbon price could increase to \$200/tCO_2 (which would add about \$90 to a barrel of oil and \$1.90 to a gallon of gasoline) .

There are many assumptions in the models that have an important influence on the results, e.g., future projections of population, economic growth, adoption of low-carbon technologies and their costs. One of the more important assumptions in the models regarding low-carbon technologies is that the diffusion of advanced technologies is instantaneous, that is, all new technologies are essentially homogenous in performance across all the countries of the globe. Table 1-1 provides the names, developers, and key characteristics of selected climate economic models which help to distinguish their analytical frameworks (Weyant, de la Chesnaye, and

Blanford, 2006). The second column identifies the basic model type as either: (1) multi-sector general equilibrium models that include the inputs and outputs to a number of economic sectors in the economy, (2) models that consider only the aggregate economic output produced by the economy, or (3) market equilibrium models that include market supply and demand conditions for a number of energy and non-energy sectors of the economy. The third column indicates whether a model deals with current production and investment decisions based on current prices of inputs and outputs, and includes an intertemporal optimization that considers the prices over the lifetime of possible investments. These two model characteristics are often, but not always, found together in economic models given that it is computationally easier to solve an intertemporal optimization algorithm when economic output is aggregated. The last column, and the main focus of this research, shows how the various models treat the diffusion of technology between countries, mainly from high-income (more industrialized) to low- and middle-income countries (less industrialized). For most of the models, technology diffusion is treated ad hoc, that is, there does not seem to be a common basis in the modeling literature to base rates of technology transfer or patterns of technology diffusion. Many models simply allow new GHG mitigation technology to be available instantaneously across all regions of the world. Notable exceptions include: the Japanese AIM model, which counts on expert elicitations to help assess when certain technologies become available; the MIT EPPA model, which allows the model to endogenously determine when technologies are available depending on the relative costs, including fuels, for each region; and EPRI's MERGE which applies an exogenous assumption to delay technology implication in a region based on its income level.

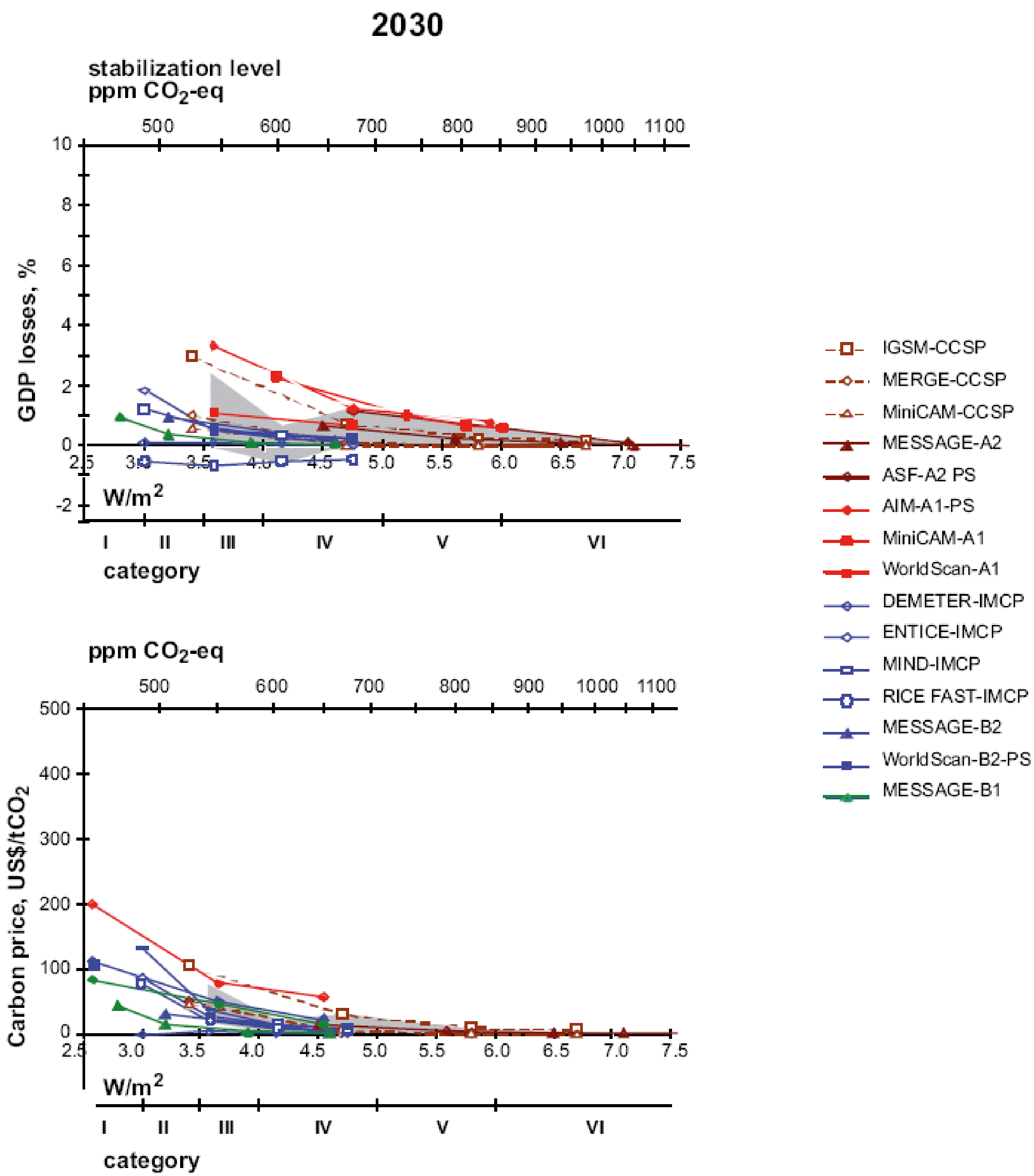

Figure 1-2: Mitigation costs across models.

Results from various climate economic models showing relationship between the cost of mitigation and long-term stabilization targets (radiative forcing compared with pre-industrial level, W/m^2 and CO_2-eq concentrations), Source: IPCC 2007b, Figure TS.9.

Model	Model Type	Solution Concept	Technology Diffusion
AIM: Asian-Pacific Integrated Model (Kainuma, et al, 2007)	Multi-Sector General Equilibrium	Recursive Dynamic	Expert elicitation on introduction of new technologies
GEMINI-E3: General Eq. Model of Int. Interaction for Economy-Energy-Env (Bernard et al, 2006)	Multi-Sector General Equilibrium	Recursive Dynamic	Instantaneous
EPPA: Emissions Projection and Policy Analysis Model (Paltsev, et al, 2005)	Multi-Sector General Equilibrium	Recursive Dynamic	Endogenously determined depending on technology costs, incl fuels, for each region
MERGE: Model for Evaluating Regional and Global Effects of GHG Reductions Policies (Blanford et al, 2009)	Aggregate General Equilibrium	Intertemporal Optimization	Lagged by one or two decades depending on region income level
IMAGE: Integrated Model to Assess the Global Env (van Vliet et al, 2009)	Market Equilibrium	Recursive Dynamic	Instantaneous
MESSAGE: Model for Energy Supply Strategy Alternatives and Their General Env. Impact (Krey and Riahi, 2009)	Market Equilibrium	Recursive Dynamic	Instantaneous
GCAM: Global Change Assessment Model (Calvin et al, 2009)	Market Equilibrium	Recursive Dynamic	Instantaneous

Table 1-1: Key Characteristics of Selected Climate Economic Models.

Table adapted from Weyant, de la Chesnaye, and Blanford, 2006.

The importance of the assumptions on technology diffusion for global emissions and climate forcing have not yet received sufficient attention in the modeling community and could be significant in climate mitigation analyses for two reasons: First, the actual performance of low-carbon technologies, e.g., a new generation wind turbine, is likely to be different from country to country, all else equal. Second, in most models, the rate of technology transfer or diffusion is assumed to be instantaneous or very fast. This second issues helps to keep the modeled global costs of GHG mitigation down since it is assumed that GHG mitigation take place where it is the most cost effective as soon as policies mandate reductions. It is this second assumption that is the focus of this research.

1.2. Organization of this Dissertation

This dissertation is organized as follows: Section 2 provides an assessment of the needed scope and level of technological change and technology diffusion between different groups of countries for stringent climate mitigation targets. This illustrates the magnitude of the challenge but does not guide how that technology diffusion may occur. For that understanding, Section 3 relies on the body of literature related to economic and technological convergence to develop new estimates of technology convergence for energy-related sectors across 112 countries of varying income levels. With that historical basis to build on, Section 4 describes the modifications to the Global Change Assessment Model (GCAM) – developed at the Joint Global Change Research Institute at the University of Maryland—to test the importance of different assumptions on technology diffusion versus other key modeling assumption. Section 5 presents the results of the new scenarios and finally Section 6 offers some concluding observation and implication for modeling climate mitigation targets based on this new work.

2. Assessment of Technological Change and Diffusion

2.1. Technical Assessment of the Magnitude for Change

This section provides a technical assessment of the needed technological change by focusing on the implications for the global electric power sector under a stringent climate change target. It is a robust finding in the climate mitigation literature, including all the mitigation reports of the IPCC, that in order to reduce global GHGs to avoid dangerous climate change there needs to be a whole transformation of the global energy system. The two main sectors in the energy system are electric power generation and transportation, which account for about 25 and 11 percent of global GHG emissions, respectively, in 2000 (WRI, 2009).

To gain a better understanding of the possible need for technological change or transformation, the analysis conducted here focuses on the global electric power sector power given its importance and the modeling ability to broadly estimate the number of power plant changes which can be easier to intuitively understand. The analysis evaluates the changes in the electric power sector power in both Organization for Economic Co-operation and Development (OECD) and non-OECD countries for a climate target that limits the increase in global average surface temperature to no more than 3°C above pre-industrial levels (or 1850). The main modeling scenario for this analysis is from a published study coordinated by the Energy Modeling Forum which included many of the leading integrated assessment models (Clarke et al, 2009). Within that study, the overall economy-wide and total energy system data for both a reference case without climate policy and the 3°C target are from the MERGE model (Blanford et al, 2009). For the analysis presented here, further work was done with MERGE to disaggregate the results specific to the electric sector for the OECD and non-OCED countries by major power generation technologies, i.e., fossil fuels, nuclear power, and renewables.

MERGE is a model for estimating the regional and global effects of GHG mitigation and is classified as an integrated assessment model (see Manne et al, 1995 for more details). It quantifies alternative pathways for various mitigation scenarios and contains a significant level of detail for electric power generation technologies. MERGE includes submodels for the domestic and international economy, energy-related emissions of GHGs, non-energy emissions of GHGs, and a reduced form representation of the global climate system. The model can disaggregate the global economy into various regions (e.g., OECD and non-OECD) and is consistent with a Ramsey-Solow model of optimal long-term economic growth. Price-responsiveness is introduced through a top-down production function. Output depends upon the inputs of capital, labor and energy. Important for this analysis, energy-related emissions are projected through a more detailed, bottom-up perspective. Separate technologies are defined for each source of electric and nonelectric energy. Each period's GHG emissions are translated into global concentrations and in turn to the impacts on mean global indicators such as temperature change. In order to meet a new climate change target, the model solves for a least-cost solution by making changes to the global energy and economic systems. The changes to the electric power system in the OECD and non-OECD countries are explored in greater detail below. It is important to state here that the material presented below is only from one model for only one long-term climate target. There are significant uncertainties in projecting the future global economic system, the energy system, and attempting to model long-term developments in technologies, including their costs and associated policies, e.g., the future of nuclear non-proliferation policies. For the purposes of this assessment, using one model does make it possible to focus on the electric sector, its key technologies, and the nature of technological change, and technology diffusion. The insights gained from this analysis should be broadly consistent across many of the leading climate economic and integrated assessment models used today.

A good place to start this technical assessment of the needed technological change in the global electric power sector is to first appreciate what the reference case (i.e., no climate policy) holds for global CO_2 emissions and electric power technologies. Figure 2-1 shows historical and projected CO_2 emissions from the OECD and non-OECD countries, latter split between the three dominant developing countries, Brazil, Russia, India, and China (BRICs), and the rest of the world. Although the OECD emissions have been the largest source up until the first decade of the 21st Century, non-OECD emissions, especially from the BRICs are projected to dominate in the future.

A few stark contrasts can be made by comparing a key driver of CO_2 and other GHG emissions, population, with the share of historical global emissions to a modeled emissions pathway consistent with the 3°C target. This is presented in Figure 2-2 where it is easy to see that the emissions pathway for a stringent climate target will require a dramatic transformation of the world's economy and energy system.

As stated above, electricity generation from fossil fuels, mainly coal, is the single largest source of global GHG emissions. Coal is abundant and relatively a much less expensive fuel that other sources of power generation, mainly natural gas, nuclear power, and renewable power which includes solar, wind, and biomass from agriculture. If there is no climate policy that internalizes the environmental cost of continuing to use fossil fuels, thereby changing the relative prices of the fuels so that fossil fuels become more expensive to use, then there should not be much of a change in the projected continued and accelerated use of fossil fuels for power generation. These projected trends along with alternative scenarios are presented in Figure 2-3.

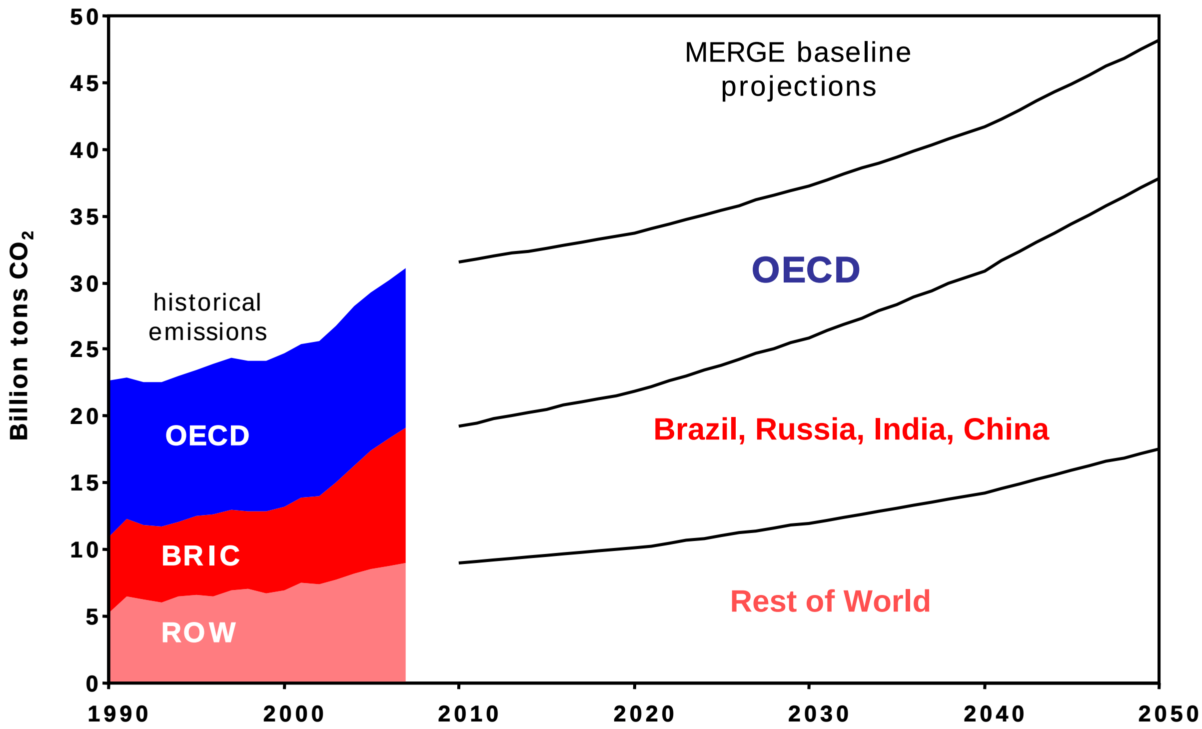

Figure 2-1: Projected reference case CO_2 emissions.

Source: Blanford et al, 2009.

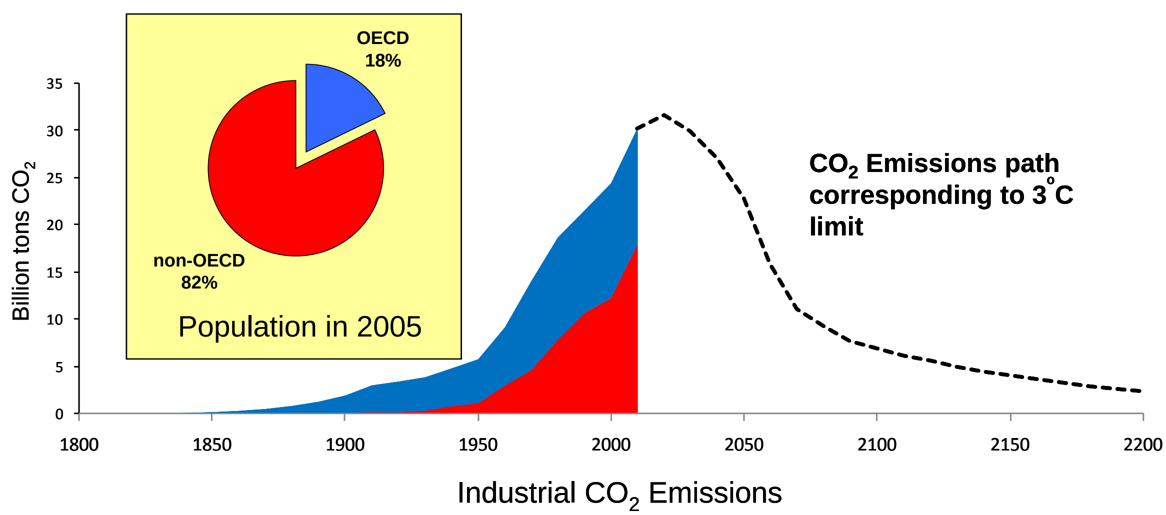

Figure 2-2: OECD and non-OECD population and emissions.

Source: Blanford et al, 2009.

As populations and economies continue to grow in the non-OECD countries, reference electricity generation from fossil fuels, and emissions, continue to growth and is identified as non-OECD Ref (solid red line). It is important to note that although increasing over time, there is an endogenous improvement in electricity intensity or technology over time which means that less and less electricity is required to produce economic output. But even with this autonomous energy efficiency intensity improvement the growth in fossil generation in the non-OECD is dramatic.

With the imposition of a 3°C target and a hefty carbon price on fossil generation that continues to increase at a 5 percent discount rate, there is an equally dramatic shift in fossil generation. With the policy starting in 2010, the retirement of conventional fossil generation begins quickly and is identified as the orange (non-OECD) and light blue (OECD) dashed lines. As the old technology is retired, new advanced fossil generation technology must take its place. New generation technology is modeled to be Integrated Gasification Combined Cycle (IGCC) plants with carbon capture and storage (CCS) of CO_2. This is a combination of two new technologies which are just now starting to be tested at-scale for power generation. The expected growth in these new technologies is identified as the red (non-OECD) and dark blue (OECD) dashed lines. Given that most of the current development work on IGCC-CCS plants is being done mainly in Canada, Europe and the U.S. (although China has started making recent progress), the significant growth in advanced fossil generation in the non-OECD countries will necessitate unprecedented levels of technology transfer from the OECD to the non-OECD countries in the coming decades. At least that is the conventional thinking and theory embodied in current integrated assessment model and climate change negotiations in the UNFCCC meetings.

The objective of this section was to assess the need technological change or scope of technology transfer by estimating how many new electric power plants would be required by region. Using the same scenarios describe above, it is possible to approximate the number of plants for both fossil generation and nuclear power. Figure 2-4 provides estimates for the number of fossil fuel power plants, both conventional and advanced technologies, for the OECD and non-OECD countries. To estimate the number of plants (units really), the number total TerraWatt hours per year were divided by proxy typical plant with a generation capacity of 500 MegaWatts (MW) per hour running 90 percent of the year. In the past, units were smaller than 500 MW and in the future they are expected to increase in size. The 500 MW size in an average and also is intended to provide a perspective given today's typical generating unit. The same pattern as is shown in Figure 3 shows up in Figure 4 but now it is easier to get a sense of needed number of physical units and more importantly the transformation in technology from conventional fossil generation, about 1,500 units by 2040 to a switch of about equal numbers, about 250, for conventional and advanced fossil generation. Not only is there a significant change in fossil generation technology, there is also a more dramatic away from fossil technologies to nuclear power and renewables.

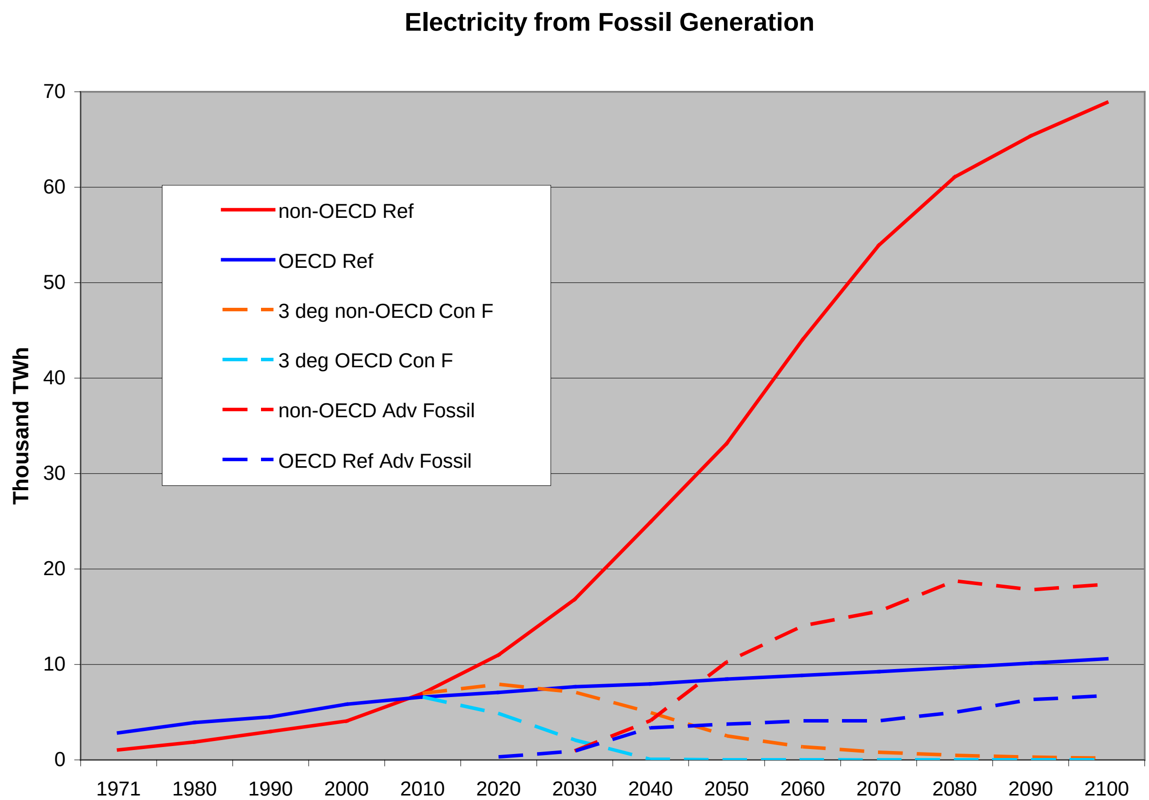

Figure 2-3: Historical and projected electricity generation from fossil fuels. TWh means Terra (10^{12}) Watt Hours. Sources: Historical data, IEA, 2009; Projections, Blanford et al, 2009.

This shift to a different technology is presented in Figure 2-5 which follows the same methodology to estimate the number of nuclear plants. The main difference is that here the proxy typical nuclear plant with a generation capacity double that of the proxy fossil plants or 1GigaWatts (1GW = 2 X 500 MegaWatts) per hour running 90 percent of the year. This approach while not exact provides a reasonable benchmark as the same calculation yields 100 plants for the U.S. where in reality there are 104 current operational nuclear plants (EIA, 2014a). Globally, there are 436 current operational nuclear plants (IEA, 2009), which is consistent with the date presented in

Figure 2-5. Evaluating the difference between the non-OECD reference case and the 3° C non-OECD target provides an estimate of the needed technological change and technology transfer which is easier to see than in the fossil fuel plant estimates. The reference case of non-OECD (solid red line) shows a steady increase in nuclear power plants until about 2050 with about 160 plants which then start to be de-commissioned mainly because the model project that conventional fossil generation will outcompete nuclear based on cost. However, in the 3° C target scenario the estimated number of nuclear plant in the non-OECD countries (dashed red line) is about 490, which means an addition of about 330 plants over a 40 year period. The pace of nuclear power installation continues to accelerate to where the model projects over 1,800 plants by 2100. As a point of reference, commercial nuclear power generation started in the U.S. in 1958 and there are 104 nuclear plants licensed to operate as of 2014 (EIA, 2014a).

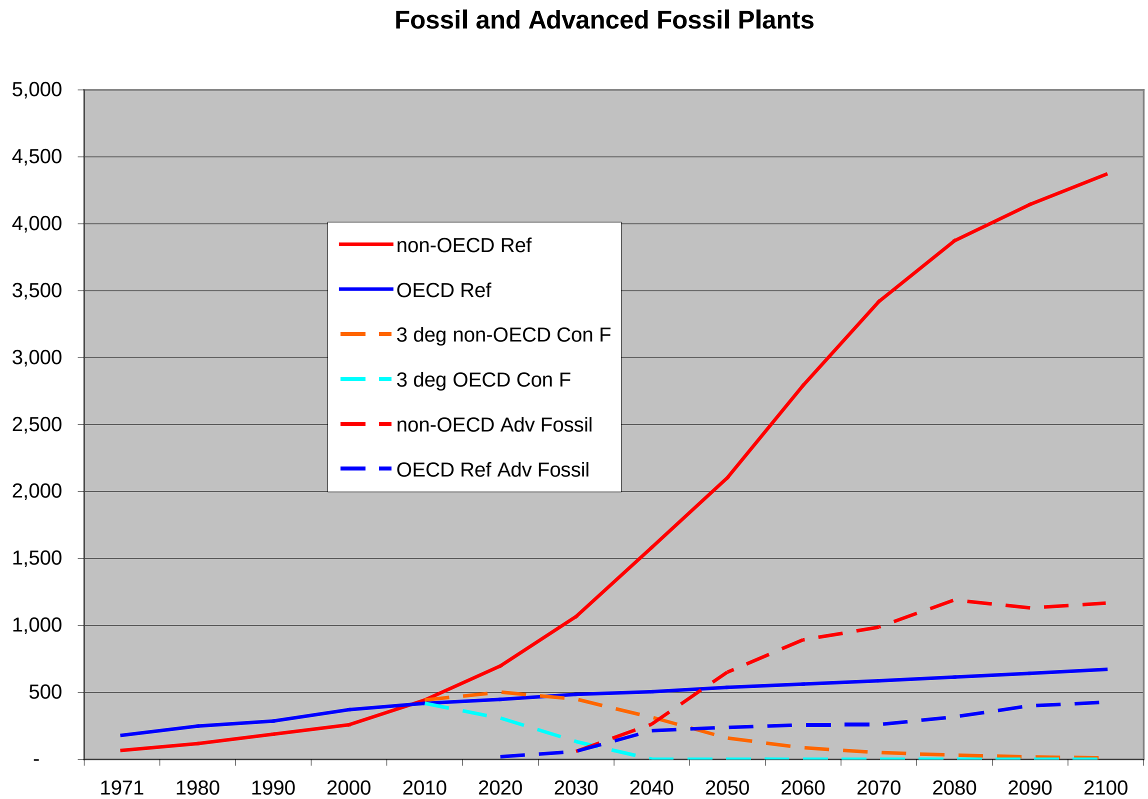

Figure 2-4: Approximation of the number of fossil fuel power plants.

Based on historical and projected electricity generation data. Sources: Historical data, IEA, 2009; Projections, Blanford et al, 2009.

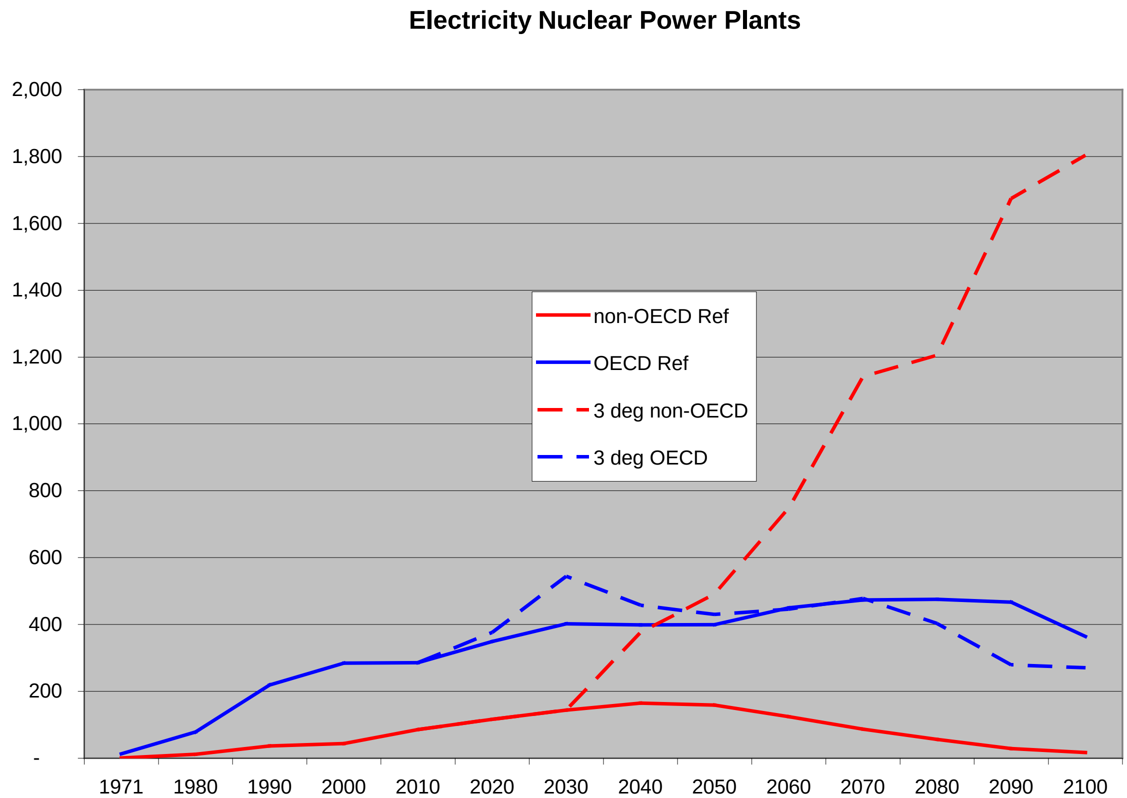

Figure 2-5: Approximation of the number of nuclear power plants.
Based on historical and projected electricity generation data. Sources: Historical data, IEA, 2009; Projections, Blanford et al, 2009.

2.2. Related Concepts on Technological Change

A good place to start is with the concept of technological change as formulated by Josef Schumpeter (in 1942) where innovation and technological change were key driving forces of the modern economic system. Schumpeter identified three steps for technological change to take place (Jaffe, Newell, and Stavins, 2001): First, there needs to be the invention of new technology through investments made by the private sector, public sector, or both. Second, the new technology must be commercialized, that is, made available outside of the early circle of developers. Lastly, the new technology must be widely available and successfully adopted by many entities –the process of technology diffusion– for its full measure to be realized. The concept of "technology change" in the context of climate economic analysis means the successful research, development, deployment of new climate mitigation technologies and their effective diffusion to most if not all countries around the world. The principal motivator for new technology is assumed to be a global climate policy that places a limit on GHG emissions that would then lead to a decrease in global warming. New technology development by itself can't solve the climate problem without a policy to limit GHG emissions and may in fact lead to increased emissions by the use of more emission-intensive technologies, for example converting coal to a liquid fuel for transportation. This section provides a summary of the literature on technology change and diffusion.

2.2.1. Technological Change

Technology is commonly associated with hardware devices, e.g., hybrid cars, wind turbines, but for it to be fully effective "technology" also includes the information and knowledge needed for the production and use of technological hardware (software), as well as the institutional settings and policy incentives for its deployment (Grübler, 1998). For the purpose of evaluating technical change, the future direction and rate of that should be analyzed as a range of possible futures given the many policy, engineering, and cost uncertainties. It is still possible to identify key features of the technical change process (Grübler, 1998):

- The process is fundamentally uncertain: outcomes are not certain and cannot be predicted.

- Research, development and innovation draws on underlying scientific or other knowledge.
- Many new technologies depend on the exploitation of foundational knowledge based on experience.
- Experimentation (trial and error) is usually involved.
- Technological change is a cumulative process and depends on the history of the individual or organization involved.
- Technological change is linked to the economic and cultural environment of a country or sector that is broader than an individual company.

Technological change may be supply driven, demand driven, or both. Some of the most significant technological advancements were designed to respond to the most pressing needs; a prime example is wartime in order to address resource constraints or military objectives. From the other side of societal needs, some technological innovation is the result of curiosity or the desire to meet a technical challenge. Market forces, i.e., prices, also can act as a strong stimulus for innovation by firms and entrepreneurs aiming either to reduce costs or to gain market share (Nordhaus, 2007).

Combustion turbine technology is one example of a technology where there has been cross-sector exploitation of prior experience and foundational knowledge and where long-term advancements have been the result of a cumulative process. Conventional fossil-fueled power stations have been designed around steam turbines to convert heat into electricity with conversion efficiencies of new power stations above 40 percent. More current technology, such as supercritical designs that involve new materials to allow higher steam temperatures and pressures, enable efficiencies of closer to 50 percent. More recently and in the near future some dramatic breakthroughs of combined cycle gas turbines (CCGTs) have been and should be achieved. The technology involves expanding very hot combustion gases through a gas turbine with the waste heat in the exhaust gases used to generate steam for a steam turbine.

During the end of the 19th Century and beginning of the 20th, steam turbine technology was primarily developed for electricity generation. That was then ported over to early designs for jet engines in the 1920s, which eventually lead to the first jet aircraft at the end of WWII (Rand, 2002). In turn, advancements in extreme high-speed turbines, metallurgy, and engineering related to jet aircraft found their way back to the next generation of gas turbines. Jet engine designs have frequently been modified to turn them into gas turbine engines. The gas turbine can withstand much higher inlet temperatures than a steam turbine, which produces considerable increases in overall efficiency. The latest designs currently under construction can achieve efficiencies of over 60 percent and have been rising by over 1 percent per year for a decade (EPRI, 2008).

2.2.2. Technology Diffusion and Transfer

Given the focus on climate mitigation technology, using the Intergovernmental Panel on Climate Change (IPCC) as a starting point to define technology diffusion and transfer is appropriate. According to the IPCC, technology transfer is:

> "a broad set of processes covering the flows of know-how, experience and equipment for mitigating and adapting to climate change amongst

> different stakeholders such as governments, private sector entities, financial institutions, non-governmental organizations (NGOs) and research/education institutions" (IPCC, 2000).

The IPCC Mitigation Report (2007b) continues by stating that "although there are numerous frameworks and models put forth to cover different aspects of technology transfer, there are no corresponding overarching theories. Consequently there is no framework that encompasses such a broad definition of technology transfer." It seems that technology transfer is easier to identify once it has taken place but harder to establish robust policy frameworks for its implementation. At the same time, the IPCC report does classify the important stages of technology transfer as:

- identification of needs,
- choice of technology, and
- assessment of conditions of transfer, agreement and implementation.

There are additional aspects of a workable technology transfer policy and program, again from the IPCC 2007 report: "Evaluation and adjustment or adaptation to local conditions, and replication are other important stages. Pathways for technology transfer vary depending on the sector, technology type and maturity and country circumstances. Given this variety and complexity, <u>the report concludes that there is no pre-set answer to enhancing technology transfer."</u> [emphasis added].

Even though the diffusion of new technologies is one of the most important requirements for effective climate mitigation there is not an agreed upon approach or policy as there is for other important policy issues, for example the implementation of a cap and trade policy to reduce GHG emissions is the case in the European Union and now starting some low- and middle-income countries, e.g., China and Mexico, but not under consideration in the U.S.

2.3. *Pathways and Sources of Technology Diffusion*

Traditionally, there have been two pathways for the transfer of technology from the more advanced countries (mainly those within the Organization for Economic Co-operation and Development - OECD) to the non-OECD countries which are public programs and private sector investments. Public funding of technology transfer is mainly in the form of official developmental assistance (ODA) from governments or non-governmental organizations (NGOs). Compared to private investment, ODA flows are small, but they are important in areas of the world that receive little foreign investment. Private firms transfer technology between countries in three ways:

1. Trade. According to the World Bank, GDP attributed to imported high-tech products has grown by over 50 percent in low-income countries, and by over 70 percent in middle-income countries, since 1994.
2. Foreign Direct Investment, mainly from multinational corporations (MNC) by the establishment of subsidiaries. FDI was about $390 billion in 2007 (World Bank, 2008).
3. License to a Local Firm where a MNC could instead choose to license its technology to a firm in the recipient country. About $22 billion in licensing fees in 2006 (World Bank, 2008).

Whether the diffusion of technology is done through public or private means, a critical element of the long-term effectiveness of any technology is the determination of the appropriateness of the technology. From Carl Pray's assessment of technology transfer in the Green Revolution (1981), he concludes that “[t]he type of transfer that occurred during the green revolution depended on the *agroclimatic similarity* of the adopting country with the country of origin and also on the sophistication of the local research system. The initial diffusion of high yield varieties in India, Pakistan, Turkey, and Malaysia was largely a material transfer because their agroclimatic conditions were similar to Mexico and the Philippines.” In this case, public and private sector involvement were critical for the diffusion of the technology. Jeffery Sachs (2003) adds that many technologies are highly ecology-specific: “The diffusion of technology from the advanced to the lagging countries, so important in the process of catching up, works best when the laggard shares the same ecological zone as the leader . . . and works most poorly when the laggard is geographically isolated and in a distinct ecological zone.”

In addition to environmental conditions, it is also important to bear in mind the cultural and political appropriateness of new technologies. Frondel’s study (Frondel et al, 2004) evaluates the importance of market and regulatory mechanisms by looking at OECD data of over 4,000 firms and find that more than ¾ of all abatement measures adopted are for cleaner production rather than end-of-pipe reasons. Aubert (2004) argues that diffusion of technology could go through a number of different, locally appropriate channels: “metrology, standards and quality control, extension services (for manufacturing and agriculture), information and training programs, demonstration and pilot projects.”

A country's infrastructure or lack of infrastructure must also be weighted heavily in the determination of appropriate technology. For example, Larson (2006) analyzes fuel cell technology and suggests that it may be adopted in less developed nations before developed nations, since the need is greater and there is an absence of a reliable power infrastructure where fuel cells could follow the path of cell phones. This is the "leap frog" technology approach. For climate mitigation and energy security policies a possible "leap frog" technology is electric transportation for light duty (passenger) vehicles. One of the difficulties for this technology to reach a substantial share of total vehicles is the new electric charging infrastructure, especially in highly populated urban areas. (Think of the difficulty is installing sufficient charging stations in the street of New York or Los Angeles.) This is in contrast to many cities in South America that can plan ahead and install the needed electric infrastructure as their urban and suburban areas develop beyond many of the dirt roads currently in use.

2.3.1. Technology Convergence

There is no doubt that technology diffusion occurs in many different sectors and across a variety of technologies between countries of varying income levels. The pertinent question for the subsequent sections of this research is: what are the rates at which technology diffuses between countries and can we learn something from that assessment that is useful for modeling forward projections? This is a similar to the question addressed in empirical research on classical convergence on income and more recent work on convergence of GHG intensities. Classical convergence research (Sala-i-Martin and Barro, 2003) focuses on neoclassical economic growth models based on the Solow-Swan formulations. The theory and assessment is that higher-income countries exhibit diminishing returns to investment which lead to declining growth rates of a country as it approaches a steady state level of capital per unit of labor. The further implication being that the lower-income countries grow faster or “catch-up” to the higher-income economies, all else equal. From income converge researchers continued the line of inquiry on energy and GHG intensity with an emphasis on climate change policy. Notable research by Strazicich and List (2003), Stegman and McKibbin (2005), and Aldy (2006) find that there is convergence in energy and emissions intensities among countries of different income levels but that it is important to track and understand the underlying structural changes in the economies and the difference in energy mix and technologies as the lower-income countries continue to industrialize. The reason to continue the converge approach from income, to energy intensity, and finally to technology performance is to identify an empirical evidence of convergence of some economic or technology performance variables across countries to enhance the predictive capacity of forward looking models, climate economic models (See Table 1-1). Furthermore, technological change and, in particular, technology diffusion has been a newer focus in the re-evaluation of economic growth models –since the late 1980s and early 1990s– to assess the differences in growth or convergence between the low-income and high-income countries (Rutan, 2002). One of the early papers to specifically draw attention to the connection between technology diffusion and economic convergence was Bernard and Jones (1996) which concluded that economic growth models at the time ignored the importance of technological change and diffusion and that even simple model which included these dynamics were better suited to modeling economic growth and convergence. More recently Keller (2004) explores the role technology diffusion plays in the variation of income across countries and estimates that foreign sources of technology –attributed to diffusion– accounts for a significant fraction (~90%) of domestic productivity growth in the lower-income countries.

To help use the established literature on income and energy/GHG intensity convergence and its application to technology convergence or how the performance of technologies converge over time, I draw on work of Comin and Hobijn (2004). Their work carefully examines the historical diffusion of more than twenty technologies across twenty-three of the world's leading industrial or high-income countries. This is covered in greater detail in the next section. This section and the above material define and describe the relationships between technological change and the importance of technology diffusion. The objective is to use the literature on technology convergence, which is a historical assessment, and the work presented in the following section to help develop more realistic estimates of technology diffusion for climate economic projections of mitigation targets.

3. Testing Technological Convergence

3.1. Methods for Testing Technological Convergence

There is a significant body of literature on the importance of technology and climate change mitigation that has been developed over the last two decades. Some of the more recent organized volumes include *EMF 19: Alternative technology strategies for climate change policy edited* (Weyant, J., Ed., 2004); *Endogenous Technological Change and the Economics of Atmospheric Stabilisation* (Edenhofer, et al, eds. 2006); *Multi-gas mitigation and climate policy* (de la Chesnaye and Weyant, eds., 2006); and *International, U.S. and E.U. Climate Change Control Scenarios: Results from EMF 22 (*Clarke, L., Bohringer, C., and Rutherford, T., eds, 2009). There is also a robust literature evaluating economic and GHG emissions converge between high-income and low- and middle-income countries. Once of the seminal papers on convergence is by Barro and Salai-i-Martin (1992). Other notable papers on economic converge include Lall and Yilmaz (2000), Sala-i-Martin and Barro (2003), Mathur (2005), and Ralhan and Dayanandan (2005). On the more specific question of energy and GHG convergence a good resource is by Stegman & McKibbin (2005) published as Brookings Institution Discussion Paper. However, when it comes to assessments of technology diffusion, transfer, or cross-country technology adoption there is a very limited body of work. One of the seminal papers in the area and one of the most cited is Comin and Hobijn in *Cross-country Technological Adoption: Making the Theories Face the Facts* (2004). In their paper, Comin and Hobijn examine the diffusion of more than twenty technologies across twenty-three of the world's leading industrial or high-income countries. For the purposes of my dissertation this paper is important for at least two reasons: First, I plan to follow and expand on the methodology applied by Comin and Hobijn to test for technology converge between countries; and second, that paper covers two of the three of the energy sector technologies of interest, i.e., transportation and electricity. The third sector technology evaluated is petroleum refining.

An important limitation in the Comin and Hobijn paper, as in many other analyses, is that the assessment of technology convergence was done only for industrial or high-income countries. I believe that a more pressing question to be addressed and the first part of my dissertation research should be: Is there a pattern of technological diffusion and convergence between middle & low income countries and high income countries similar to the pattern observed within high income countries, particularly in energy-related technologies?

The data that Comin and Hobijn developed is more important than the methodology they followed to evaluate variation in technologies over time and the degree of technological convergence between countries. As the authors state “at the heart of the empirical analysis” is the Historical Cross-Country Technology Adoption Dataset (HCCTAD- Comin and Hobijn, 2003a). Table 3-1 lists the technologies and technology measures contained in the dataset. A very important point to keep in mind is that the technology measures in the HCCTAD are proxies for the level of technology adoption between the countries in the dataset.

The research in this section encompasses two major data collection efforts: First, add technology measures for another energy related sector, that is, petroleum refining/liquid fuels for both conventional and non-conventional fuels and add additional details for electric power generation; and Second, expand the country coverage to include technology measures for low- and middle-income countries. The objective is to obtain as much data as possible for as many countries as possible focusing on the following large CO_2 emitting LMI countries. Details on the data collection for this research follow in the next section.

The HCCTAD contains annual data on technology measures for high-income countries with some of the data going back to the 18^{th} century. Given that reliable data for low- and middle income countries is usually not available for series starting before 1970, the data range is limited for the period 1970 to 2005 for all countries for which data I can obtain. Data sources included the U.S. Dept. of Energy, the International Energy Agency, the OECD, and the World Bank.

Transportation (rail, road-, and airways)

Freight traffic on railways (TKMs) per unit of real GDP

Passenger traffic on railways (PKMs) per capita

Trucks per unit of GDP

Passenger cars per capita

Aviation cargo (TKMs) per unit of real GDP

Aviation passengers (PKMs) per capita

Electricity

MWhr of electricity produced per unit of real GDP

Other technology measures in the HCCTAD

Textiles, e.g., Fraction of spindles that are mule spindles

Steel e.g., Fraction of tonnage of steel produced using Electric Arc furnaces

Telecommunication, e.g., Mobile phones per capita

Information Technology, e.g., Personal computers per capita

Table 3-1: Technologies covered in the Historical Cross-Country Technology Adoption Dataset.

Adapted from HCCTAD (Comin and Hobijn, 2003).

3.2. *Descriptive Statistic from Technological Convergence Assessment*

In their paper on technological diffusion and convergence Comin and Hobijn (2004) estimate cross-sectional coefficients of variation[1] to show the differences in adoption rates for various technology groups. The coefficient of variation is useful for this purpose since it measures the variability of in the data series independently of the unit of measurement, e.g., technology measures for different technologies. Table 3-2

[1] The coefficient of variation is defined as the standard deviation of a variable divided by its mean.

below, reproduced from Comin and Hobijn's original work (2004), shows cross-sectional coefficients of variation for the information technology, transportation, and electricity technology groups. By evaluating the time series of the coefficient of cross-section variation of technology adoption, a pattern of technological convergence can be seen. As the coefficients of variation decrease over time, this indicates that variability in the technology measures (which again are a proxy for technology adoption) decrease, leading to convergence. There is also an indication of a technology "catch up" phenomenon for most of the technologies that are in the innovation, growth, and maturity phases. This can more easily be seen in the more globalized technologies, especially in shipping and cars as manufacturing technologies and performance through competition and spillovers become more standardized across many countries.

The second test for converge carried out by Comin and Hobijn (2004) is on Beta convergence of technology adoption which is drawn from the literature on economic convergence studies as mentioned above. The standard regression equation employed by the authors is:

$$Y_{ijt} = \alpha + \beta \, Y_{ijt-1} + e_{ijt}$$

Where, Y_{ijt} is the measure of technology adoption for the *jth* technology in country *i* at time *t*, and is measured in logs whenever the variable is not a share. The measures of technology adoption are those defined in Table 3-1. According to the authors, the speed of convergence over the time period evaluated is then given by $-\ln(\beta)$.

Table 3-2 presents selected results from the Comin and Hobijn (2004) paper on estimates of β convergence.

The first column is an estimate across all technology groups over the all the time periods. The second and third rows include estimates for samples before and after 1945 by the indicated technology groups. Comin and Hobijn point out two important findings: First, they notice that the speed of convergence indicated by their estimates is quite high with an average speed of convergence just over 11 percent for most of the 20th Century. Second, they find an acceleration of the speed of convergence both on average (increased from 10 to 14 percent) and within technology groups.

	All	Information	Transportation (non-shipping)	Transportation (shipping)	Electricity
Total	0.89 (0.00) 12%				
Pre 1945		NA	0.92 (0.01) 8%	0.83 (0.03) 19%	0.89 (0.02) 12%
Post 1945		0.92 (0.03) 8%	0.90 (0.01) 11%	0.32 (0.04) 114%	0.93 (0.01) 7%

Table 3-2: Estimates of βs and the speed of convergence.

In percent, for selected technologies. Standard errors are in parenthesis. Speed of convergence is calculated as –ln(β). Source: Comin and Hobijn (2004).

The key findings from the Comin and Hobijn paper are mainly three: (1) They observe common patterns in the diffusion of a broad range of technologies across many countries. (2) They suggest a pattern of what they term “trickle-down” diffusion that is robust across technologies. They find that most of the technologies evaluated in their study originated in the more advanced countries and then trickle down to relatively less advanced countries. And (3) they find that the overall rate of technology diffusion has increased over time, especially in the post -WWII era.

3.3. Testing Technological Convergence in Energy Production

My contribution in this research is to build on the above described work by Comin and Hobijn on technological convergence testing by expanding the set of technologies evaluated, particularly in the energy sector, that is, in electric energy generation and petroleum refining and consumption. See Table 3-3 for the list of energy sector categories. I selected this list of technologies because of their direct association to the energy part of the economy and close relationship to improving energy intensity and climate mitigation, e.g., renewable power generation. In addition to expanding the set of technologies, I also broadened the coverage of countries in the assessment of technological convergence –particular to energy technologies– by including 29 high income countries and 83 middle and low income countries (total of 112).

Since the analysis on convergence is over a 36 year time period (1971 to 2007) and among various country income levels, I needed to select an income definition at the start of the data series given that countries normally advance between the classifications. The country income classifications used are as of 1971 according to the World Bank. Earlier country classifications were "developing" vs. "industrial" countries but that was changed in 1989 to more quantitative classification of income per capita or gross national income (GNI), converted to U.S. dollars using the World Bank Atlas method, divided by the midyear population. The first definitions between the middle-income and high-income countries were set at $6,000 per capita in 1987 prices. Currently, economies are classified by their 2011 GNI per capita: low income, $1,025 or less; lower middle income, $1,026 - $4,035; upper middle income, $4,036 - $12,475; and high income, $12,476 or more (World Bank, 2012).

Table 3-4 lists the countries included in this analysis. I started the countries selection process with 144 countries for which there was data for both the energy sets and GDP. Due to some gaps in energy data for middle and low income countries, mainly in Africa and Asia, and also due to change in country composition, mainly after the fall of communism, my resulting country data set contained 112 countries. There was some special data manipulation required to construct consistent data series for some countries whose regional make up changed over the analysis period from 1971 to 2007, e.g., Former Yugoslavia and the Czech Republic.

There are several reasons to the World Bank definition or cleavage of countries for the analysis of technology convergence in this section and for the subsequent modeling of long-term mitigation targets in Section 4. First, as discussed above, studies of technology change evaluate the dynamics of technology diffusion along this or similar country groupings based on per capita income and show that diffusion of technologies from high-income to lower-income countries account for an important part of international technology change (see Grubler et al, 1999 and Keller, 2004). Second, these same country and income groupings are the traditional basis for analysis in the long-standing economic convergence literature listed above in Section

3.1 and the more recent GHG-intensity convergence literature (see Stegman and McKibbin, 2005 and Aldy, 2006). Third, most of the models used in analyzing long-term energy policy and climate mitigation targets also group countries by income per capita, as illustrated above in the MERGE example in Section 2.1. This approach is also consistent with the climate policy consideration under the United Nations Framework Convention on Climate Change with the definition of Annex I and non-Annex I countries primarily done along income per capita considerations (UNFCCC, 2014). Last, is the importance of consistency. The objective of conducting research of technology convergence is to determine if we learn something from that assessment that is useful for modeling forward projections in climate mitigation analyses. Without having the similar country groups it would be difficult to accomplish this task.

The country specific energy data on energy production for electric energy generation and petroleum refining and consumption is from the International Energy Agency, specifically the *Energy Balances of non-OECD Countries* (IEA, 2010a) and *Energy Balances of OECD Countries* (IEA, 2010b). These two reports provide data on the supply and consumption of coal, oil, gas, electricity, heat, renewables and waste as energy balances. Electricity data is expressed in terms of Kilo Watt Hour (KWh) which is a unit of energy equivalent to one kilowatt (1 kW) of power expended for one hour (1 h) of time. Oil related energy balance data is expressed in terms of kilo tons of oil equivalent (KTOE). Both electricity and oil data are reported from 1971 to 2008. However, the last year for which there were full and consistent data was 2007.

Electricity generation
MWhr of electricity produced per unit of real GDP per year
MWhr of electricity produced by coal units
MWhr of electricity produced by natural gas units
MWhr of electricity produced by biomass and waste renewables
MWhr of electricity produced by wind and solar renewables
Petroleum refining / fuels
Kiloton of Oil Equivalent (KTOE) per unit of real GDP per year
KTOE of petroleum for Transportation
KTOE of petroleum for Oil Refining (excluding transportation uses)
KTOE of petroleum for Chemical and Petrochemical production

Table 3-3: Technologies added to evaluate energy and climate mitigation technology convergence.

3.4. Energy Related Output Data

Electricity is expressed in megawatt hours and measured as gross electricity production, which in turn is measured at the terminals of all alternator sets in a power plant. This gross estimation includes the energy taken by station auxiliaries and losses in transformers that are parts of the station. According to IEA, parasitic loads (i.e., difference between gross and net production) range from 7% for conventional thermal stations, 6% for solar stations, and to 1% for hydro stations.

Electricity produced by coal units is via the combustion of coal to produce steam, also known as thermal coal, where the fossil fuel is burned in a boiler to heat water and produce steam. That steam then turns a turbine to generate electricity. Electricity produced by natural gas alternatively has more options. Similar to coal, the most basic natural gas-fired electric generation is also via a steam generation unit. Natural gas also can be used in gas turbines and combustion engines where hot gases from burning the gas are used to turn the turbines. Lastly, and more recently, natural gas power plants have been developed as combined-cycle units where there is both a gas turbine and a steam unit in the same plant. In these combined-cycle plants, the exhaust heat from the turbine process also is used to improve the steam generation and hence achieve higher efficiencies.

Wind energy represents the kinetic energy of wind used for electricity generation. Solar energy is the solar radiation used for electricity generation by flat plate collectors, mainly of the thermosyphon type. Passive solar energy for the direct heating, cooling and lighting of dwellings or other buildings (also considered as distributed generation) is not included.

Turning to the second energy category, petroleum, it is expressed as gross energy consumption per year in units of kilotons of oil equivalent (KTOE), which is defined as the amount of energy released by burning one ton of crude oil. Three categories of petroleum balances were selected due to the high number of country commonality: Transportation, Oil Refining (excluding transportation uses), and Chemical and Petrochemical production. According to IEA (2010), transportation includes all fuels used for transport in industry and covers domestic aviation, road, rail, pipeline transport, domestic navigation and non-specified transport. It excludes international marine bunkers and international aviation bunkers. Oil Refining includes the use of primary energy for the manufacture of finished oil products and the corresponding output; as a result the total estimates include transformation losses.

The last petroleum category, Chemical and Petrochemical industry, is quite broad. It excludes petrochemical feedstocks but includes the manufacture of chemicals and chemical products, defined as the transformation of organic and inorganic raw materials by a chemical process, and the formation of products. It also includes the manufacture of pharmaceuticals and the manufacture of biological and medicinal products.

The representation of technologies via the aggregate metric for electricity generation of MWhr of electricity produced per unit of real GDP per year (further broken down by primarily energy types) and for petroleum refining of KTOE per unit of real GDP per year (further broken down by fuel end-use) is an aggregate approach but suitable for the assessment of technology convergence for the purposes of this dissertation. The principal reasons for the appropriateness of these metrics are the following: First, it is important that the data set evaluated covers both high-income and lower-income countries in a consistent manner. It is possible to find data on specific technologies, e.g., automobiles, passenger aircraft, and also on sector technologies, e.g., coal power generation, but the data coverage is incomplete and limited in terms of numbers of countries. Second, the data needs to cover the most relevant sectors of the economy and the above described, more detailed data adds to the existing data collected in the previous convergence studies. Third, this level of aggregation sufficiently captures the key technologies per sector, for example, coal or natural gas power generation in the electric sector. These technologies can be further broken down by more specific types and fuels however the data for that categorization is not collected consistently across countries and over time which would strictly limit the available data. The final reason for the use of these aggregate metrics is a practical one on two counts: (1) the data used needs to be easily obtainable for researchers and reliable; the data from the IEA meets all of the above criteria; and (2) the data used in climate economic models to set the models up and in reporting results is similarly aggregated and hence also fully consistent with these aggregate metric on technology representation.

3.5. Economic Output Data

Country specific economic data, for the countries in Table 5, is gross domestic product (GDP) at constant prices which refers to the volume level of GDP where the constant price estimates are in terms of a base period which is 2005 and indexed to U.S. dollars (USD). The data source is the United Nations Statistical Division (UN, 2010). According to the UN report, the price and quantity components of a value are identified and the price in the base period is substituted for that in the current period. Two main approaches are used in developing the data: First, the "quantity revaluation", is based estimated by multiplying the current period quantity by the base period price. Then second, "price deflation", requires dividing price indexes into the observed values to obtain volume estimates. The resulting price indexes are calculated from prices of the major items contributing to each value.

3.6. *First Test of Technological Convergence: Cross-sectional Coefficients of Variation*

The first examination for convergence across the newly added, more detailed energy sector and related climate mitigation technologies is calculating the cross-sectional coefficients of variation. This was done over the 112 countries in the dataset for the four electricity generation types, i.e., coal, natural gas, biomass and waste renewables, and wind and solar renewables; and for the three petroleum types, i.e., petroleum for transportation, petroleum for oil refining, and petroleum for chemical and petrochemical production.

The coefficient of variation for each of the technology types is defined as the standard deviation of a variable divided by its mean over the country dataset. In this analysis, the data are the respective measures of technology represented by intensity measures: (1) MWhr of electricity produced per unit of real GDP per year, and (2) KTOE per unit of real GDP per year.

High Income (29)	**Middle and Low Income (83)**		
Australia	Albania	Guatemala	Philippines
Austria	Algeria	Haiti	Qatar
Belgium	Angola	Honduras	Romania
Canada	Argentina	India	Saudi Arabia
Cyprus	Bahrain	Indonesia	Senegal
Czech Republic	Bangladesh	Iran	Slovakia
Denmark	Benin	Iraq	South Africa
Finland	Bolivia	Jamaica	Sri Lanka
France	Brazil	Jordan	Sudan
Germany	Brunei Darussalam	Kenya	Syria
Greece	Bulgaria	Korea	Tanzania
Hungary	Cameroon	Korea, DPR	Thailand
Iceland	Chile	Kuwait	Togo
Ireland	China	Lebanon	Trinidad & Tobago
Israel	Colombia	Libya	Tunisia
Italy	Congo	Malaysia	Turkey
Japan	Congo	Malta	UAE
Luxembourg	Costa Rica	Mexico	Uruguay
Netherlands	Cote d'Ivoire	Morocco	Venezuela
New Zealand	Cuba	Mozambique	Vietnam
Norway	Dominican Republic	Myanmar	Yemen
Poland	Ecuador	Nepal	Zambia
Portugal	Egypt	Nicaragua	Zimbabwe
Singapore	El Salvador	Nigeria	
Spain	Ethiopia	Oman	
Sweden	Former USSR	Pakistan	
Switzerland	Former Yugoslavia	Panama	
United Kingdom	Gabon	Paraguay	
United States	Ghana	Peru	
Total 112 countries			

Table 3-4: List of counties evaluated – classification as of income level in 1971.

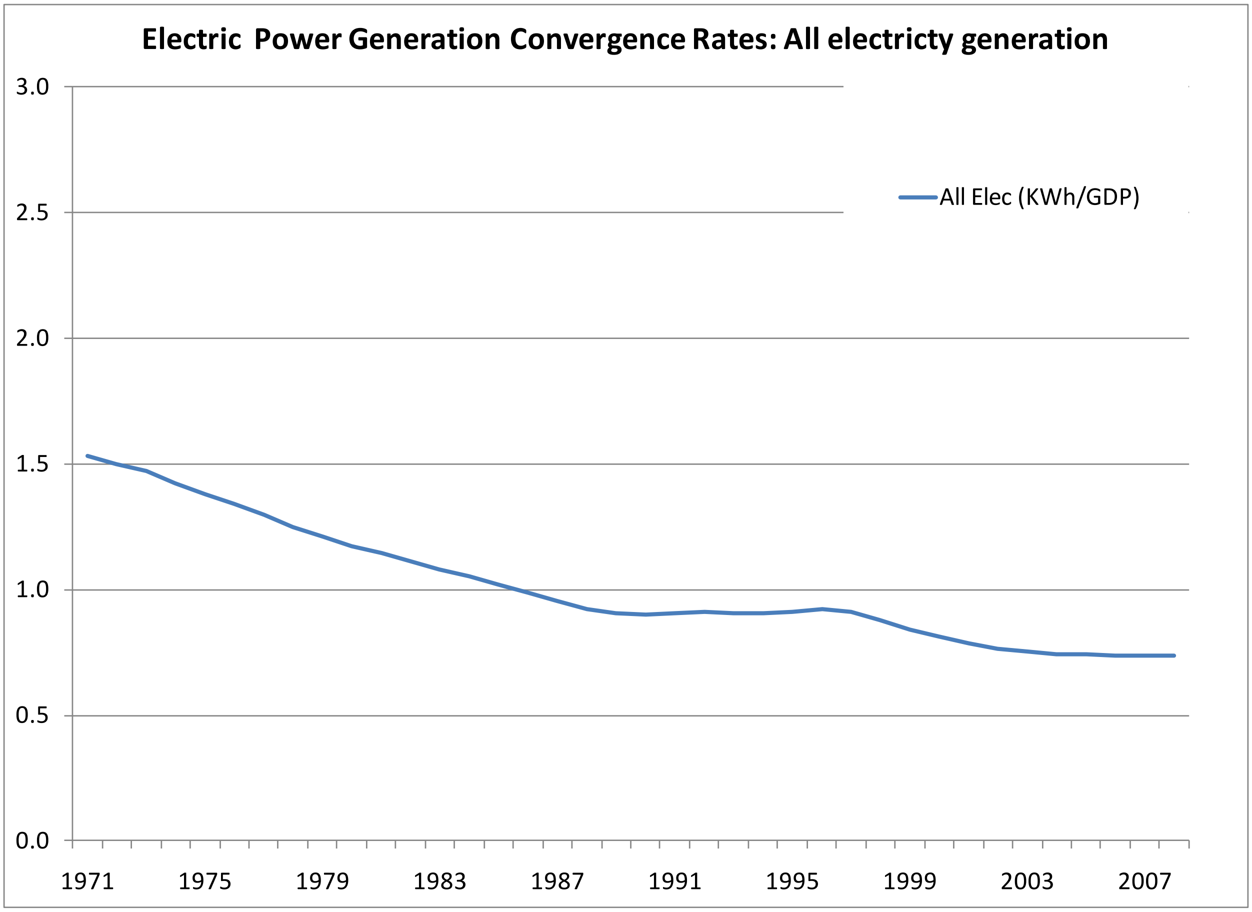

Figure 3-1: Electric Power Generation Convergence – All generation.

The results of the calculated time-varying coefficients of variation for the selected technology measures are presented in Figures 3-1to 3-10. Figure 3-1 shows the coefficients of variation for aggregate electricity generation technologies. In comparison to the earlier Comin and Hobijn (2004) research two key observations are made. First, the level of convergence is similar in the later period of analyses, starting in 2000 with my coefficient estimate of 0.7 to Comin and Hobijn's estimate of 0.6, indicating more converge of the combined electricity generation which is consistent with maturity phase of electricity production as a key input into overall economic activity across the countries in the dataset. Second, there is a clear greater divergence in convergence in my data set between 1971 and 1990. This can be attributed to the much broader range of country incomes and more countries in my dataset. This is an indication of the growing share of electric energy as an input to economic production or electrification across countries evaluated.

The above measure of all electric generation is the one measure that is the same as the original Comin and Hobijn (2004) research, albeit over a smaller and different country-income range. A key objective of this research is to evaluate more specific technological convergence in energy and climate mitigation technologies which can be seen in the following figures by focusing on the convergence of particular electricity generating technologies.

Coal generation convergence is illustrated in Figure 3-2. For this technology, which has the broadest and longest data coverage across the countries in the dataset and the longest, continued use for electricity generation, the degree of convergence has remained relatively stable. This is surprising since I expected a traditional example of technological convergence for a mature technology, that is, with the coefficient of variation approaching zero. Given the available data I can only offer a suggestion as to why this is the case. Within the broad category of fossil coal combustion for power generation, there are variations in the types of power plants technologies, e.g., from sub-critical pulverized coal, to supercritical pulverized coal, to ultra-supercritical pulverized coal, which have different heart-rate efficiencies and costs. These differences in fuel-specific technologies could persists over time and between the high-income and low- & middle-income countries so that, in a broad, aggregate measure, i.e., coal, a divergence persists and absolute converge is not observed over time. A more detailed dataset with further breakdown of coal unit technologies could help illuminate these dynamics but I have not found a sufficiently consistent and robust enough set of data to conduct that analysis.

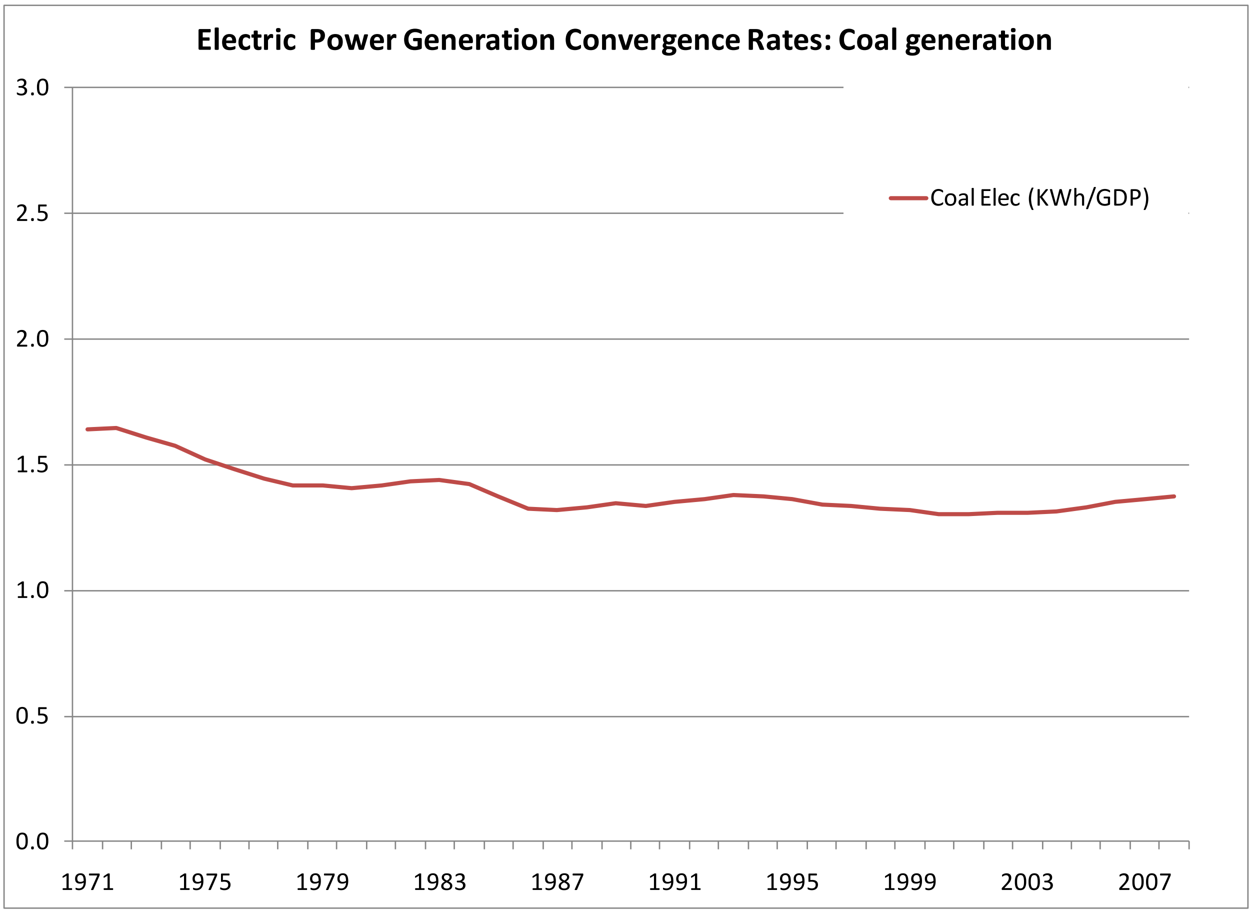

Figure 3-2: Electric Power Generation Convergence – Coal.

Evaluating the convergence of biomass and waste renewables in Figure 3-2 shows a greater degree of convergence than in the coal measure over time but still exhibiting a degree of divergence persisting at the end of the time period evaluated. Biomass and waste are classified as renewables but the use of these fuels has primarily been to take advantage of cheap and available waste material and not necessarily for the purpose of reducing carbon dioxide emissions and climate change concerns. In this context, electricity generated from biomass and waste can be considered a more mature technology than newer renewable technologies that have been developed with GHG mitigation in mind, i.e., solar and wind power renewables.

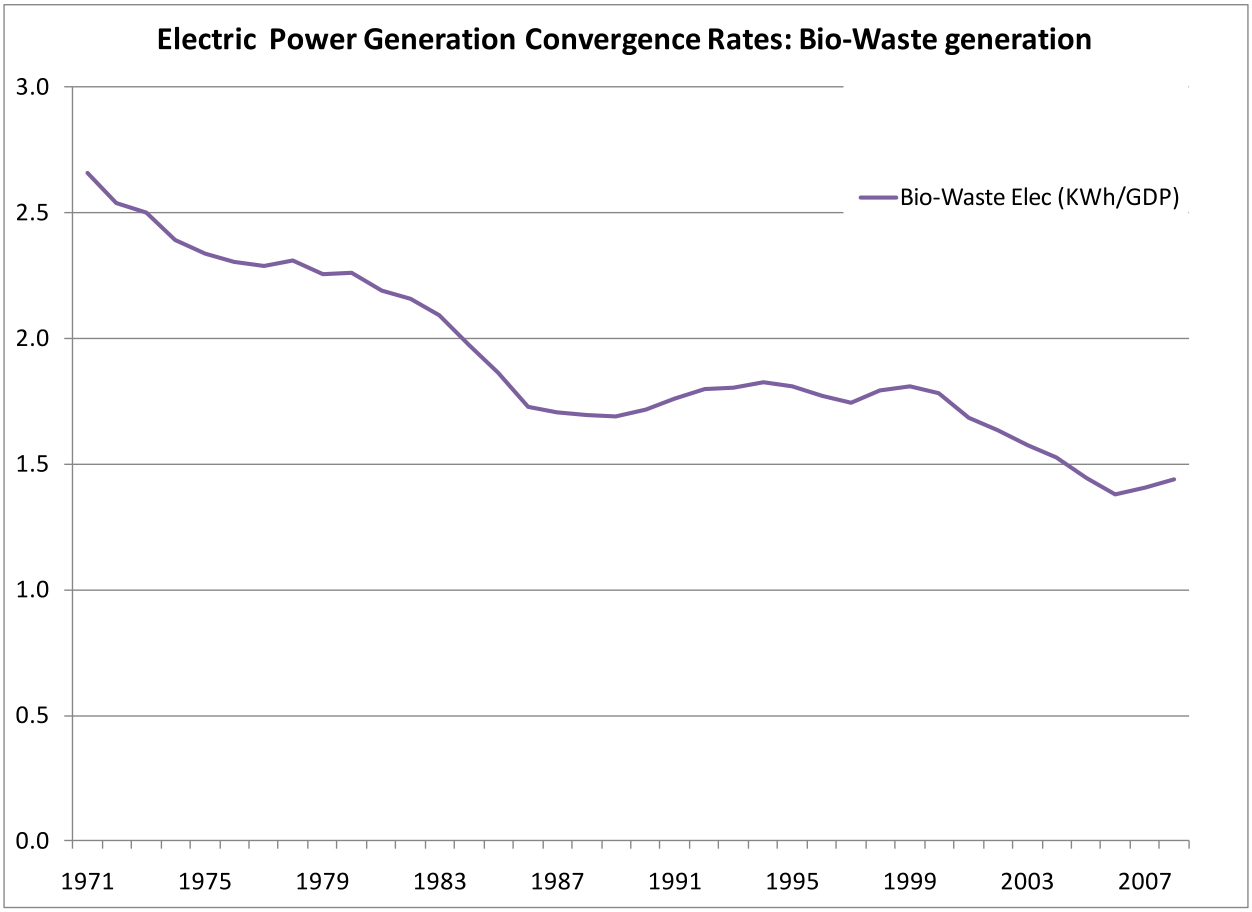

Figure 3-3: Electric Power Generation Convergence – Bio-waste.

The convergence in the use of natural gas for electric power generation, as shown in Figure 3-4, exhibits a similar trend that that of biomass and waste renewables, although with a more pronounced and smooth trend toward convergence. Here too, however, there is not an absolute convergence closer to a zero coefficient of variation.

Turning to more traditional forms of renewable power, we can see convergence rates for wind and solar power electricity generation in Figure 3-5 (notice that the scale is changed). Here a clear and distinct pattern of convergence can be seen in the coefficient of variation, starting at about 7.5, continuing sharply down to just over 1.5 at the end of the period with a noticeable disruption in around 1990. This observed dynamic in wind and solar power electricity generation shows a pronounced catch-up effect expected of newer technologies. At the same time, there has not been total convergence, which is also expected given the rapid pace of technology development on this area.

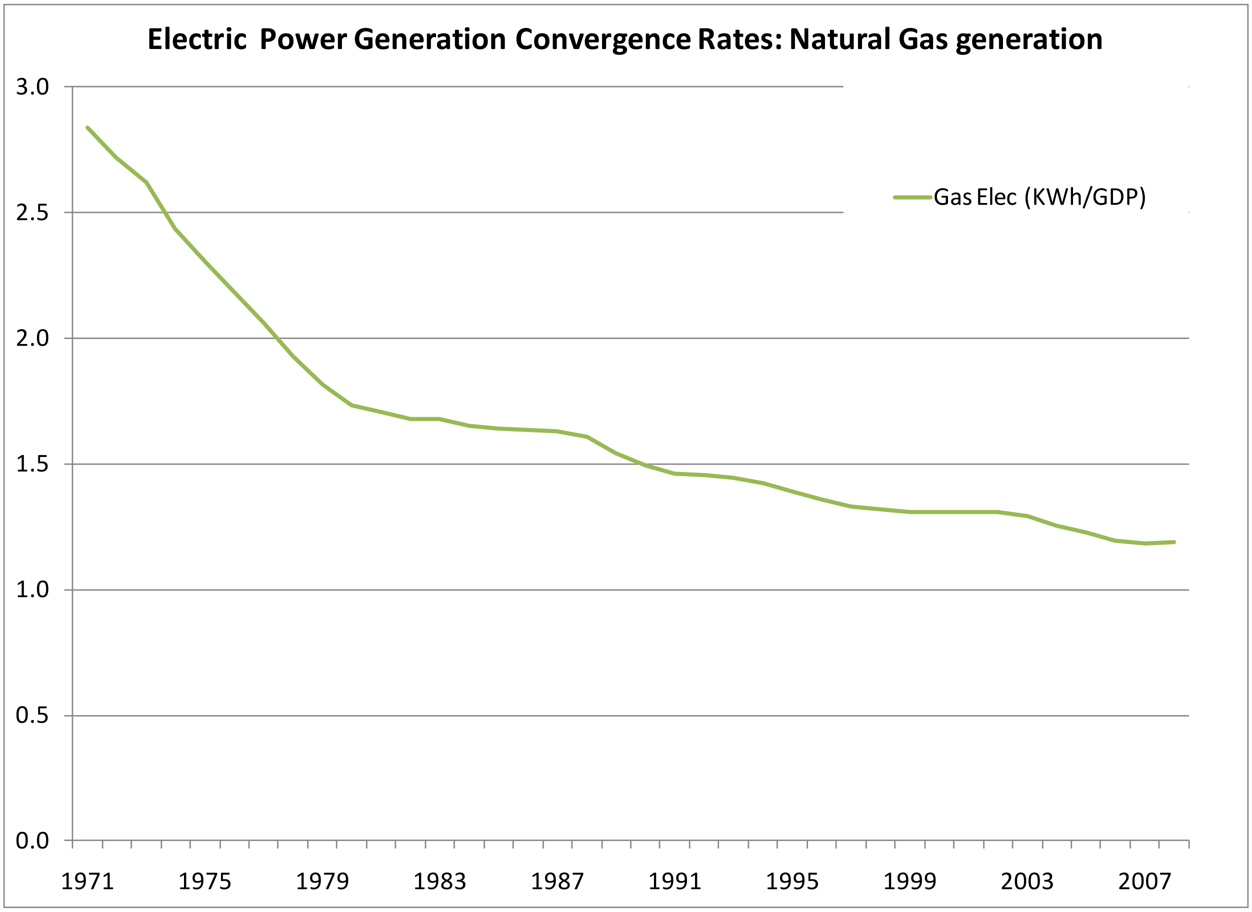

Figure 3-4: Electric Power Generation Convergence – Natural Gas.

Lastly, Figure 3-6, puts the converge rates of all of the electricity generation measure on one chart for easier comparison. Here the very different range and rate of convergence of the newer, renewables technologies of wind and solar are even more distinct. In addition, the patterns of convergence between the different technologies make sense in that the older, more dominant technology, coal, has the least amount of convergence or catch up given that it is more widely established than the others. This is then followed by slightly higher degree of converge with both the gas and biomass & waste technologies. Lastly, the newer and more GHG mitigation specific renewables of wind and solar shows the greatest convergence across the electricity generation measures evaluated.

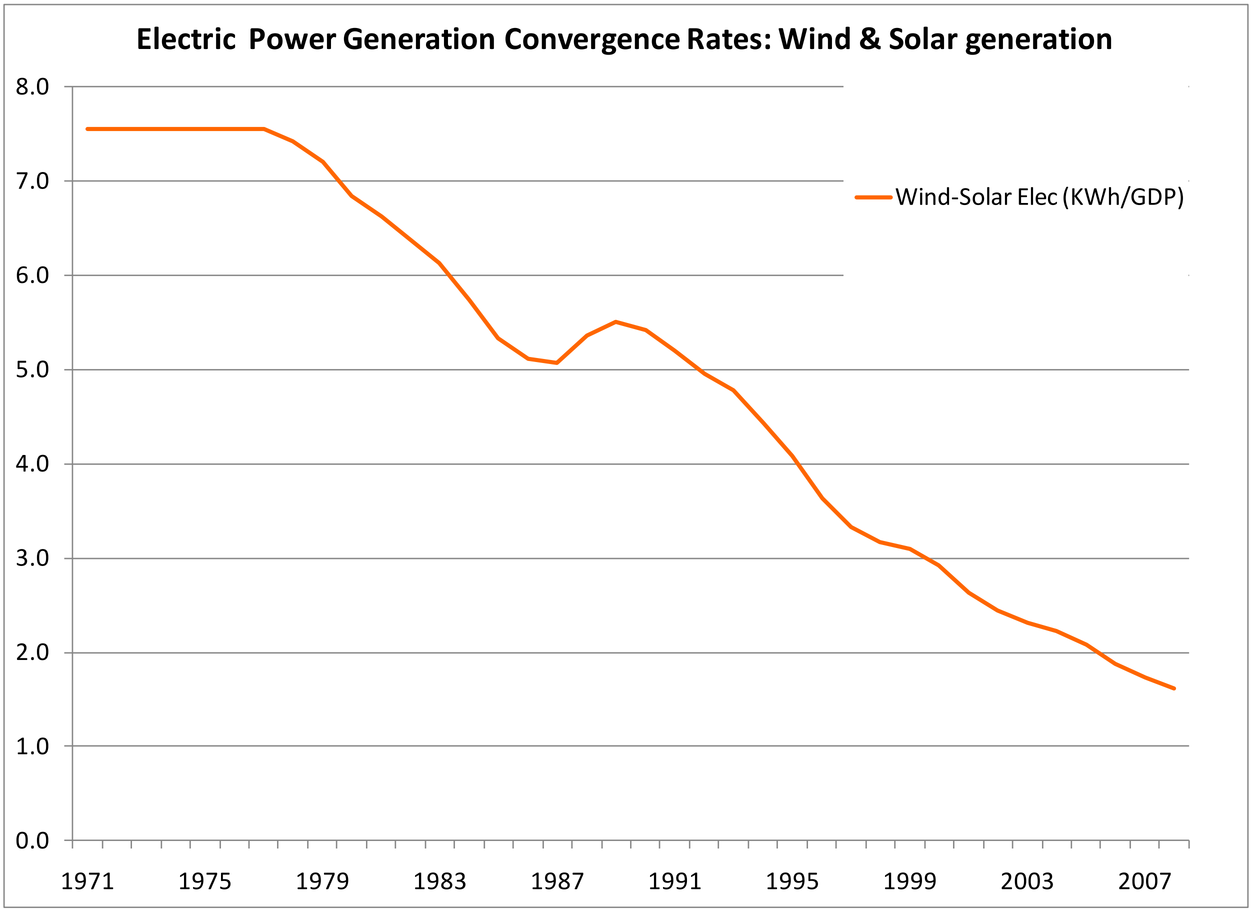

Figure 3-5: Electric Power Generation Convergence – Wind and Solar.

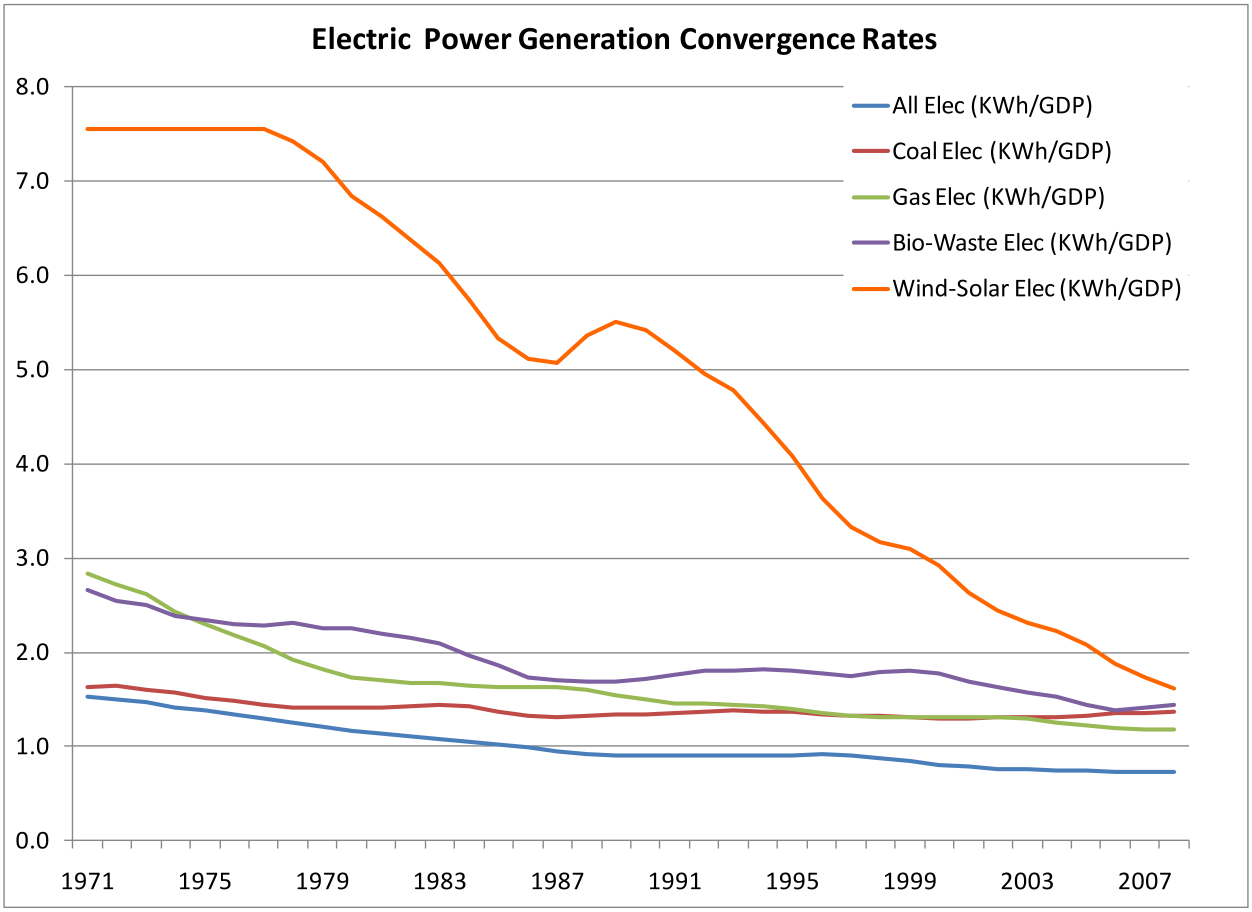

Figure 3-6: Electric Power Generation Convergence – All detail.

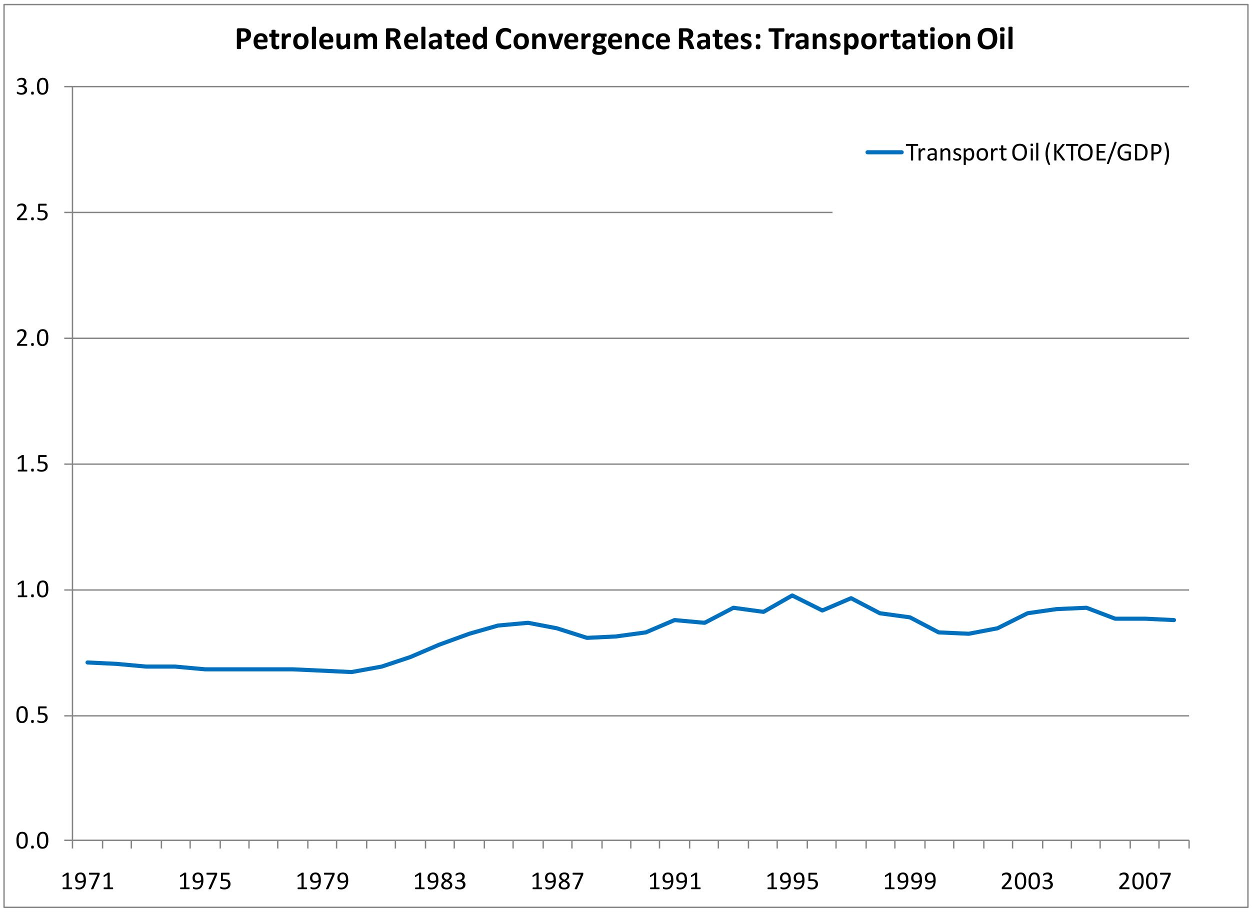

Figure 3-7: Petroleum Convergence – All.

The second set of estimates, based on the 112 countries in the dataset, is on the three petroleum types, i.e., transportation, oil refining, and chemical & petrochemical production, which provide an assessment on technological convergence and energy intensity related to another key energy sector. For these convergence estimates the country data used is in terms of KTOE per unit of real GDP per year. The original research by Comin and Hobijn (2004) does not include any analysis of the convergence of petroleum in any form.

The first petroleum convergence assessment is that for transportation, Figure 3-7, which in this context means petroleum used for all domestic transportation. The refining of petroleum into various transportation fuels, e.g., gasoline, diesel, can be considered a stable and established technology, especially over the time period analyzed (1970 to 2007). It is somewhat surprising that there is not a higher degree of convergence toward the end of the time series or the coefficient of variation getting closer to zero. This is a further example where a technology has reached a decline phase in terms of technological progress and where the catch up effect or convergence is not observed. At the same time, the coefficient values start small and remain stable throughout. This may be a similar situation as the electric coal generation analysis above in that a more detailed technological assessment may show different patterns of convergence.

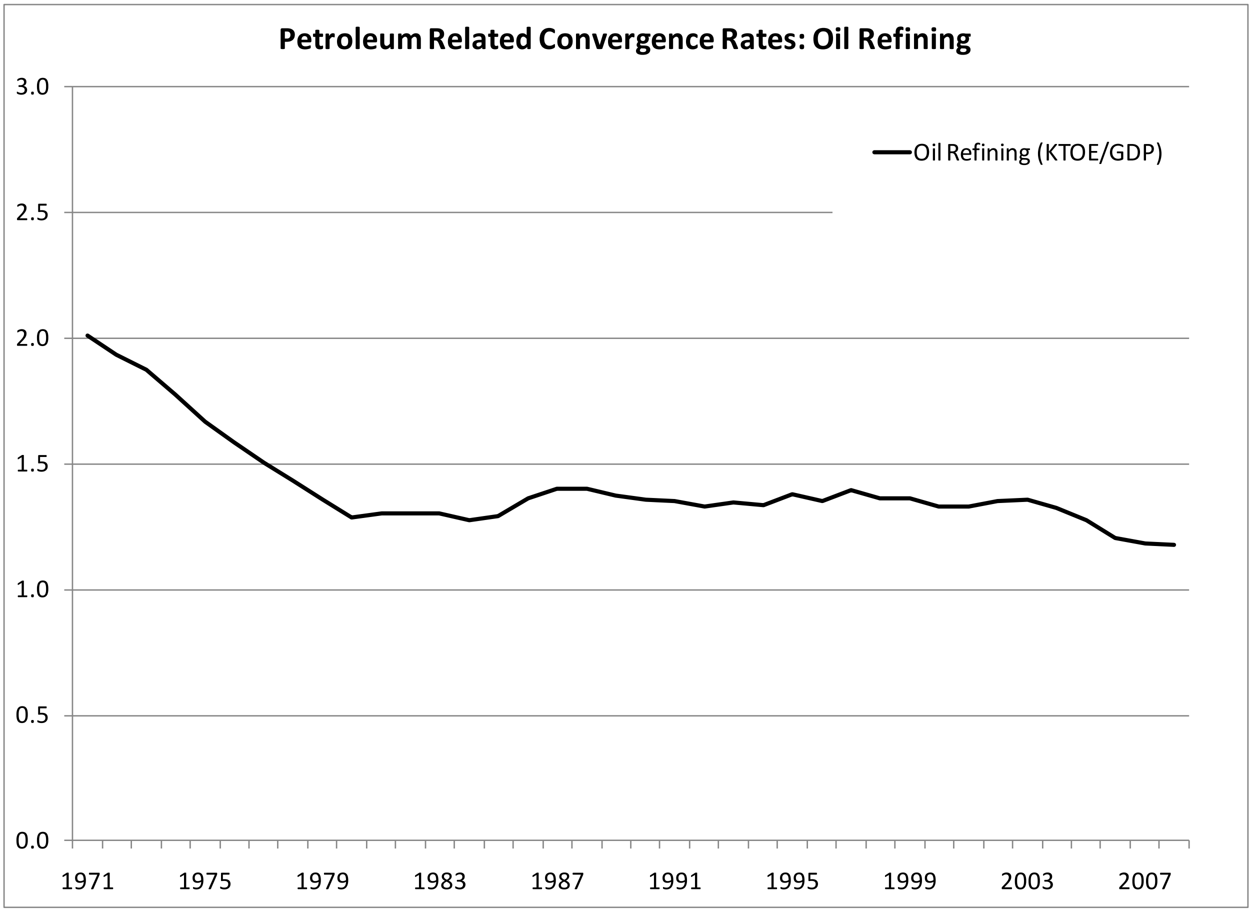

Figure 3-8: Petroleum Convergence – Oil.

The convergence rate for the oil refining sector is illustrated in Figure 3-8. This energy measure includes the use of petroleum, as primary energy, for the manufacture of finished oil products and the corresponding output. This trajectory shows a decadal catch up period during the 1970s which is then followed by a similar stable path out to 2007. This different occurrence of convergence is worth further exploration to determine the driving forces of that short period of convergence. Starting around 1980, the technology on oil refining shows the similar decline phase and the associated stagnation of technological convergence.

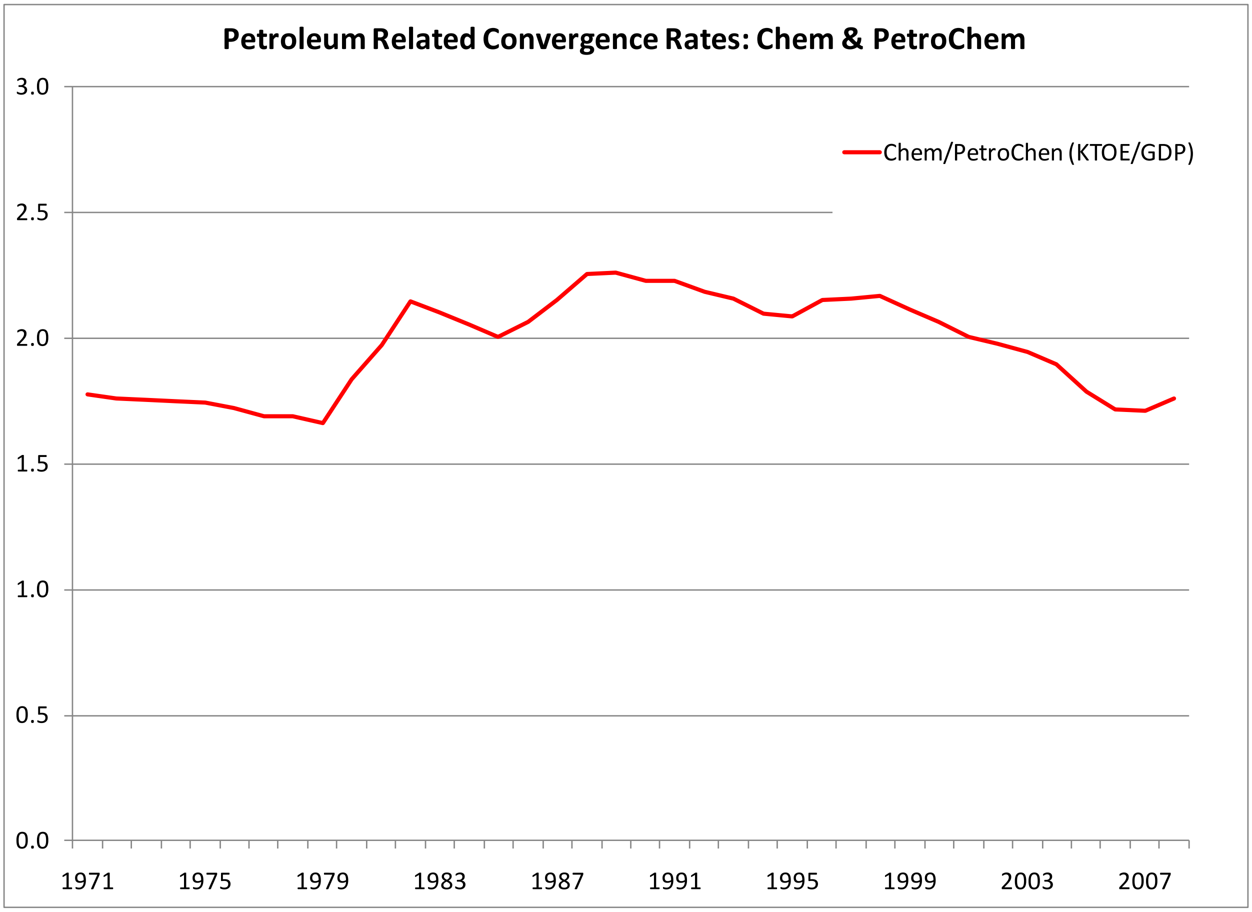

Figure 3-9: Petroleum Convergence – Chemicals and Petrochemical.

In the assessment of the convergence rate for last petroleum category, Chemical and Petrochemical industry, a very different dynamic is seen, one that is unique to all the technology measures evaluated in this research. After the 1970s, where stability was experienced, Figure 3-9 shows almost two decades of technological *divergence* in the chemical and petrochemical industry. The first observation to make is that similar to the transportation sector, a lack of technological convergence here is an indication that, in aggregate, this sector has reached its technological decline phase. The second observation is that given the broad number of sub-sectors included in this measure, such as chemical products, transformation of materials by a chemical processes, and also the manufacture of pharmaceuticals, there may be other dynamics pushing the divergence across the countries evaluated. One that comes to mind is the impact of international trade where the associated chemical and petrochemical industries can move to low-& middle-income countries and import the needed petroleum feedstocks. Comin and Hobijn (2004) point to international trade as a possible explanation in the similar lack of convergence observed in the dataset for the global textiles industry. A comparison of the various petroleum related convergence rates in shown in Figure 3-10.

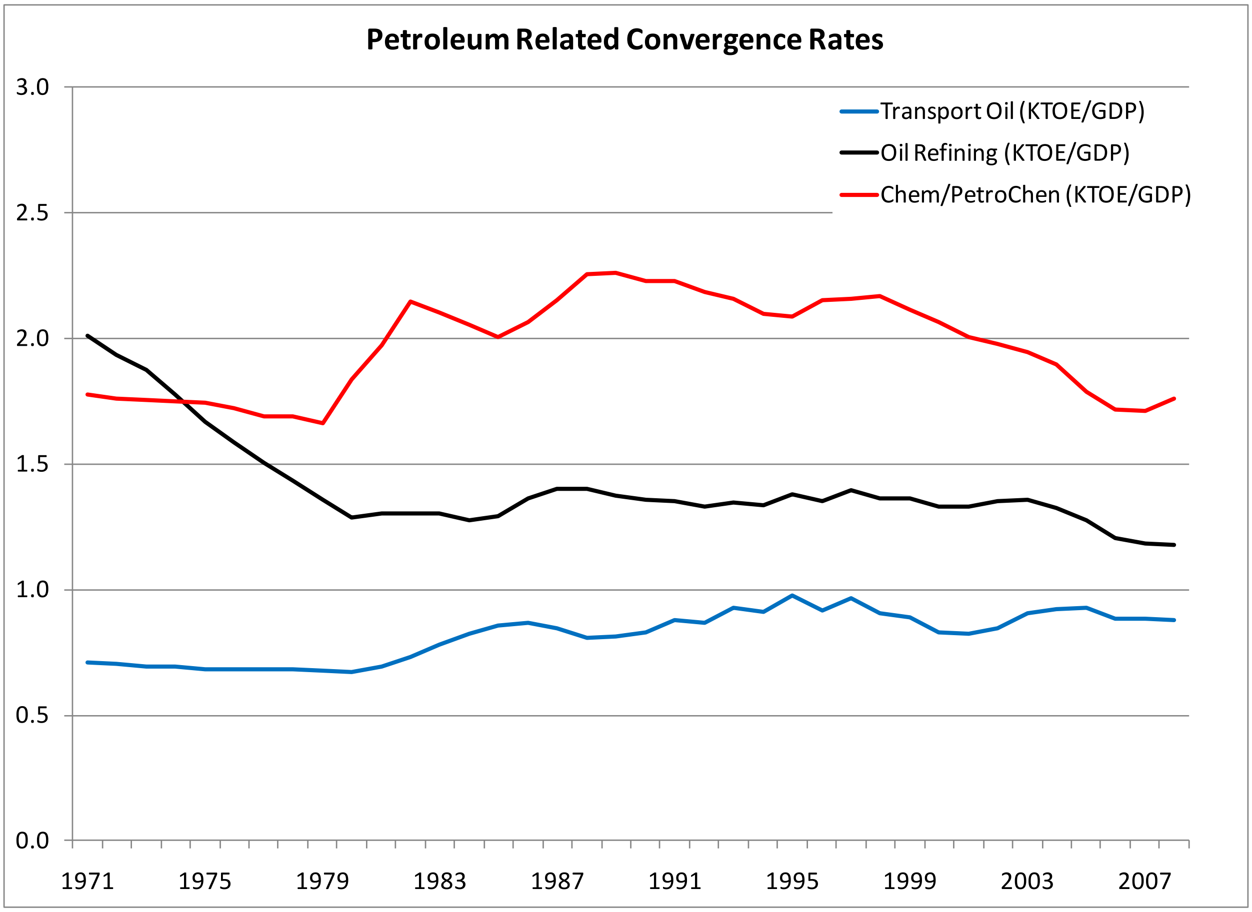

Figure 3-10: Petroleum-related Technological Convergence – All detail.

3.7. *Second Test of Technological: Beta convergence*

Following on the original Comin and Hobijn (2004) research, I also conducted a second test for converge or Beta (β) convergence of technology adoption. In the economic growth literature, β convergence is defined as a negative relationship between the growth rate of a variable of interest in a future time period and the initial time period from the countries analyzed (Barro and Salai-i-Martin, 1992). The standard regression equation drawn from the literature on economic convergence and used here is:

$$Y_{ijt} = \alpha + \beta\, Y_{ijt-1} + e_{ijt}$$

Where, Y_{ijt} is the measure of technology adoption for the *jth* technology in country *i* at time *t*, and is measured in logs whenever the variable is not a share. The key estimated variable is β which can be use to estimate the speed of convergence given by -ln(β). Table 3-5 provides the regression results on evaluating the 8 technology measures across the dataset of 112 countries.

From these measures of convergence or the pace of convergence a few key observations can be made. First, it is important to remember than these estimates are developed by comparing two periods of time, in this case 1971 and 2007. Second, it is important to evaluate these technology measures by sub-sector if at all possible.

All Electricity	**Coal Electricity**	**Gas Electricity**	**Bio-Waste Electricity**	**Wind-Solar Electric**
0.71 (0.05) 34% R-^{2} = 0.66	0.43 (0.22) 86% R-^{2} = 0.67	0.85 (0.07) 16% R-^{2} = 0.67	0.83 (0.11) 19% R-^{2} = 0.50	0.56 (0.16) 57% R-^{2} = 0.18
Transportation Oil	**Refineries Oil**	**Chemical Petrochemical**		
0.58 (0.07) 54% R-^{2} = 0.37	0.92 (0.03) 8.4% R-^{2} = 0.90	0.77 (0.06) 27% R-^{2} = 0.70		
Standard errors are in parenthesis. Speed of convergence is calculated as -ln(β).				

Table 3-5: New Estimates of β Convergence.
Estimates of βs and the speed of convergence, in percent, for selected technologies

This can be seen where the speed of convergence for the All Electricity measure is 34 percent whereas it can range from a very high estimate of 84 percent for coal electricity to mid to high teens for gas and bio-waste electricity. The speed of convergence for wind-solar electricity is also estimated to a high value of 57 percent but the very low R^2 value indicates that this is the least robust measure of the set. The results are consistent with expectations in that: (a) the more widely used coal electricity generation technology has a high speed of convergence, that is, the similar technology (as defined above) is utilized across the country dataset; and (b) the newer and more divergent technologies, mainly gas and bio-waste electricity have a slower pace of convergence.

Turning to the petroleum measures of convergence, similar observations can be made. The speed of convergence estimated for transportation oil is highest at 54 percent, again given that it is a widespread technology utilized across many countries. Similarly, the two other petroleum-related technology measures, refineries and chemicals, with speed of convergence estimates of 8 and 27 percent, respectively, are more widespread across the country dataset.

In the evaluation of both technology measure sets, electricity generation and petroleum, it is clear that there are appreciable and measurable differences in the rate of adoption of technologies across and between high income and low- & middle income countries.

3.8. Observations on Convergence Testing

From the original work of Comin and Hobijn (2004) paper, based on their convergence analysis of mainly OECD high-income countries, they highlighted three main conclusions:

1) They observe common patterns in the diffusion of a broad range of technologies across many countries;
2) They suggest a pattern of what they term "trickle-down" diffusion that is robust across technologies. They found that most of the technologies evaluated in their study originated in the more advanced countries and then trickle down to relatively less advanced countries; and

3) They find that the overall rate of technology diffusion has increased over time, especially in the post -WWII era.

My contribution to the analysis of technological convergence, with a link to technology diffusion, is to: (a) add more detailed energy sector and related climate mitigation technologies for the four electricity generation types, i.e., coal, natural gas, biomass and waste renewables, and wind and solar renewables; and for the three petroleum types, i.e., petroleum for transportation, petroleum for oil refining, and petroleum for chemical and petrochemical production; and (b) expand the analysis to 112 countries covering 29 high-income countries and 83 middle-& low-income countries.

The main conclusions I draw from this analysis are the following:

- Similar to Comin and Hobijn (2004) I find an observed pattern of technological convergence between high-income countries and middle-& low-income countries for the technology measures evaluated; however;
- For the one similar measure between the Comin and Hobijn (2004) paper and this analysis, aggregated electricity generation technologies, convergence is faster between high-income countries and middle-& low-income countries (this analysis) than that observed between OECD countries;
- The rate of convergence differs based on how the technology measure in aggregated, e.g., all electricity generation show a different patterns than coal electricity, an established technology, and even more different than wind and

solar renewable electricity, a newer technology;

- This is the same for oil refining, however, transportation and chemical production show very distinct patterns;
- Established technologies that have a broad utilization across most countries, like coal electricity, exhibit a degree of convergence that has remained relatively stable;
- Newer technologies (wind and solar) exhibit much faster convergence rates than stable technologies;
- For all of the technologies evaluated, there was not one technology that showed full technological convergence, that is with the coefficient of variation approaching zero, which I think this is a particular aspect of energy technologies; and finally
- For the one sector that is most related to international trade, for chemical and petrochemical production, there is an observed period of technological divergence in the country dataset.

The implications of the research up to this point, particularly for the next section on modeling different rates of technology, are mainly three: First, details within technology groups matter; the more detail the better for specifying convergence rates of technologies. Second, newer technologies have faster convergence than older more established technologies. Finally, the assumption of total, full convergence of technologies, at least for energy sector and climate mitigation-related technologies is not supported by the historical data and a broader country analysis.

3.9. Additional Technology Evaluation Measures

In addition to the new research on technology convergence completed in the previous section, a couple of different measure or metrics for evaluating and comparing technology performance between countries of different income groups, particularly in electric power generation, is provided in this section. Including these additional technology performance comparisons, on electric power fossil efficiencies and renewable capacity installment, have the same objective as the technology convergence analysis, that is, to see if historical rates at which technology diffuses between countries can help inform and improve new climate economic modeling projections.

Using data from the International Energy Agency from two recent publications (Klaassen, 2011; Taylor,2008) allows for a historical comparison of electric power coal-fired efficiencies across a range of countries, both in the High-Income group, e.g., Japan, Germany, the UK, and USA, and in the Lower-Income group, e.g., China, India, and South Africa.

Data on fuel inputs to public electricity and CHP plants and electricity and heat outputs from these plants are taken from IEA statistics for both the OECD and non-OECD countries. It is important to note that the IEA data used in the efficiency calculations covers the following (Taylor, 2008): Energy inputs for combined heat and power (CHP) and electricity units are based on net calorific values; and the energy outputs are defined as the gross production of electricity and heat. In addition and for consistency the particular approach used to calculate electric power efficiencies is as follows:

$$E = (P + H \times s) / I$$

Where:

E = energy efficiency of electricity production

P = electricity production from CHP and electricity plants;

H = useful heat output from public CHP plants;

s = correction factor between heat and electricity, which is defined as the reduction in electricity production per unit of heat extracted;

I = fuel input for public electricity plants and public CHP plants

Both studies find that average global efficiencies for coal-fired electricity in more recent years is just under 35%, for natural gas-fired electricity it is just under 40%, and for oil-fired electricity it is about 37%. Figure 3-11 below highlights efficiency levels from a few countries from both income groups, showing patterns over time for coal-fired electricity. This data show that coal efficiencies in the lower-income countries are lower than those in the high-income countries, generally, and that the gap between the two, persist over time. South Africa and South Korea are exceptions with the former's deployment of high-efficiency units in the early 1980s and the latter's in the early 2000s. With the exception of India, efficiency levels have improved over time for most countries.

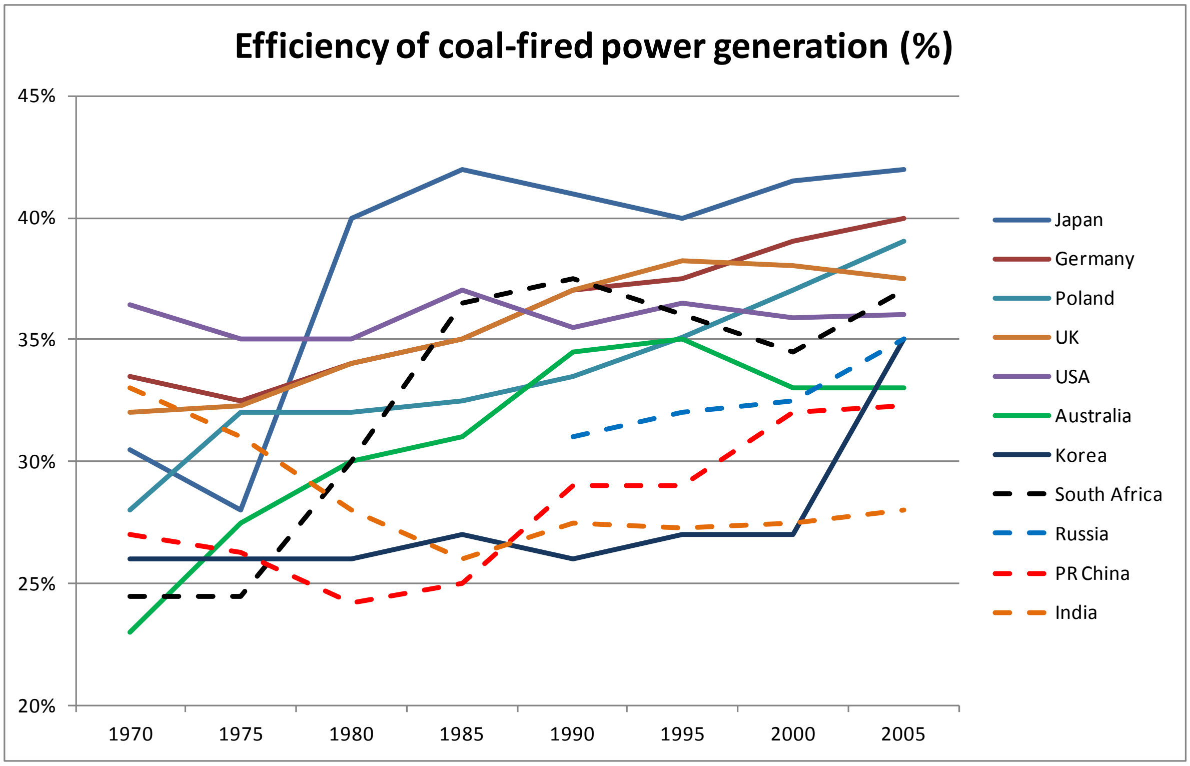

Figure 3-11: Efficiency of coal-fired power generation.

Data sources: Klaassen, 2011; Taylor,2008

Using the same approach to calculate electric power fossil efficiencies Maruyama & Eckelman (2009) covered coal- and gas-fired generation and also grouped countries by the OECD and non-OECD classifications. This study provides a good comparison to the High-Income and Lower-Income classifications used in the convergence analysis above and also for the climate mitigation modeling in the subsequent section. Summaries of Maruyama & Eckelman (2009) assessment on efficiencies are provided in figures 3-12 to 3-14. Coal-fired efficiencies show the same pattern as in Fig 3-11 above and also show the persistent gap between non-OECD and OECD groups over a 30-yr plus period. In addition, the performance of the non-OCED coal plants by the end of the time period (2005) does not catch up or converge to the performance of the

OECD plants at the beginning of the time period (1973). There are exceptions, of course, as noted above by the example South Africa but the general pattern is clear: there is at least a 30-year gap in performance between the OECD (High-Income) group and the non-OECD (Lower-Income) group of countries and has even widened somewhat in the 2000s.

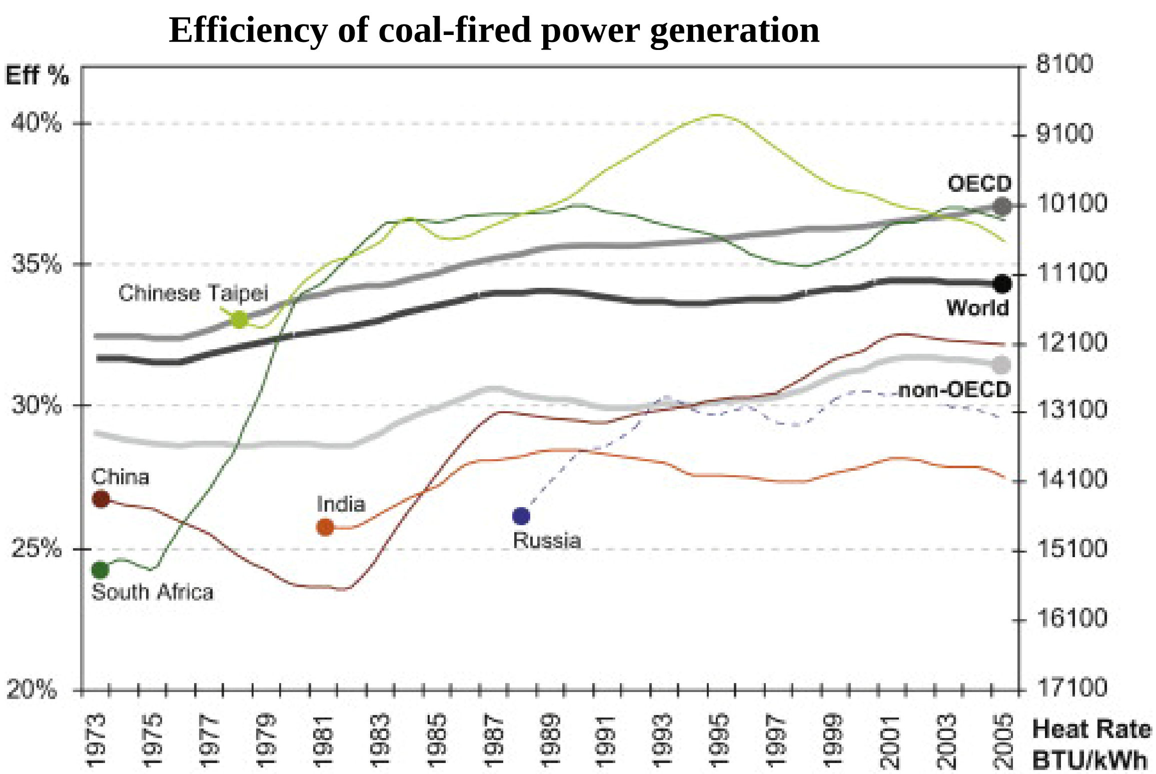

Figure 3-12: Coal electric power efficiencies.
Source Maruyama & Eckelman (2009).

Evaluating natural gas-fired electric efficiencies in Figure 3-13 below shows similar patterns to coal efficiencies over the 30-year period but some closure of the gap between OECD and non-OECD groups starting the 1990s. Efficiencies in both groups continue to improve and at a faster pace than coal efficiencies. The same key observation is made for natural gas efficiencies: there is not a clear indication of catch up or convergence between the non-OECD and OECD groups in the period evaluated.

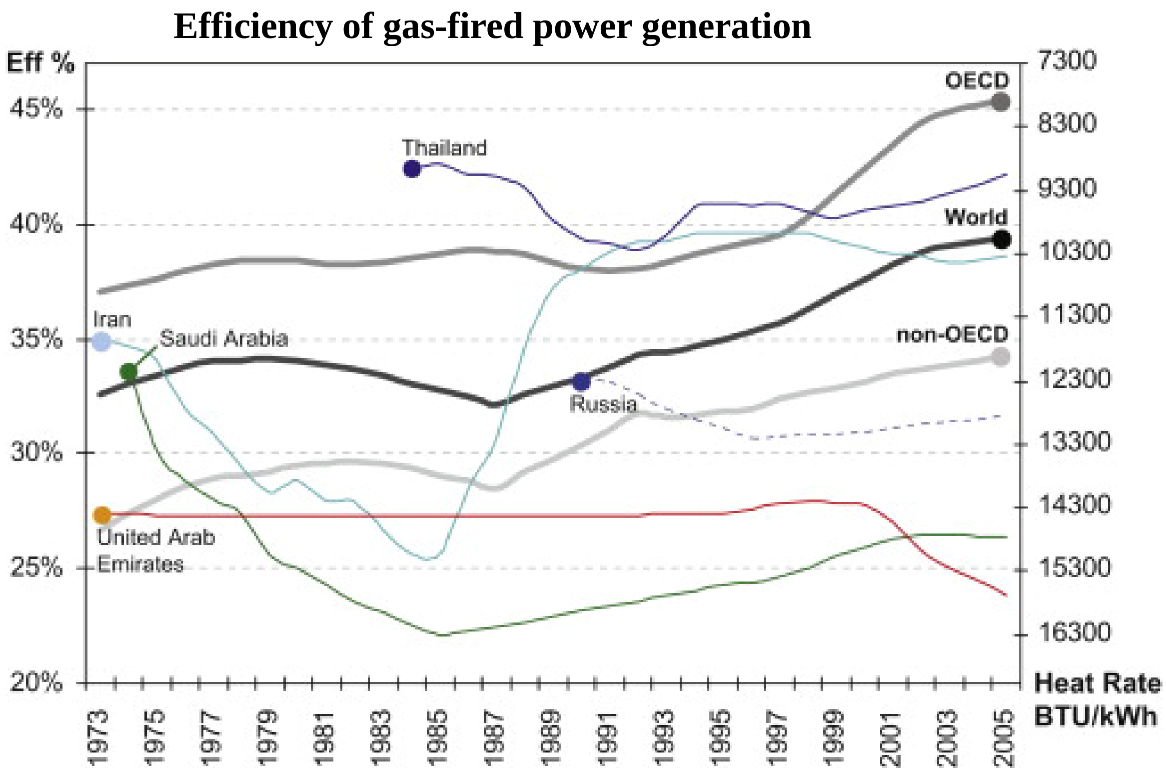

Figure 3-13: Natural gas electric power efficiencies.
Source Maruyama & Eckelman (2009).

A further electric sector measure or metrics that can help in evaluating and comparing technology performance between countries of different income groups is renewable power. More specifically, the data below compare the amount of installed renewable capacity for wind power and solar & tidal wave power, respectively, to total non-hydro renewable power. The other renewable power technologies included in non-hydro power include geothermal and biomass & waste renewables. Given that solar and wind power technologies have not been globally deployed until more recent times, consistent global data only spans 2005 to 2011. The data is from the Energy Information Administration (EIA, 2014b). Comparing wind power and solar & tidal wave power to total non-hydro renewable power allows for a more detailed appreciation of the diffusion these newer technologies. Hydro power has remained relatively stable over the time period evaluated so there is not much of an advantage in including it. And including all power generation technologies swamps over the contribution of wind and solar & tidal wave power thereby making the regional comparison more difficult. As a result these comparisons provide more of a current snapshot versus the longer-term trends assessed above for electric power efficiencies.

Figure 3-14 provides the first comparison for wind power and shows three distinct groupings. At the lower end are the Central and South America countries where wind power capacity share does not raise above 15% by the end of the period. The second grouping is the African continent which starts at 25% in 2005 and over the next six years achieves a level higher than Europe and close to the World level of 60%. This increase in Africa is lead by the countries of Nigeria, Tunisia, Egypt, and Morocco where wind is the only non-hydro renewable power technology. The third and highest percentage groups are North America, where wind is over 70% of non-hydro renewables in both the U.S. and Canada by 2011, and Asia & Oceania, where China and India reach 85% and 80%, respectively, by 2011. Using this metric, wind power as percentage of total non-hydo renewables, provides a different assessment for the potential for technology diffusion with at least two principal lower-income countries, China and India, demonstrating that it is possible to attain similar levels as the high-income regions of Europe and the U.S. Again, this should be considered a short-term comparison of technology diffusion but still instructive in the ability of lower-income countries to deploy newer technologies.

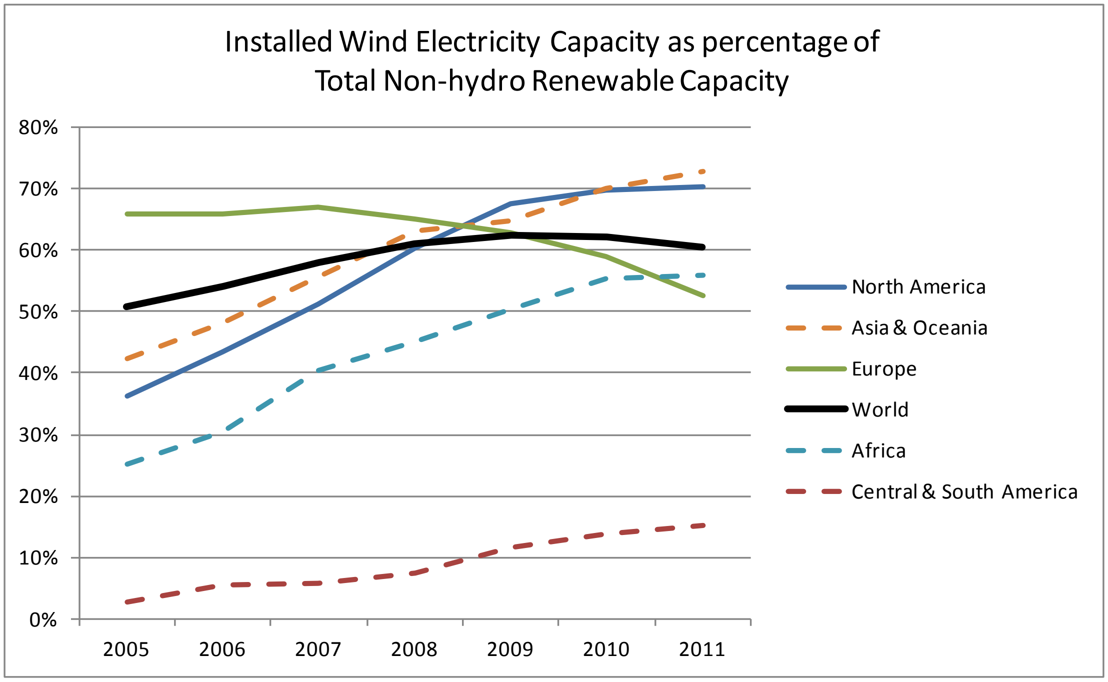

Figure 3-14: Wind Capacity as percentage of total non-hydro renewables.
Source: EIA, 2014b.

The assessment of solar and tidal wave power capacity however tells a different and somewhat distorted story. Solar power renewable technologies have not penetrated the global electricity sector as well as wind power in most regions, including Central and South America, Africa, and even North America. Asia and Oceania's share of solar and tidal wave power reaches just under 10% by 2011 with the majority of installed capacity occurring in China, Australia, and then India. The distortion is caused by Germany given that by 2011 it had installed more solar power (25 GigaWatts) than all of Asia and Oceania (11 GW) or about 38% of total world solar power capacity. These relationships and the high increase in Europe's (mostly Germany) share are illustrated in Figure 3-15 show solar and tidal renewables as share of non-hydro renewable power.

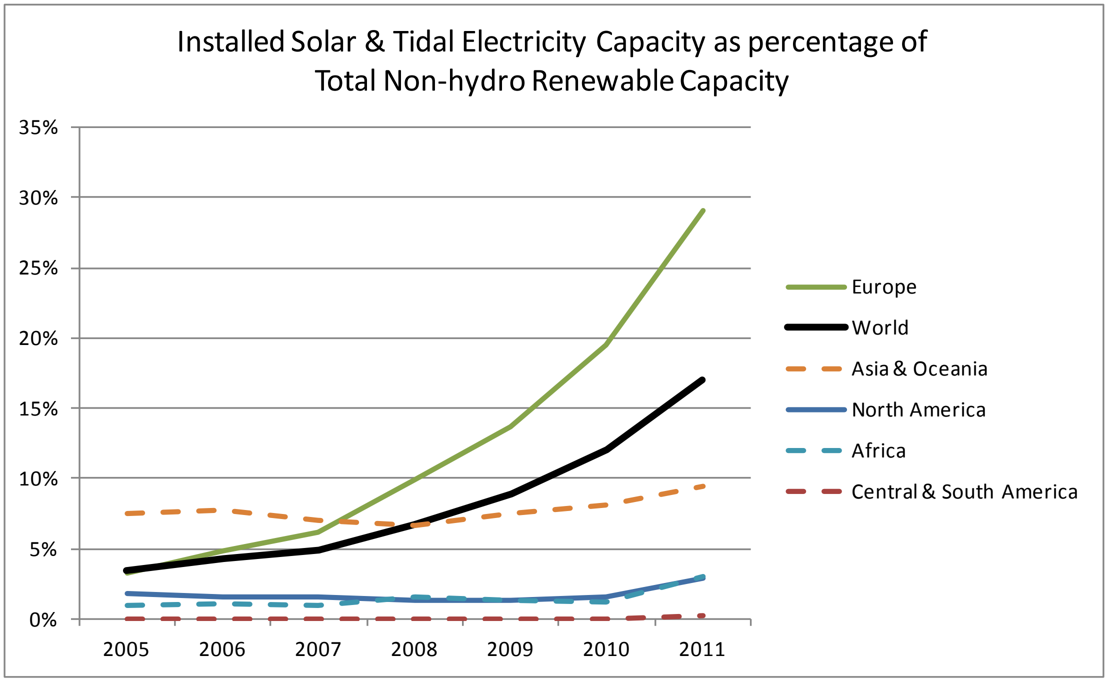

Figure 3-15: Solar & Tidal Capacity as percentage of total non-hydro renewables.

Source: EIA, 2014b.

Comparing wind and solar renewable power capacity of different regions (that also have different income classifications) shows that there are examples of the deployment of newer technologies where lower-income regions (Asia) are not necessarily different, and may even be faster, than higher-income regions (North America in the solar case). The principal point remains that deployment of newer technologies or technology diffusion lags in the lower-income relative to high-income regions as exemplified by the performance of the regions of Central and South America and Africa.   While there are examples of lower-income countries deploying newer technologies on par with high-income countries (e.g., Thailand and South Africa) in the fossil electric efficiencies and Asia in renewable power capacity installments, these additional assessments of technology performance are consistent with the technology converge analysis presented in the above section.

4. Modeling Different Rates of Technological Diffusion Between High-Income and Low- and Middle-Income countries

This section will cover new climate economic modeling to test the impact of different rates of technology diffusion in energy-sector related, climate mitigation technologies and compare them to other key assumptions included in modeling analyses.

The model utilized for this part of the dissertation analysis is the Global Change Assessment Model (GCAM) which was developed and is maintained at the Joint Global Change Research Institute at the University of Maryland (JGCRI, 2013). The main reasons I selected to use the GCAM model apart from other climate economic models is because of the geographic disaggregation and detailed technology representation that allowed me to specify different rates of technological diffusion between high-income countries and low- and medium-income countries.

I provide a summary description of GCAM here to better explain the scenario set up and relationships.

4.1. *Description of the Global Climate Assessment Model (GCAM) used for the analysis.*

GCAM is in a class of economic models commonly referred to as climate economic models when used to evaluate energy, climate mitigation, or technology policies. GCAM can also be considered a highly aggregated integrated assessment model for the purposes of analyzing boarder issues related to climate change such as agriculture and landuse changes, multiple greenhouse gas, aerosols, and other substances that effect global warming, and atmospheric composition leading to global-mean climate changes. For the purposes of this analysis, I focus on evaluating the impact on CO_2 emissions from changes to economic, population, and technology assumption. The model divides the globe into 14 geographic regions and is configured and run as a partial equilibrium model that balances the demand for energy and with the supply of energy from principal commodities or sources of oil, gas, coal, uranium, and renewable sources. The model runs in 15-year time steps from 1990 to 2095. Technologies are represented in the model in the transformation of energy, e.g., electric power generation from coal, and in the use of energy, e.g., gasoline in light-duty vehicles for passenger transportation.

One of the principle reason I selected GCAM for the climate mitigation modeling work in this dissertation is because it has a sufficient level of regional disaggregation in that it breaks up the globe into 14 different geographic regions which are listed in Table 7. Even with this level of detail the model's aggregation is still considerable when in come to countries' populations, land areas, and energy use as exemplified by the regions of Africa, Latin America, Western Europe and Easter Europe. Modeling the whole world in a climate economic or energy model necessities this type of aggregation for the purposes of computational tractability, a degree of model and data management, and ultimately an ability to understand and make use of model outputs.

For the purpose of the analysis on different rates of technology diffusion I needed to organize the 14 GCAM regions into two separate groups by income levels corresponding as closely as possible to the groups evaluated in Section 2. There are various approaches to grouping countries for the purpose of climate mitigation analysis depending on the issues or questions evaluated. The first consideration was along the lines of country or region income level where the “high income” countries were included, that is, United States, Canada, Western Europe, Australia & New Zealand, and Japan. Two regions that are just below that income level but were included in the High Income group are Eastern Europe and South Korea due to technology, geopolitical, and climate policy similarities. These seven countries and regions comprise the full High Income group in Table 4-1 below. The remaining seven countries and regions make up the Middle and Low Income group. These classifications are not perfect as there are countries in specific regions that enjoy higher income than others in their assigned region, e.g., Mexico which is a member of the OECD is in the Latin America region; and there are also countries exhibiting relatively greater technological advancement than others in their regions, e.g., the Baltics in the FSU.

High Income	**Middle and Low Income**
1. United States	8. China/Asia Reforming
2. Canada	9. India
3. Western Europe	10. Former Soviet Union (FSU)
4. Eastern Europe	11. Middle East
5. Australia & New Zealand	12. Latin America
6. Japan	13. Africa
7. South Korea	14. (rest of) S&E Asia

Table 4-1: Regions in GCAM and income groupings.

4.2. *Description of the research scenarios*

In addition to testing the implications of different rates of technology diffusion, I run various other scenarios to test changes in a few other input assumptions key to climate economic modeling analysis. As the rates of technology diffusion are specified exogenously, the other key parameters selected also are specified exogenously, these are: the rate of population growth; the rate of economic growth; and the rate of economic convergence between high-income and middle- & low-income countries. Each one of these changes produces a separate baseline scenario defined as a case where there is no specified CO_2 policy, or no-mitigation case. Each scenario provides an indication of what global CO_2 emissions may be in the absence of concern over the potential for global warming and the ensuing climate change impacts.

Against each of these baseline scenarios a policy case is applied starting in 2015 that specifies a global CO_2 concentration stabilization level of about 420 ppm by 2100. The CO_2 policy is a global constraint that allows countries (or regions of countries as aggregated in the model) to reduce emissions across their energy sectors that produce CO_2 emissions at a level that is consistent with a global carbon price, that is, the model applies an equalized marginal carbon price across all regions. There are various policy approaches to implementing a mitigation policy in climate economic models from a cap-and-trade approach with either a global target that apportions mitigation costs on specified some economic rational (Fisher, et al, 2007) or a multitude of country and regional targets that yield some non-optimal, global mitigation level (Blanford, et al, 2014). The economic policy levers are also diverse in that one could apply costs to GHG emissions, e.g., a carbon tax, at various levels or use subsidies to incentivize clean energy investments in non- and low-CO_2 emission technologies, e.g., a production tax credit for renewable power. For the analysis in this study, applying an equalized, global CO_2 marginal cost is straightforward and allows a focus on the main question evaluated in this dissertation which is the importance of assumptions on technological diffusion.

Below I provide a more detailed description of the model and the changes made to the model structure to execute the scenario run. The scenarios modeled for this dissertation consist of two main sets. The first set of scenarios use the standard model assumptions of technology diffusion where the other key identified exogenous parameters are modified. The first four scenarios yield both a corresponding baseline and climate mitigation case:

1.a. Reference (no policy) case.

This includes the model's standard inputs and assumptions on global population growth, economic growth, economic convergence, as well as the model initial inputs on energy prices, technology costs, and initial conditions on the structure of each regions energy infrastructure and system. With all these initial standard inputs and assumptions the model is then run forward, in this case to 2095, to produce a Reference case where there is no specified CO_2 policy.

1.b. Global CO2 Stabilization policy case from Reference.

Once the Reference case is generated, a policy case is applied starting in 2015 that specifies a global CO_2 stabilization level of about 420 ppm by 2100. This produces a very different and divergent global CO_2 emissions trajectory with regional emissions levels varying based on the level on the energy intensive production of each region and the share available energy sector mitigation technologies based on the model's standard assumptions. This CO_2 or climate mitigation policy can be considered a physical limit that policymakers have endorsed in the expectation of limiting potential damages from climate change in the future.

2.a. High Population (no policy) case.

GCAM uses the projections on global population from the U.N. central statistical agency (UN, 2010). The central population estimates lead to 8.9 billion worldwide by 2050 which grow to a maximum of 9.2 billion in 2075 and then level out at 8.9 billion by 2095. The global numbers are the aggregate of more region specific estimates. U.N. statistics are provided at the county level which are then aggregated into the 14 GCAM regions. A High population case was developed to test the impact of changing this key assumption on global CO_2 emissions. The expectation is that greater growth in population leads to higher energy demand, higher economic output, and results in higher CO_2 emissions, given the same level of technology and in the absence of a CO_2 mitigation policy.

2.b. Global CO_2 Stabilization policy case from High population case.

With the alternative baseline CO_2 emissions trajectory based on a higher world population, I then apply the same global CO_2 stabilization target as above in scenario 1.b. Comparing policy scenario 2.b. to 1.b. --with the reference population level, provides a measure of how more difficult (or easy) it may be for the world economies to limit their emissions and reach the physical, global CO_2 emissions stabilization.

3.a. High GDP Growth (no policy) case.

Global GDP is an aggregate of the same 14 GCAM regions described above where each region's GDP growth is specified exogenously. In this model regional GDP is principally a function of labor productivity and population growth or more specifically the growth in the labor force that is some share of total population. To adjust regional economic growth I increased the rate of labor productivity while keeping population growth the same as the GCAM reference case. With higher levels of economic output occurring over time, there will be greater demand for energy leading to higher global CO_2 emissions than the reference case –again maintaining the same levels of energy technologies and in the absent a mitigation policy.

3.b. Global CO_2 Stabilization policy case from High GDP Growth.

In the same pattern as for the previous two CO_2 stabilization scenarios, this one also applies the same physical, global constraint but now on the higher

CO_2 emission trajectories to test what the implication is on changing the GDP growth assumption.

4.a. Low economic convergence (no policy) case.

The last of the no policy scenarios is one where the rate of economic development convergence between the low- and middle-income countries is lower than the GCAM reference scenario. The prevailing view in economic growth theory (Solow, 1956) which has been brought over to climate economic modeling (Grübler et al., 2004) is that today's low- and middle-income countries should have higher rates of economic growth relative to high-income countries so that over time the per capita wealth between those sets of counties narrows; this is also called "catching up" in economic modeling. To test the impact of this modeling assumption, I adjust the exogenously specified economic growth rates of the low- and middle-income countries out to reach lower economic levels by the end of the modeling horizon or 2095. With lover levels of economic growth in the low- and middle-income countries, where the bulk of future emissions growth is expected, overall global CO_2 emissions will be lower.

4.b. Global CO_2 Stabilization policy case from Low economic convergence

Again the same CO_2 stabilization target is applied, now to the Low economic convergence emissions levels to test the effect of changing these input assumptions.

Second set of modeling cases modify the GCAM assumptions of technology diffusion based on analysis done in earlier sections for the same global CO_2 stabilization target. These results are then compared to the above first set of modeling runs.

5.a. Technology diffusion focused on just the electric generation sector.

This scenario places two separate conditions on the model that are different from the standard GCAM baseline. First, I modify the inputs in GCAM to approximate different rates of technological convergence observed in Section 2 above for the electric generation sector only; all other sectors in the model maintain the GCAM standard parameters. For example, the standard inputs in GCAM have the cost and availability for advanced fossil power generation with carbon capture and storage (CCS) the same between the U.S. and Latin America. I modify the model so that the availability of CCS is delayed by two to three decades in Latin America after the U.S. This is not a mandate for CCS at a later period as it still must compete economically with other technologies. For the second condition, I run the model with the same CO_2 stabilization target as in applied in the above policy scenarios so that the results can be compared to scenarios 1.b., 2.b., 3.b., and 4.b. which will provide an indication of how much of an impact changing the technology diffusion assumptions has on mitigation costs relative to the other key assumptions. A detailed description of the changes made to GCAM for this scenario is described below.

6.a. Technology diffusion for the transportation sector.

This scenario is similar in design to scenario 5.a. above but the changes to GCAM are focused on the transportation sector and then added to scenario 5.a. An example for this sector is the adoption of advanced plug-in hybrid electric passenger vehicles where the introduction of the vehicles is delayed by two decades between Europe and South East Asia representing the groups of High-Income and Low-Income countries. After the GCAM modifications are in place, the same global CO_2 stabilization target is run to then assess the impact of the changes to transportation sector assumption on technological diffusion versus the other key assumptions. Details on the changes to technological diffusion in the transportation sector by region in GCAM are also described below in the model section.

7.a Technology diffusion on ALL energy-related sectors.

The third and last sensitivity case run on technological diffusion combines three energy sectors, electric generation sector, transportation sector, and the petroleum refining, which correspond to the same sectors evaluated in Section 2 on historical convergence rates. First, the GCAM changes made for scenarios 5.a. and 6.a. are combined with additional changes to the rates of diffusion for the refining sector between High-Income and Middle and Low-Income regions. Second, the CO_2 stabilization case is applied with the revised diffusion rates in place to test the impact of this combined-sector scenario. For this scenario, additional details on the changes made to the refining sector are provided below.

4.3. *Changes made to GCAM to implement the new economic and emissions scenarios.*

1.a. GCAM Reference (no policy) case.

GCAM's reference case is the results of running the model with the standard or reference set of inputs and assumptions as selected by the modeling team at the Joint Global Change Research Institute (JGCRI). I ran the model with the standard assumption to establish the reference levels of outputs specific to the global energy system and CO_2 emissions.

1.b. Global CO_2 Stabilization policy case from Reference.

To impose a global CO_2 emissions limit in GCAM I had to specify a new objective function to stabilization CO_2 concentrations at 420 ppm by 2100. To meet this target, the model to seek reductions across all regions by applying an increasing equalized carbon price until the emissions level is met. The results are a globally applied carbon tax and a CO_2 emissions trajectory that significantly diverge from the reference case.

2.a. High Population (no policy) case.

The model uses as its standard input on population the U.N. median global data which is aggregated to the corresponding GCAM regions. To modify the population inputs requires two steps. First is to obtain the different population dataset which in this case is the UN High population case which reaches 13.7 billion in 2095 and then re-aggregate the data to match up with GCAM regions. Second is to modify the GCAM configuration file to use that new data instead of the standard population data.

2.b. Global CO_2 Stabilization policy case from High population case.

Once the High population, no-policy case is run, I apply the same stabilization objective function as in scenario 1.b. to achieve the same level of CO_2 emissions for the common policy case.

3.a. High GDP Growth (no policy) case.

In this type of climate economic model GDP is modeled as a straightforward relationship between population, or more specifically, the share of a region's population that is the labor force, and rates of labor productivity increases that are specified exogenously. GDP is set in the base year 1990, and then as the model is run forward it is normalized against that initial value. In GCAM, regional GDP is estimated based on the following equation:

$$GDPindex_t = GDPindex_{t-1} * (1+Pro_{lm,t})^{Nstep} * Laborforce\_index_t$$

where,

$GDPindex_t$ is the normalized GDP value (normalized against the base-year GDP value and as such makes GDPindex for the base year (t) equal to one);

$Pro_{lm,t}$ represents the labor productivity increase from one point in time to the next;
Nstep is the time span from one time period to the next (set to 15 years);
$Laborforce\_index_t$ stands for the ratio of the labor force at time (t) divided by the labor force at the previous point in time which is simulated as the ratio of the product of the population and the fraction of the population in the labor force engaged productive activities.

To create a High GDP case I adjusted upward the individual region labor productivity rates in the labor prod input file so that each region generated more GDP than in the reference case. Table 8 below provides the reference case labor productivity rates and the revised ones for the High GDP case.

Region	Reference rates in 2050 & 2095	Revised rates in 2050 & 2095
1. United States	1.5% & 1.5%	1.7% & 1.7%
2. Canada	1.7% & 1.6%	1.9% & 1.8%
3. Western Europe	1.5% & 1.2%	1.7% & 1.5%
4. Eastern Europe	3.2% & 2.6%	3.4% & 2.8%
5. Australia & New Zealand	1.3% & 1.3%	1.5% & 1.5%
6. Japan	1.5% & 1.2%	1.7% & 1.4%
7. South Korea	2.1% & 1.9%	2.3% & 2.1%
8. China/Asia Reforming	4.3% & 2.3%	4.5 & 2.5%
9. India	4.2% & 3.4%	4.5% & 3.7%
10. Former Soviet Union (FSU)	3.2% & 2.6%	3.4% & 2.8%
11. Middle East	1.5% & 1.9%	1.7% & 2.1%
12. Latin America	2.4% & 2.7%	2.6% & 2.9%
13. Africa	2.0% & 3.2%	2.2% & 3.4%
14. (rest of) S&E Asia	4.0% & 3.0%	4.1% & 3.2%

Table 4-2: Labor productivity rates by region – High GDP Case.

3.b. Global CO_2 Stabilization policy case from High GDP Growth

Same as in scenario 2.b., after establishing the High GDP Growth under a no policy condition, I apply the same stabilization objective function to achieve the 420 ppm level of CO_2 emissions as the policy case.

4.a. Low economic convergence (no policy) case

This scenario requires the same manipulation to the input date file on labor productivity rates but instead of adjusting all regional rates upward I only adjust the rates for the Middle and Low-Income countries so that their overall rates of economic growth are slower relative to the reference scenario and, as a result, economic convergence to the High-income regions takes longer to achieve.   The reference case labor productivity and adjusted value for this scenario are listed in Table 9 below.

Region	Reference rates in 2050 & 2095	Revised rates in 2050 & 2095
1. United States	1.5% & 1.5%	no change
2. Canada	1.7% & 1.6%	no change
3. Western Europe	1.5% & 1.2%	no change
4. Eastern Europe	3.2% & 2.6%	no change
5. Australia & New Zealand	1.3% & 1.3%	no change
6. Japan	1.5% & 1.2%	no change
7. South Korea	2.1% & 1.9%	no change
8. China/Asia Reforming	4.3% & 2.3%	4.0% & 2.0%
9. India	4.2% & 3.4%	4.2% & 2.0%
10. FSU	3.2% & 2.6%	2.1% & 1.9%
11. Middle East	1.5% & 1.9%	1.5% & 1.2%
12. Latin America	2.4% & 2.7%	1.5% & 1.5%
13. Africa	2.0% & 3.2%	1.5% & 1.5%
14. (rest of) S&E Asia	4.0% & 3.0%	2.1% & 1.9%

Table 4-3: Labor productivity rates by region – Low Convergence Case.

4.b. Global CO_2 Stabilization policy case from Low economic convergence

Same as in the previous two scenarios, the same stabilization objective function is applied to the Low economic convergence scenario in order to evaluate the differences in achieve that climate policy target.

The scenarios described above were run to establish the standard GCAM reference results for regional population, GDP, energy consumption, and CO_2 emissions that are aggregated to global totals. Additional sensitivity cases were developed to test the impact of changing key assumptions on population growth and GDP growth and how those resulting changes affect the degree of difficulty or cost in achieving a global CO_2 stabilization target.

4.4. *Changes made to GCAM to implement the new technology diffusion scenarios.*

The subsequent technology converge scenarios are where the bulk of the effort in modifying GCAM took place due to the detailed technology specification in the model and because the model is divided into 14 separate economic regions requiring that changes are needed in each regional model parameterization. The work entailed in interpreting results from Section 3 on historical patterns of technological convergence, modifying the appropriate GCAM structure and data files, and executing the new scenarios is described in the subsections below. The scenario results are presented in Section 5.

Given the partial equilibrium solution approach, regional structure, and technology details of GCAM there are three possibly ways to differentiate technology diffusion rates between the regions. One approach would be to specify the costs of new technologies differently in each of the model's 14 regions. If a particular technology, e.g., advanced coal power generation with carbon capture and storage, was more expensive in a lower-income country than in a high-income country then it would generally deploy later given a normalized climate mitigation policy. Similar technologies would be more expensive in lower-income countries due to a difficulty in accessing capital, fees for the transfer of technology, and an insufficient infrastructure basis among other factors (World Bank, 2008). This approach was not selected since region-specific cost data on near-term and advanced technologies is not readily available and uncertain, particularly with as-yet commercialized technologies. More importantly, this cost-variation approach is inconsistent with the technology convergence research completed in the previous section and the additional historical time series assessment of electric power efficiencies both of which show a clear technology gap over time.

A second approach would be to use the logit-share (or logit-choice) equations in GCAM which control the degree of switching between technologies or fuels in response to price changes (JGCRI, 2013). For example, during the transformation of energy from raw fuel to refined fuel to final fuels consumed by end-users, all fuels compete based on relative prices. The competition among fuel prices is governed in GCAM by the logit-share equations which are based on fuel prices and their elasticities. In addition, various costs like transportation costs, taxes, non-fuel costs, and structural factors are also included in delivered fuel costs. The use of the logit-share equation approach in GCAM also ensures that fuels and their related technologies can contribute in some way to total energy demand and that transition between fuels and technologies change in a smooth fashion as prices or policies change over time. For addition detail of the logit-sharing formulation in GCAM see Clarke and Edmonds (1993). The use of the logit-share approach was not used in this research for much of the same reasons as above on the differential technology-price formulation: region-specific, logit-share equations or expansion rates would need to be specified and this approach is inconsistent with the research completed on technology convergence in previous sections. A recent paper by Iyer et al (2013) does use the logit-share formulation to evaluate different expansion rates of low-carbon technologies only in the electric sector under a tight climate mitigation scenario. In further research it would be worth evaluating and comparing the approach taken in the Iyer et al paper, a more price-response approach to technology diffusion, to the more time-dependant and region specific approach taken in this dissertation.

The third approach that can be used in the GCAM model to specific diffusion of technologies is the share-weight parameter. Share-weights are denominated as the percentage of total capacity that a specific technology may attain in a given year. Share-weights are initialized on a model base year, e.g., 2000, and then allow gradual movement away from that starting calibration year. For example, in one particular region's electric power sector, generation of electricity from coal is 50% of total in a base year with natural gas at 25% and renewable power at the remaining 25% of total capacity. If there were no specified share-weights, the amount of capacity attributed to the mix of generation technologies would be solely based on the economic competition among the options, that is, markets would rapidly transition in response to newer technologies that generally exhibit greater efficiencies. The use of share-weights takes into account engineering, market, and technology transition considerations not captured in the pure economic optimization in the model. According to the GCAM documentation (JGCRI, 2013), the principal lever or parameter that allows the introduction of new or advanced technologies in GCAM is the Share-weight. This is the approach taken in this dissertation.

Table 4-4 below provides the standard configuration in GCAM for the share-weight parameter dealing with the introduction and penetration of advanced fossil technologies for the power generation sector.

Fossil - Reference - share-weight (tech level)				share-weight						
Region	supplysector	subsector	technology	2010	2020	2035	2050	2065	2080	2095
ALL	electricity	Coal	Coal (IGCC)_CCS	0	0.333	1	1	1	1	1
ALL	electricity	Gas	Gas (CC)_CCS	0	0.333	1	1	1	1	1
ALL	electricity	Oil	Oil (IGCC)_CCS	0	0.333	1	1	1	1	1

Table 4-4: GCAM standard configuration of the share-weight parameters.

The specifications (columns) in the above configuration input file are defined below:

Region: this instructs GCAM to apply the specification equally to all of the 14 regions in the model. This is one of the important specifications to modify in order to test the implications of different technology diffusion rates.

Supplysector & Subsector: this identifies to which energy supply sector and subsector (or fuel type) the technologies are applied.

Technology: this identifies the specific technology whether for energy transformation, as in this example, or energy use, e.g., transportation technologies for passenger use. Here the advanced technologies are integrated gasification combined cycle (IGCC) for coal and oil with CO_2 carbon capture and storage (CCS) for electric power generation; and combined cycle units for natural gas with CCS.

Share-weight: this is the key parameter which is exogenously specified. For existing technologies the share-weight, or percent of total allowable capacity, is calibrated to a base year, e.g., 2000, based on historical data. For advanced technologies which are not yet commercially available the share is zero (0) as above for 2000. For the standard configuration in GCAM, starting in 2020 the model will allow up to one third of total capacity to be comprised of CCS technologies for those respective generation-fuel types in all of the 14 regions as there is no regional differentiation. The resulting amount of generation is determined on an economically competitive basis between the technologies depending on costs, fuel prices, and the type of policies imposed.

For most of the energy sector-related technologies represented in GCAM the share-weight specification regarding regions is similar to the example above in that all advanced technologies are allowed to deploy at the same time across all 14 regions.

That is, there is no allowance for different rates of technological diffusion for advanced technologies with the exception of some transportation technologies which are covered below. The standard approach is simple and efficient as just a few lines in the input file configure the model as needed. In order to test the impact of technological diffusion on climate mitigation targets I needed to change the GCAM share weight parameters for each technology and for each region. That means modifying the share-weight input files for each technology of interest and expanding the file to properly specify different rates of technology diffusion. Using the above share-weight specification example with three advanced technologies, which are applied to ALL regions this mean that a new file need to be created with 42 different row specifications (3 technologies X 14 different regions). This additional work, model specification, and regional detail is perhaps why most climate economic models use the more simplified assumption of making all technologies similarly available globally. Below I describe the changes to the standard GCAM structure to model different rates of technology diffusion in the electric generation sector, the transportation sector, and then all a combined energy sector case by adding refining to the previous two sectors.

5.a. Technology diffusion focused on the electric generation sector

Electricity is part of energy input to economic production where it competes with and also uses other primary energy sources, e.g., natural gas, oil, and coal. Electricity can be generated by a variety of technologies where the mix of generation in any one particular region will be determined by the technology availability and the relative prices of energy sources which include carbon or other environmental policies if applicable. Table 4-5 below lists the various electricity generation technologies and their respective primary fuel sources as well identifying the existing or near-term technologies and the advanced technologies available in GCAM. Each technology is characterized by specific data on its cost and performance.

Existing or near-term technology	Advanced Technology
Fossil Generation	
(1) Oil	integrated gasification combined cycle (IGCC) stand alone IGCC with carbon capture and storage (CCS)
(2) Natural Gas	natural gas with CCS
(3) Coal	IGCC IGCC with CCS
Nuclear	
(4) Nuclear GEN II & III reactors	GEN IV reactor
(5) Fusion - not available	Available
Renewables	
(6) Solar PV	Solar PV with energy storage
(7) Wind power Types	Wind with energy storage
(8) Hydro power	NA
(9) Biomass	IGCC IGCC with CCS
Other Advanced	
(11) Hydrogen fuel cells – NA	Available
(12) Satellite solar - NA	Not included

Table 4-5: Electricity Generation Technologies in GCAM.

In the standard GCAM configuration there are no differences between regions in a technology's cost or performance (common assumption in most climate economic models), and all technologies are allowed to deploy at the same time across all regions. Table 4-6 below is a simplified representation of the input file in GCAM specifying the respective share-weights for electricity generation technologies that determine the pace of technology diffusion. For each different generation and fuel combinations the advanced technologies are highlighted in darker shading. Notice that in the standard configuration these rates are applied to "ALL" regions equally in the model.

To test the implication of different rates of technology diffusion two important modifications were made to the above input file. First, instead of using the ALL regions designation, separate region-specific and technology-specific parameters were developed. Second, for each advanced technology type a different projected share-weight specification was applied depending on the current income level of each region. This second step is the representation of different rates of technology diffusion which I based on the research completed in Section 3. I further describe the modifications for each of the main technology generation and fuel combinations below. The full, newly developed share-weight input file is provided in Appendix B.

INPUT_TABLE									
Variable ID									
37a			share-weight						
Reference - share-weight (tech level)									
Region	supplysector	Technology	2005	2020	2035	2050	2065	2080	2095
ALL	Electricity	Coal (conv pul)	0	1	1	1	1	1	1
ALL	Electricity	Coal (existing)	1	0	0	0	0	0	0
ALL	Electricity	Coal (IGCC)	0	1	1	1	1	1	1
ALL	Electricity	Coal (IGCC)_CCS	0	0.3	1	1	1	1	1
ALL	Electricity	Gas (base load conv)	0	0	0	0	0	0	0
ALL	Electricity	Gas (CC)	0	1	1	1	1	1	1
ALL	Electricity	Gas (existing)	1	0	0	0	0	0	0
ALL	Electricity	Gas (peak load conv)	0	1	1	1	1	1	1
ALL	Electricity	Gas (CC)_CCS	0	0.3	1	1	1	1	1
ALL	Electricity	Oil (base load conv)	0	0	0	0	0	0	0
ALL	Electricity	Oil (existing)	1	0	0	0	0	0	0
ALL	Electricity	Oil (peak load conv)	0	1	1	1	1	1	1
ALL	Electricity	Oil (IGCC)	0	1	1	1	1	1	1
ALL	Electricity	Oil (IGCC)_CCS	0	0.3	1	1	1	1	1
ALL	Electricity	Biomass (conv)	0	1	1	1	1	1	1
ALL	Electricity	Biomass (existing)	1	0	0	0	0	0	0
ALL	Electricity	Biomass (IGCC)	0	1	1	1	1	1	1
ALL	electricity	Biomass (IGCC)_CCS	0	0.3	1	1	1	1	1
ALL	electricity	CSP	0	1	1	1	1	1	1
ALL	electricity	CSP_storage	0	0.1	0.9	1	1	1	1
ALL	electricity	PV	1	1	1	1	1	1	1
ALL	electricity	PV_storage	0	1	1	1	1	1	1
ALL	electricity	Wind	1	1	1	1	1	1	1
ALL	electricity	Wind_storage	0	1	1	1	1	1	1

Table 4-6: GCAM input file – share weights.

Advanced Coal Units

Technologies under advanced coal for power generation include IGCC in a stand-alone mode and IGCC with CCS which can reduce CO_2 emissions up to 90% compared to a conventional coal plant. For the High Income countries the rate of technology diffusion is the same as the standard GCAM parameters as represented in the share-weights. For the Middle and Low income countries Coal IGCC units were delayed 30 years and allowed to come in fully, based on the high speed of convergence of 84% for coal electricity from the β Convergence estimates (see Table 3-5). The more advanced IGCC with CCS was delayed 45 years but with only a 25% share-weight, then some additional allowed penetration 60 years later at 50%, and finally full deployment 75 years after initial deployment in the High Income countries. This new adjustment on the Middle and Low income share-weights is based on the speed of convergence of 34% for all electricity as a representation of a slower convergence for broadly applicable technologies.

Advanced Gas Units

As was done for coal units the rate technology diffusion for the High Income countries is the standard GCAM parameters as represented in the share-weights. For the Middle and Low income countries Gas units with CCS were delayed 45 years with only a 33% share-weight, then to 50% at 60 years, and finally full deployment at 75 years. This is based on a combination of a slower speed of convergence of 16% for gas electricity from the β Convergence estimates (see Table 3-5) but also a faster convergence rate in the more recent decades (see Figure 3-6).

Advanced Oil Units

The modifications to share-weights for oil with CCS units are the same as those for coal as described above.

Advanced Biomass Units

Biomass units take agricultural and forestry products, either purposely grown or by-production/waste materials, combust them to create steam for power generation. One special feature of advanced biomass units is that when they are combined with CCS technologies they yield "negative CO_2 emissions", that is, the biomass material pulls CO_2 from the atmosphere which is then combusted in a boiler and then the CO_2 is captured and stored in a geologic formation. The result is the net removal of CO_2 from the atmosphere. The potential importance of biomass with CCS (referred to as BioEnergy Carbon Storage or BECS) as a negative emissions technology cannot be understated as many climate mitigation scenarios with tight targets, for example a 2 degree target, are not feasible unless BECS can deploy widely and immediately across the globe (Clarke, et al, 2008). For the High Income countries the standard GCAM parameters were kept. For the Middle and Low income countries both Biomass IGCC and CCS units were delayed 45 after deployments in the High Income countries and come in with only 25% penetration allowance. After 15 years this is increased to 33% and finally after 30 additional years the maximum penetration is limited to 50%. This slower rate of allowed technology diffusion in both terms of timing and reduced level of market penetration is due to the slower speed of convergence of 19% for biomass electricity from the β Convergence estimates (see Table 3-5). From all of the evaluated advanced technologies, this adjustment to the diffusion of

Biomass with CCS marks the most significant change to the standard assumption in the GCAM model.

Renewable Power

Apart from fossil electricity generation the renewable power technologies were grouped together and included solar power –both concentrated solar power and photovoltaic cells, and wind power turbines.   Hydro power was not included in any changes to technology diffusion. The renewable power options were grouped together for two reasons. First, in GCAM the differentiation between conventional renewable generation and advanced generation is the addition of energy storage technology to each generation type as listed in Table 4-5 above. Energy storage allows excess electricity --generated when wind or solar resources are available but when demand for electricity is low—to be used when demand is higher which can provide temporary solutions for regional and local capacity shortages. The second reason renewables were combined in terms technology diffusion specifications (share-weights in GCAM) is because they are also combined in the historical convergence assessments were the observed β Convergence estimates for wind and solar was 57% meaning that over the period of analysis the lower level regions gained more than half of the difference. With this in mind I adjusted the Middle and Low income countries rates so that advanced renewable technologies were delayed by 15 years with 25% penetration allowance, then 33% after an additional 15 years, increased to 50% after 15 more years, and reach the same level as High Income countries after the final 15 additional years.

Nuclear Power

The last electric power generation technology to include in the modifications of technology diffusion in GCAM is nuclear power, which given the important differences and complexities of this technology, took a different approach to the modification in the model. In the standard GCAM configuration nuclear power is differentiated in terms of diffusion and pace of growth given existing, regional nuclear power capacity and experience.
In my examination of historical technology convergence rates there was not sufficient data to conduct a robust enough analysis on nuclear power. Furthermore, and related, the deployment of nuclear power is not solely a decision of technology transfer and diffusion given concerns of nuclear weapons proliferation and safety concerns on operating a nuclear power plants (Clarke, et al, 2007). In addition, I took into account the reality that some regions defined as Low and Middle Income, e.g., the Former Soviet Union (FSU), have had operational nuclear plants in place for a few decades. As a result, nuclear power technology has the distinction of having two differently specified technology diffusion rates: For Eastern Europe, Korea, and the FSU, the more advanced Gen Type III reactors are delayed 15 years at a 25% penetration rate, then 33%, 50%, and 75% for the next 15-year intervals. The remaining Low and Middle Income countries are delayed 45

years starting at a 25% penetration rate, then increasing to 50%, and 100% for next two 15-year intervals. A variety of different timelines and diffusion rates can be developed for nuclear power that fall more in the area of regional and security studies versus energy and climate economics. The approach here can be seen as a starting example given the importance of nuclear power as a potential climate mitigation technology with security implications.

6.a. Technology diffusion in the transportation sector

The GCAM model has one of the more detailed transportation sectors among the current class of climate and energy economic models that go out to 2100. The detail covers three aspects of transportation: First is the technology representation or mode of transportation, i.e., air, bus, light-duty vehicle, rail, ship, and truck; Second the energy type, i.e., fossil fuel, electric, gas, and fuel cell; and Third is the transportation class, i.e., passenger, freight, international shipping. The advanced technologies, that is transportation that does not rely on fossil fuels, are identified as electric, hydrogen (H2) fuel cells, and compressed natural gas (CNG). The standard rates of technology diffusion for these more advanced technologies are shown in Table 4-7. All three aspects are applied in the appropriate combinations to create the standard GCAM transportation technology input configuration as shown in Table 4-8 below for the U.S.

Standard Transportation Technology share-weight path						
	2020	2035	2050	2065	2080	2095
Electric	0.1	0.25	0.5	0.5	0.5	0.5
H2 (fuel cell)	0	0.1	0.25	0.25	0.25	0.25
CNG (gas)	0.01	0.1	0.25	0.25	0.25	0.25

Table 4-7: GCAM Transportation share-weights.

INPUT_TABLE								
Variable ID 1011			shareweight					
Region	Supplysector	tranTechnology	2020	2035	2050	2065	2080	2095
USA	trn_freight	Air	1	1	1	1	1	1
USA	trn_freight	rail ICE	1	1	1	1	1	1
USA	trn_freight	rail electric	0.1	0.25	0.5	0.5	0.5	0.5
USA	trn_freight	truck ICE	1	1	1	1	1	1
USA	trn_freight	domestic ship ICE	1	1	1	1	1	1
USA	trn_passenger	Air	1	1	1	1	1	1
USA	trn_passenger	high speed rail	0.1	0.25	0.5	0.5	0.5	0.5
USA	trn_passenger	rail ICE	1	1	1	1	1	1
USA	trn_passenger	rail electric	1	1	1	1	1	1
USA	trn_shipping_intl	international ship ICE	1	1	1	1	1	1
USA	trn_pass_road	LDV ICE	1	1	1	1	1	1
USA	trn_pass_road	LDV electric	0.1	0.25	0.5	0.5	0.5	0.5
USA	trn_pass_road	LDV gas	0.01	0.1	0.25	0.25	0.25	0.25
USA	trn_pass_road	LDV fuel cell	0	0.1	0.25	0.25	0.25	0.25
USA	trn_pass_road	bus ICE	1	1	1	1	1	1
USA	trn_pass_road	bus electric	0.1	0.25	0.5	0.5	0.5	0.5
USA	trn_pass_road	bus gas	1	1	1	1	1	1
USA	trn_pass_road	bus fuel cell	0.1	0.25	0.5	0.5	0.5	0.5

Table 4-8: GCAM Input file -- Transportation share-weights.

Another advantage of the existing GCAM transportation structure is that there also is distinction in the regional configuration of transportation options and there rates of technology diffusion as represented by the share-weight parameter. The above table shows the specification for the U.S. Other regional specifications, both High and Middle & Low Income, are different given the current availability of transportation modes and technologies in each region.

As the transportation parameters were already specified by each of the 14 regions in the model this saved me the effort of creating new regional details as was done for the electricity generation technologies. For the High Income countries the standard GCAM parameters were kept as is. The new effort was in modifying the share-weights to account for different rates of technology diffusion between the High and Middle and Low Income regions for the advanced technologies. The β Convergence estimates, from Section 2, Table 3-5, for the speed of convergence in the transportation is 54% over the time evaluated. This relatively high estimate is only for historic fossil related transportation between the regions; however it does provide a starting point for modifying technology diffusion. For all of the Middle and Low Income regions, the following adjustments were made for particular combinations of transportation mode, class, and technologies: electric high speed rail was not delayed but the penetration rates were adjusted down to 50% in 2020 and 75 in 2035; electric passenger LDV was delayed by 15 years with no changes to the penetration rates; CNG electric LDV was also delayed by 15 years with no changes to the penetration rates; fuel cell passenger LDV was delayed by 30 years with no changes to the penetration rates; electric bus technology was similarly delayed only by 15 years with no adjustments for penetration rates; and finally fuel cell bus technology was 45 years with the remaining year penetration rates staying the same. No other changes were made to regional transportation parameters.

7.a **Technology diffusion on the refining sector**

The specifications and configuration of the refining sector in GCAM can be viewed as a combination of the technology detail in the electric power sector with some of the regional differentiation in the transportation sector. The technology detail is needed due to the complexities of the refining sector in the many way of producing refined liquid fuels to meet regional and global demand for energy. The refining subsectors in GCAM include the following fuels and conversions:

- unconventional oil — oil refining — coal to liquids
- gas to liquids — biomass liquids-ethanol
- regional sugar→ethanol — regional corn→ ethanol
- biomass liquids-FT — regional sugarbeet→ ethanol
  (FT stands for Fischer–Tropsch process)

The technology diffusion, as represented by the share-weight specifications, is the same for all regions for the above technologies and process except in two cases. The first is related to regional biomass liquids used for the production of ethanol and biodiesel which does have different regional share-weights to account for a region's agricultural production of the necessary feedstocks. This is related to the detailed agricultural landuse module in GCAM which produces the feedstocks based on region specific productivity and growing zones. The second reason is related to the international trade of unconventional oil for refining purposes. There are different share-weights for all the 14 regions based on the pattern of trade with the U.S. Since the pattern and reasons for differentiated share-weights in GCAM are not necessarily related to technology diffusion differences for the existing refining technologies, I do not alter them for the purposes of evaluation here.

Advanced technologies for the refining sector are characterized by the additional of carbon capture and storage (CCS) technologies –same as in the electric power– to a subset of the current refining technologies which are listed in Table 15 below as a representation of the share-weights specification in GCAM. Notice that the share-weights apply equally to all regions and the same time.

INPUT_TABLE								
Variable ID 2005			sharewt					
region	Supplysector	subsector/technology	2020	2035	2050	2065	2080	2095
ALL	refined liquids endues	coal to liquids CCS Level 1	0.3	1	1	1	1	1
ALL	refined liquids industrial	coal to liquids CCS Level 1	0.3	1	1	1	1	1
ALL	refined liquids endues	coal to liquids CCS Level 2	0.3	1	1	1	1	1
ALL	refined liquids industrial	coal to liquids CCS Level 2	0.3	1	1	1	1	1
ALL	refined liquids endues	biomass liquids-ethanol CCS Level 1	0.3	1	1	1	1	1
ALL	refined liquids endues	biomass liquids-FT CCS Level 1	0.3	1	1	1	1	1
ALL	refined liquids industrial	biomass liquids-ethanol CCS Level 1	0.3	1	1	1	1	1
ALL	refined liquids industrial	biomass liquids-FT CCS Level 1	0.3	1	1	1	1	1
ALL	refined liquids endues	biomass liquids-ethanol CCS Level 2	0.3	1	1	1	1	1
ALL	refined liquids endues	biomass liquids-FT CCS Level 2	0.3	1	1	1	1	1
ALL	refined liquids industrial	biomass liquids-ethanol CCS Level 2	0.3	1	1	1	1	1
ALL	refined liquids industrial	biomass liquids-FT CCS L2	0.3	1	1	1	1	1

Table 4-9: GCAM Input file – Refining share-weights.

In order to model technology diffusion in GCAM's refining sector the same type of modifications as made to the sector above were required here. First I needed to create a new input file for different share-weight specifications for each of the seven Middle and Low Income regions, i.e., Africa, China/Asia Reforming, India, Former Soviet Union, Middle East, Latin America, and S&E Asia. Second, I modified the standard share-weights for the advanced technologies based on consideration of the β Convergence estimates, from Section 3, Table 3-5, for the speed of convergence in the refining sector of less than 10% over the period of analysis. That estimate was for petroleum refining and is a relatively slow convergence rate compared to the other technologies evaluated. The changes made to the share-weights were a straightforward delay of 45 years for all the technologies while maintain the same penetration rates across the board.

5. Presentation, description and interpretation of the new modeling results.

This section covers the GCAM results on the seven scenario sets, resulting in 11 separate scenarios, which explore the implications of different assumptions on global CO_2 emissions and their mitigation to a common climate policy target. The scenarios and their abbreviations used in the following figures are as follows:

1.a. GCAM Reference (no policy) case =Reference

1.b. Global CO2 Stabilization policy case from Reference = NewReference_Policy

2.a. High Population (no policy) case = High_Pop

2.b. Global CO2 Stabilization policy case from High population case = High_Pop_Policy

3.a. High GDP Growth (no policy) case = High_GDP

3.b. Global CO2 Stabilization policy case from High GDP Growth = High_GDP_Policy

4.a. Low economic convergence (no policy) case = Low_Conv

4.b. Global CO2 Stabilization policy case from Low economic convergence = Low_Conv_Policy

5.a. Technology diffusion focused on just the electric generation sector = PolicyElecNucDelay

6.a. Technology diffusion in electric and transportation sectors = PolicyElecNucTransDelay

7.a Technology diffusion on ALL energy-related sectors = PolicyElecNucTransReLiqudDelay

The modeling results presented below include the main global drivers for CO_2 emissions, i.e., population, economic growth, and technology use and development; and changes to emissions and energy systems from the imposition of a CO_2 mitigation target; and ultimately the differences in mitigation costs from changes to assumptions on technology diffusion in the key energy sectors of electric generation, transportation, and petroleum refining.

5.1. Population Results

Following from the changes made to the standard GCAM inputs on population data the differences between the Reference and the High Population scenarios is show in Figure 5-1 on regional reference projections and Figure 5-2 with a global comparison of the two scenarios. In 2050 the difference is 1.5 billion people worldwide growing to a divergence of 4.8 billion by the end of the 21st century or 69% of the 2010 population estimate.

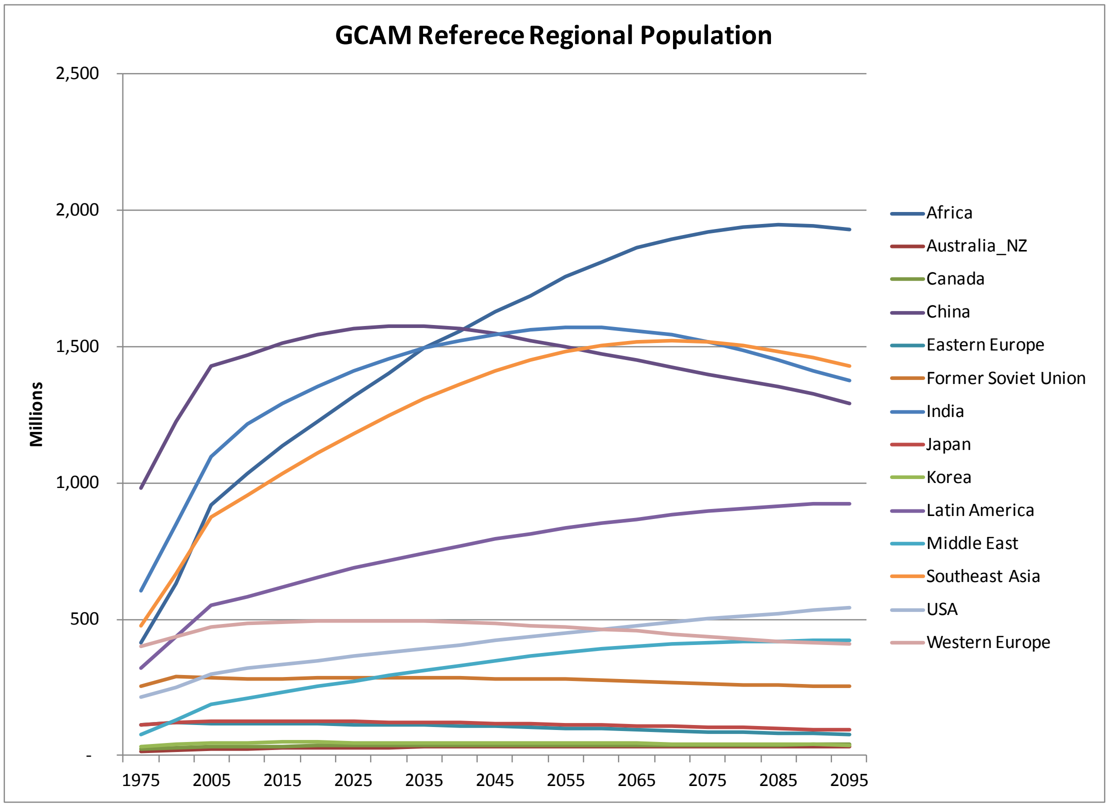

Figure 5-1: GCAM Regional population projections – Reference.

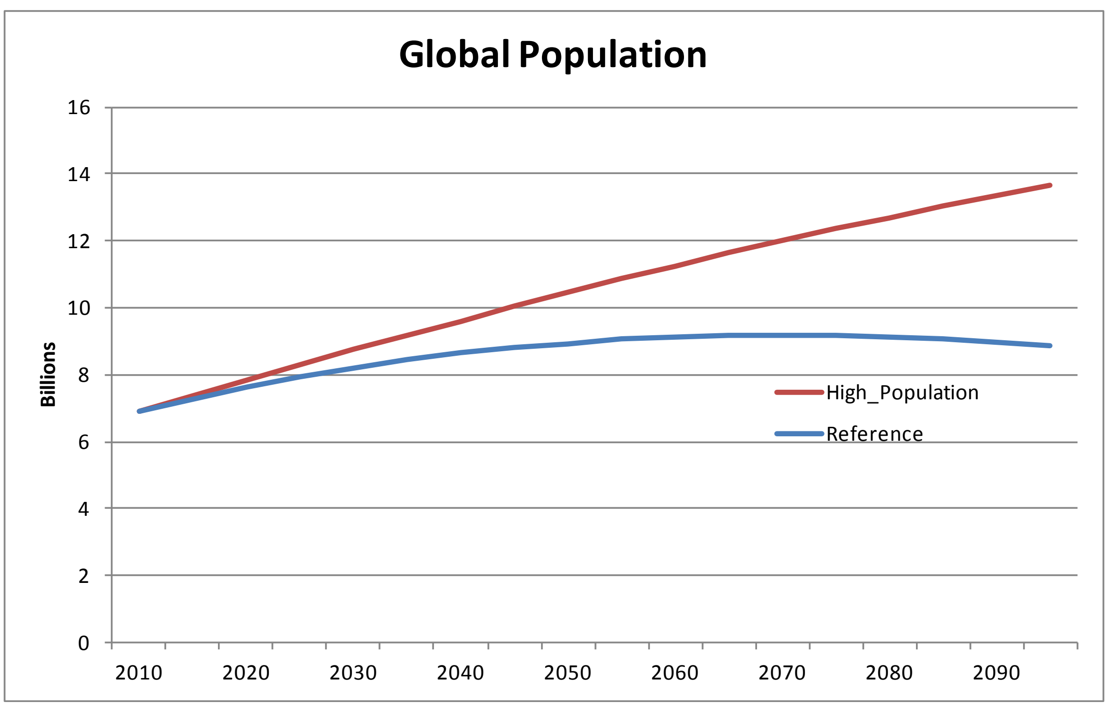

Figure 5-2: GCAM Global population projections.

5.2. GDP Results

Global economic output or the aggregate of the 14 region gross domestic production is more varied in GCAM than the population results based on the changes made to the standard set of assumptions; see Figure 5-3 below. The changes made to the High population scenario drive the highest total GDP by 2095. This is followed by the High GDP scenario were the focus was to increase all region GDP through the century.   The Lower Convergence scenario –where the Middle- and Low-Income regions experience a slower rate of economic growth– yields the lowest global GDP compared to all the scenarios given the importance of that combined region's projected economic growth in the reference which is carried forward in the High GDP and High population scenarios.

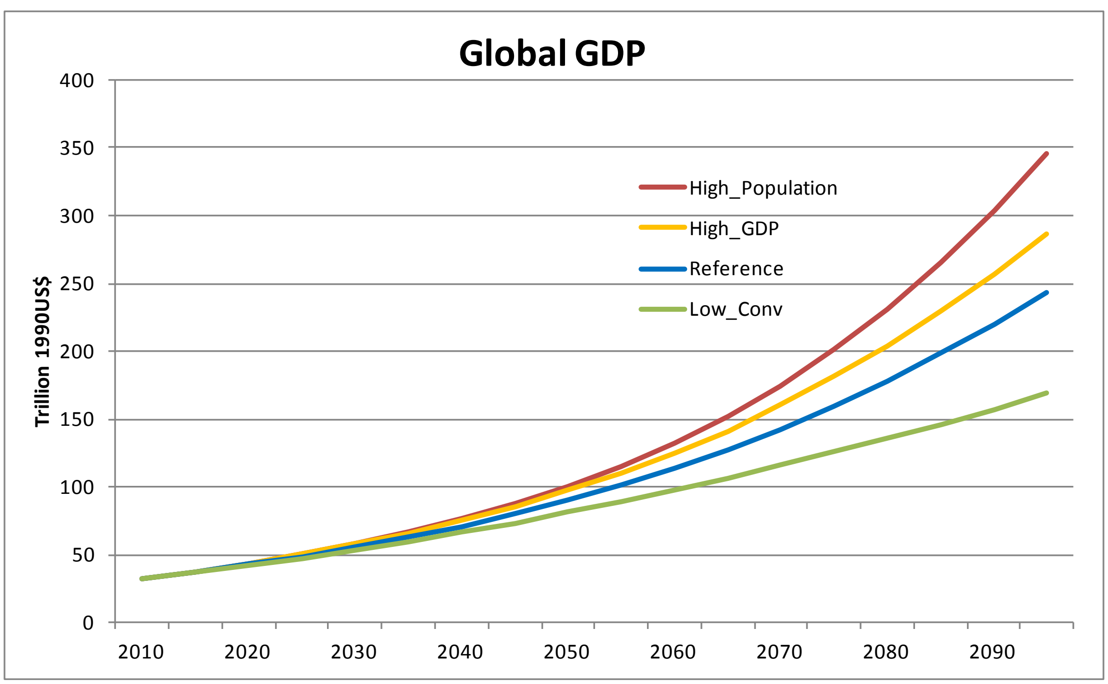

Figure 5-3: GCAM Global GDP projections.

5.3. Global Primary Energy Results

Based on the results for population and economic growth in the Reference and revised scenarios for the sensitivities on High Population, High GDP, and Low Convergence, global primary energy differs according for each scenario as illustrated in Figure 5-4.

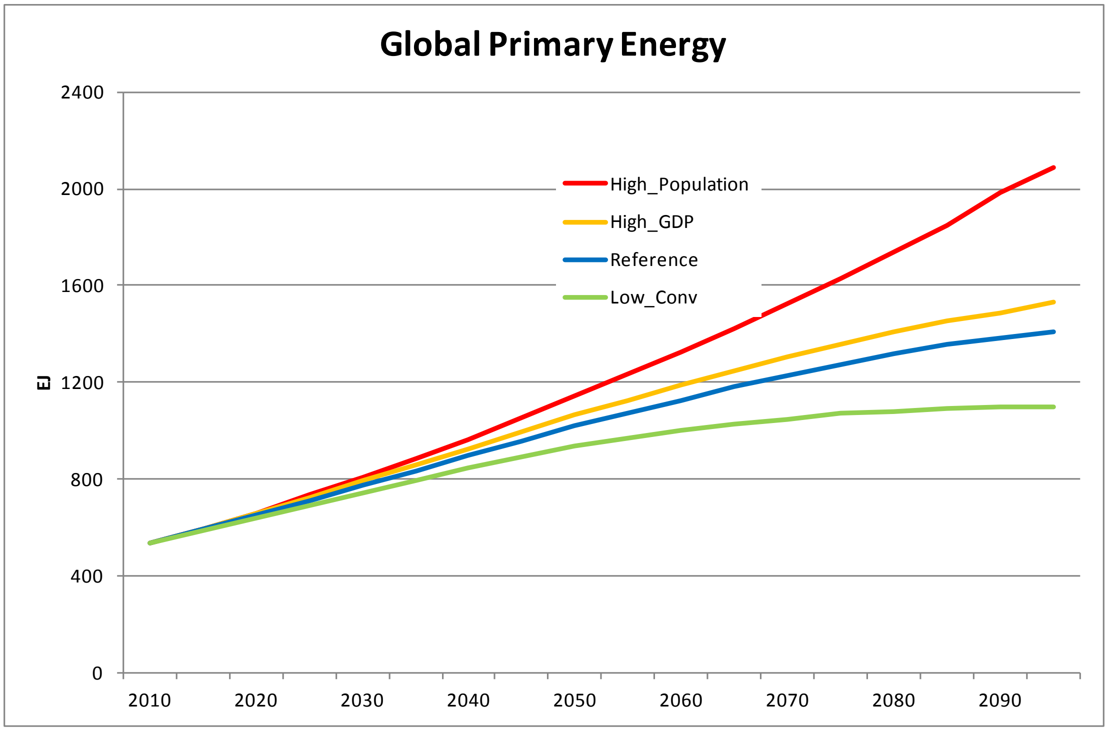

Figure 5-4: GCAM Global Primary Energy projections.

5.4. Global CO_2 Results

The combination of the population, economic growth scenarios and the long-term energy transformation and end-use technologies employed in GCAM give results to regional CO_2 emission projections which are aggregated to the global level (see

Figure 5-5). The one important scenario added to the analysis at this point is the CO_2 Mitigation policy which defined as stabilizing global CO_2 concentration levels at about 420 ppm by 2100 which represent an increase over today concentration of 390 ppm but a significant deviation from a Reference or no policy scenario where concentration would reach 800 ppm or greater. Since global concentration of CO_2, a well-mixed, long-lived atmospheric pollutant, depend upon the decadal trajectory of CO_2 emissions, that trajectory must continue to decline over the century as shown in Figure 5-5.

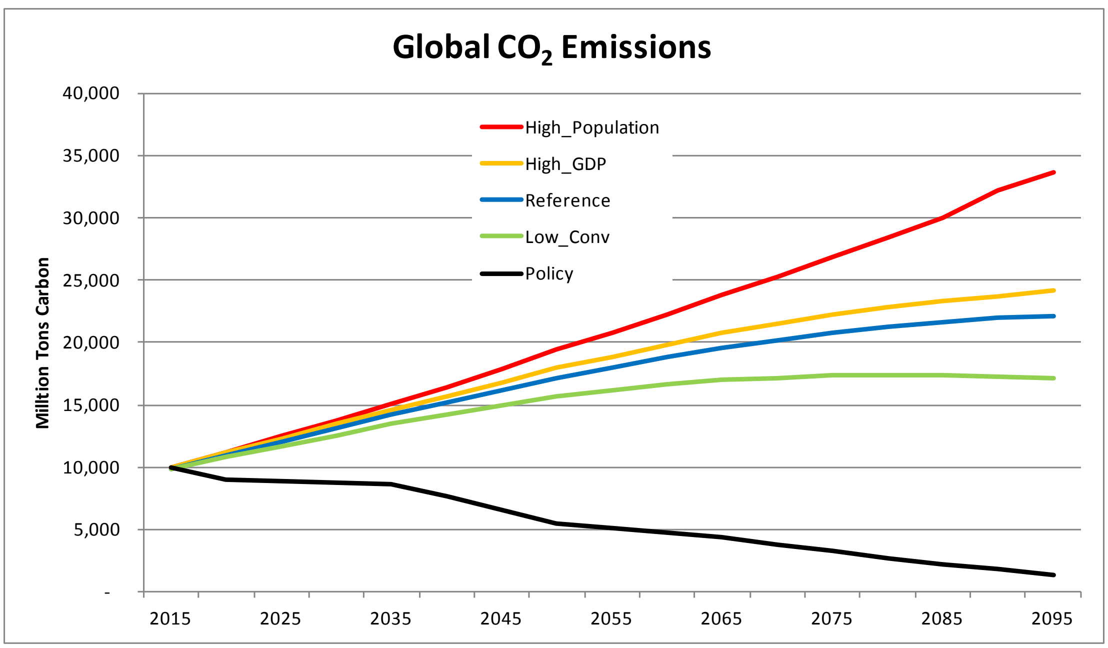

Figure 5-5: GCAM Global CO_2 projections.

5.5. *Regional CO_2 Emissions*

At an aggregate level it is difficult to appreciate the differences in CO_2 emissions for different countries and regions both in the Reference scenario and in the three mitigation or Policy scenarios. Growth in GHGs, primarily CO_2, is expected to be much greater from the Middle- and Low-Income countries than the High-Income countries as the former group experiences continued economic growth to catch up partly to the income levels of the latter group.

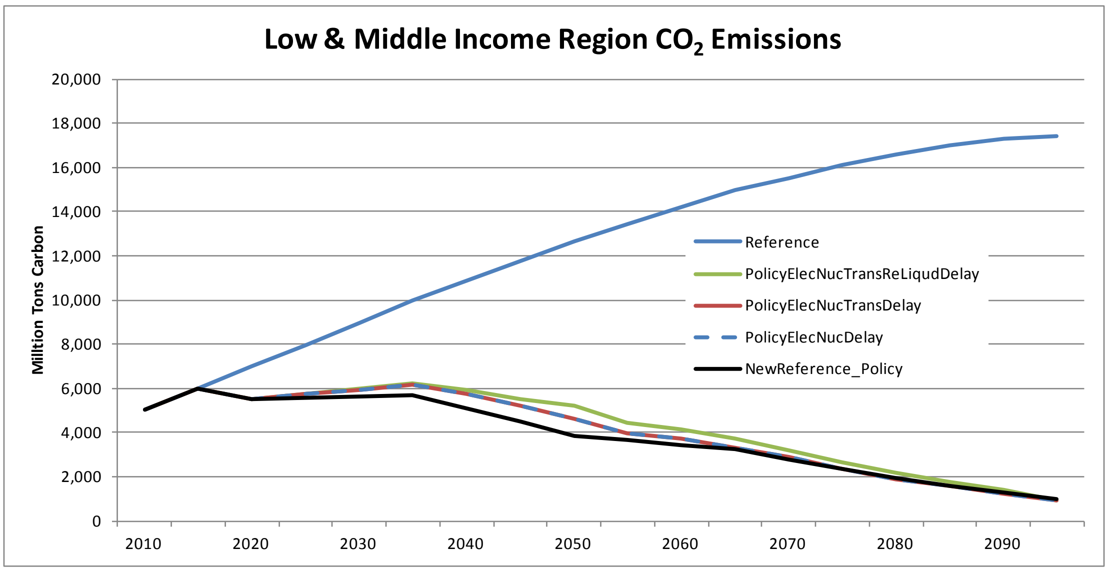

Figure 5-6: Low- and Middle Income Region CO_2 Projections.

The combined emissions from all the Low- and Middle income countries for five scenarios are shown in Figure 5-6. As expected the long-term projection in the Reference scenario is a continual upward trend that more than triples today's level of about 5,000 Million tons (MT) of CO_2 emissions in carbon terms to about 1,700 MT in 2095. In contrast the climate policy scenario, labeled as NewReference_Policy shows a dramatic and continued decline in emissions to just over 900 MT by century end. There are slight but noticeable deviations in the emissions trajectories for the three new mitigation scenarios where the rates of technology diffusion have been modified or slowed down between the High Income and Low- and Middle income countries. The changes are in line with expectations as the delay in the two scenario that include the electric and transportation sectors push off mitigation in those respective sectors 50 years plus since the more advanced and cost effective technologies are not as readily available. In the aggregate emissions of the whole Low- and Middle income regions there is no difference between these two scenarios; most of the mitigation occurs in the electric sector with very small changes in the transportation sectors. Adding the postponement of technology diffusion of the refining sectors does show up with the additional delay in the scenario labeled PolicyElecNucTransReLiqudDelay (green line) by about 40 years.

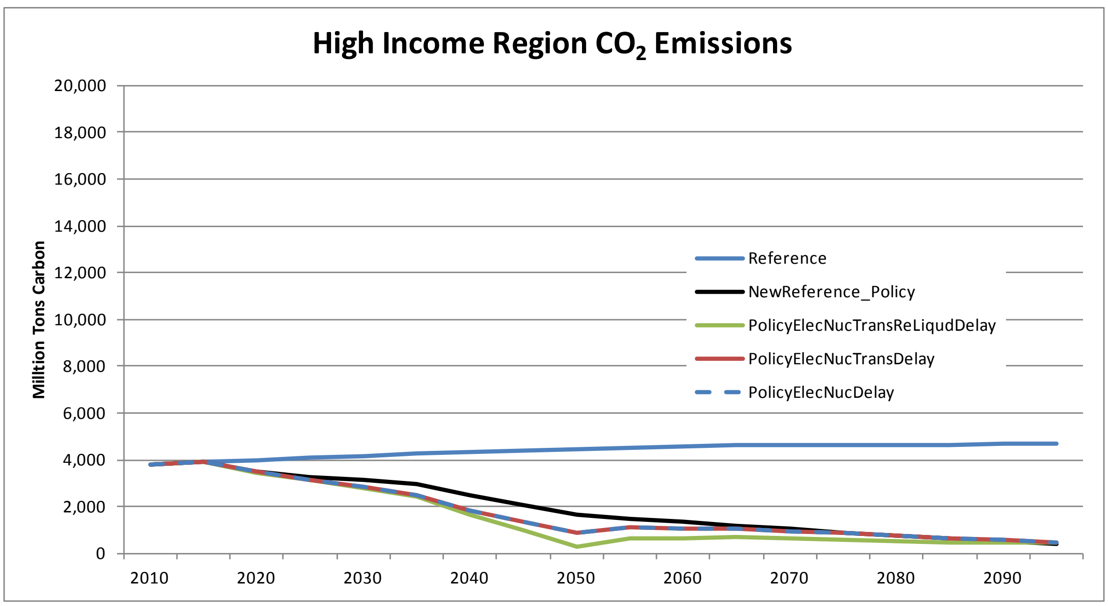

Figure 5-7: High-Income Region CO_2 Projections.

Evaluating the emission trajectories for the High-Income countries (Figure 5-7) shows a couple of key differences from those of the Low- and Middle Income countries. First, in the GCAM reference projection there is only a slight increase in CO_2 emissions over the century, from just about 4,000 MT today to just over 4,700 by

2100 representing only a 25% increase. Second, where the delay cases for the Low- and Middle Income countries show less mitigation occurring during the middle of the century, this is flipped for the High Income countries where there is a greater mitigation of CO_2 emissions. As there is a global mitigation budget it is more difficult for Low- and Middle Income countries to reduce emissions without advanced technologies then more of the burden falls on the High Income countries. This is of course in a climate economic-modeled scenario where there is a coherent and binding policy and countries/regions undertake mitigation to comply with the policy. There is a similarity in the pattern of the delay between the three technology delay scenarios albeit it almost the mirror of the figure for the Low- and Middle Income countries

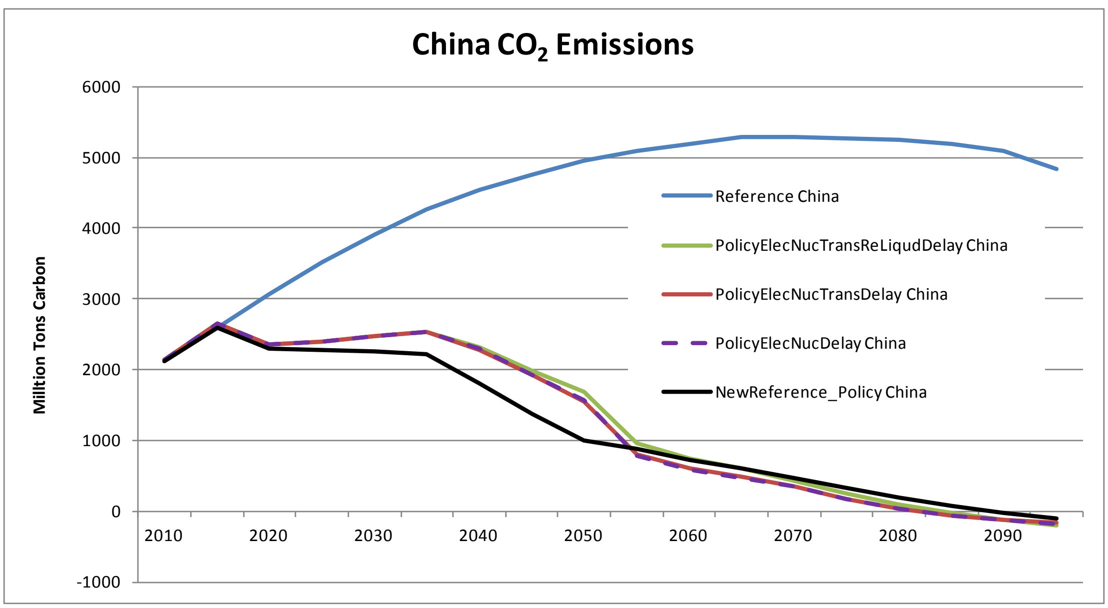

Figure 5-8: China CO_2 Projections.

To gain a better sense of the pattern of CO_2 emissions it is useful to evaluate the scenario results from two representative countries from the different income groups:

China (Figure 5-8) and the U.S. (Figure 5-9). Projected reference case emission in China follow the same overall pattern as in the broader Low and Middle Income group in that there is a significant growth in emission out to 2095 with a noticeable difference that Chinese emissions level out and even start declining due to the underlying trajectory of the population and structural changes in the that economy. The mitigation scenarios both the New Reference, i.e., the un-modified standard GCAM results, and the three delay cases shown immediate deviations from the Reference scenario with the 40-year or so postponement of the advanced technologies showing up as expected. By looking more closely at one country, which also is projected to become the highest emitter of CO_2 emission of any one country, we can see the appearance of negative emissions around 2085 due to the deployment of bio-energy energy technologies with carbon capture and storage (or BECS) primarily in the electric power generation but also to a limited extent in the refining sector.

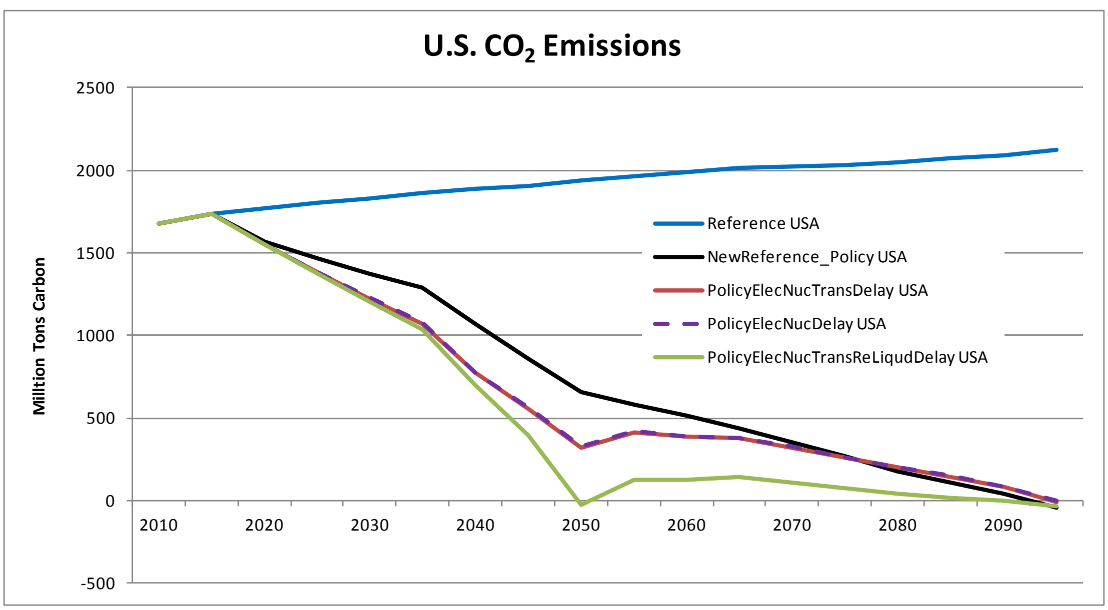

Figure 5-9: U.S. CO_2 Projections.

The CO_2 emissions across the Reference and delay scenarios for the U.S. in Figure 5-9 show a similar pattern to the High Income groups but a mainly different that the U.S. emissions exhibit greater mitigation particularly in the delay scenarios, for example momentarily hitting negative emissions in the PolicyElecNucTransReLiqudDelay scenario by 2050 and full negative emission, again due to BECS technologies, in all four mitigation policy scenarios.

5.6. *Global Sectoral CO_2 Emissions*

Emission projections for CO_2 for the aggregate income regions and two key countries can be further disaggregated by sector. Figures 5-10, 5-11, and 5-12 show the patterns of emissions for the global Electricity, Transportation, and Industrial sectors, respectively, for the Reference or no policy scenario, the un-modified GCAM mitigation scenario (Ref_Policy), and the Delay Policy scenario.

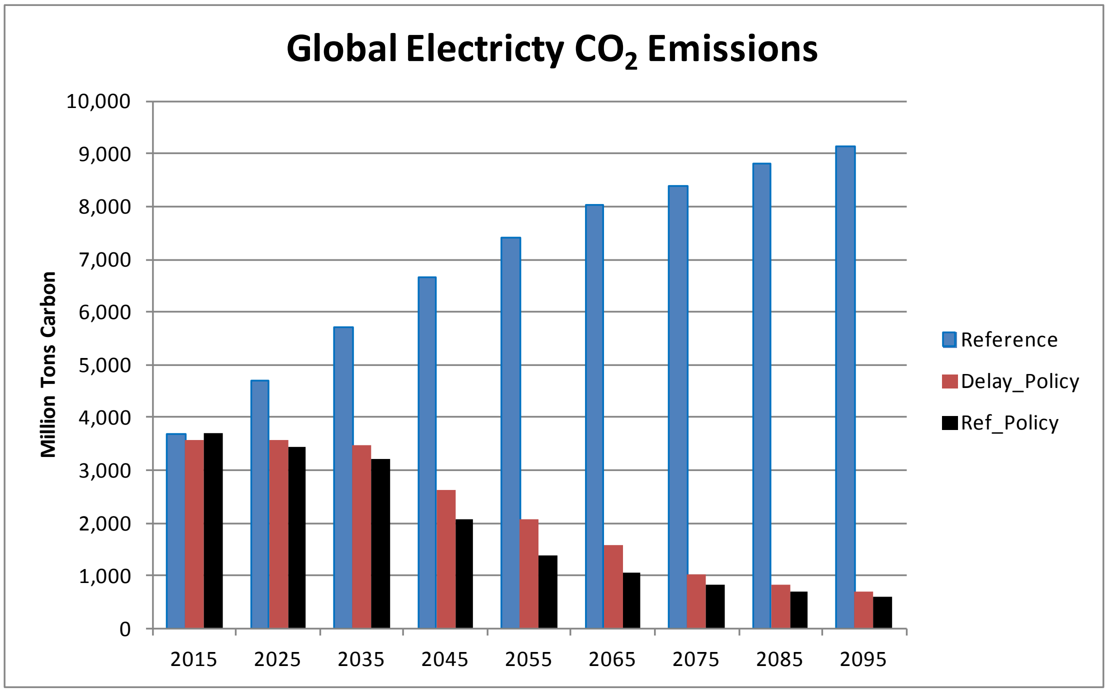

Figure 5-10: Global Electricity CO_2 emissions.

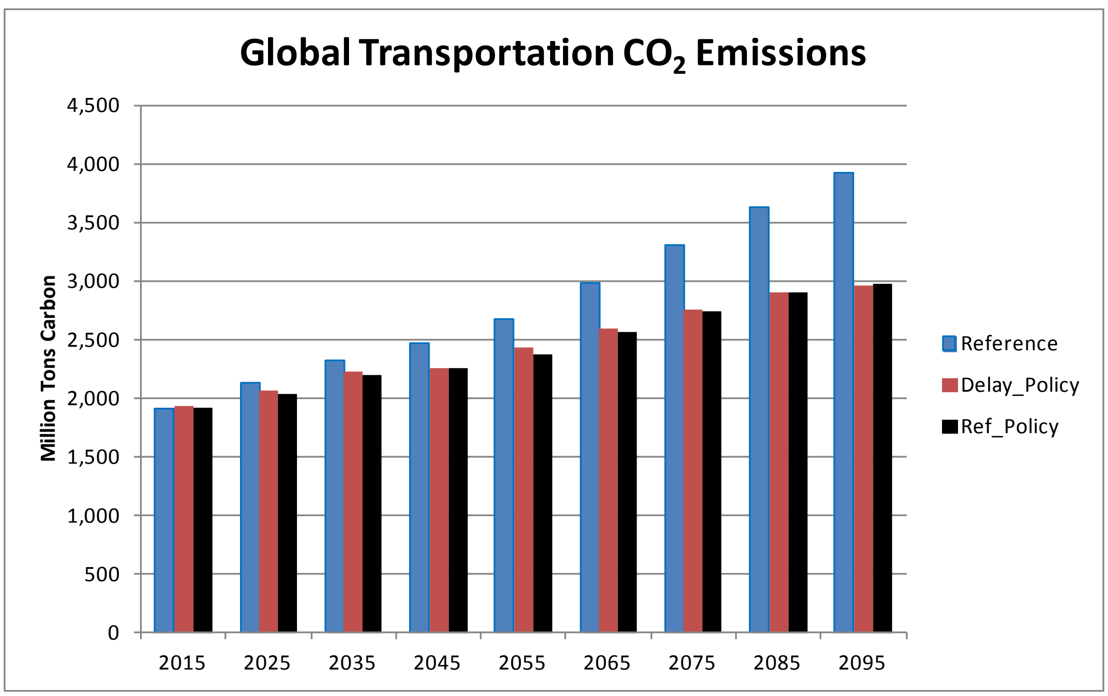

Figure 5-11: Global Transportation CO_2 emissions.

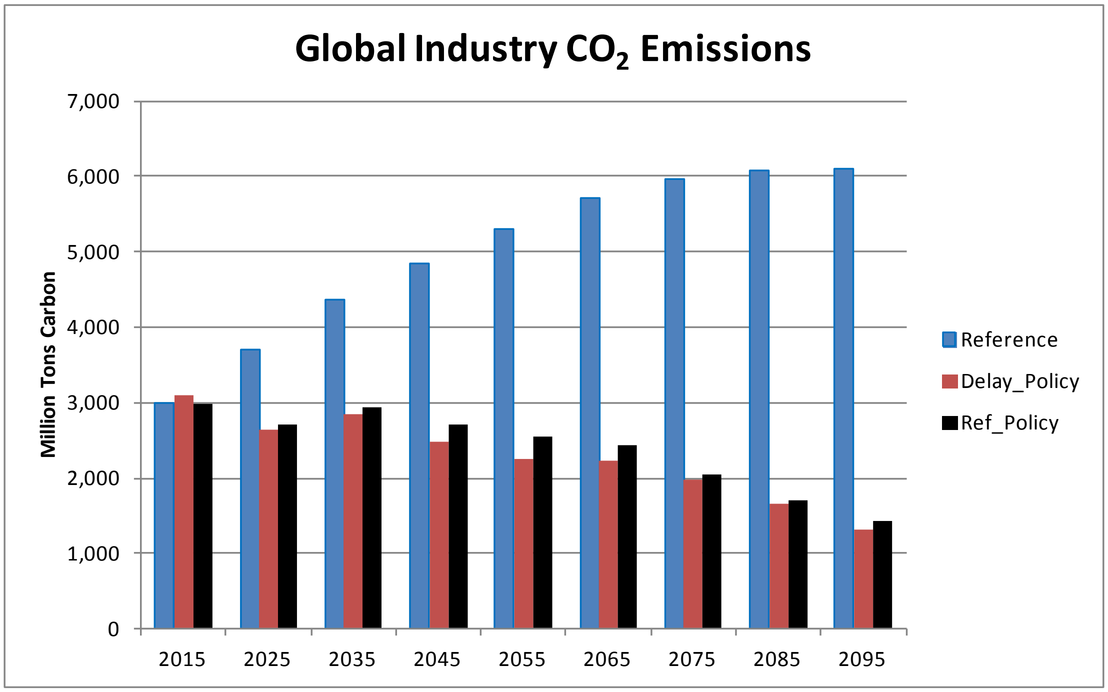

Figure 5-12: Global Industry CO_2 emissions.

5.7. Global Electric Power Generation

Decomposing the electric power generation at the global level by technology and primary energy source provides a better sense of emissions in the Reference (no policy) scenario and mitigation potential in the optimal GCAM mitigation scenario, NewReference_Policy, and the combined delay-policy scenario for the electric, transport, and refining sectors. The Reference scenario, Figure 5-13, shows a steady increase in fossil generation primarily coal-based generation which achieves a share of about 37% of total generation in 2050 which moderates to about 32% by 2095. Natural gas-powered generation also increases in the absence of a climate policy with about 27% of generation in 2050 and 20% by 2095. Fossil generation does improve in efficiency over time but does not add on any CO_2 capture technology given there is no price placed on GHG emissions. Nuclear power generation is about 12% of generation in 2050 and continues to grow to just short of 20% by 2095. Renewable energy power including hydro, geothermal, wind, biomass, and solar also increases it share of total generation with 21% in 2050 and almost 25% by 2095 where the growth in mainly from wind and solar which benefits from projected cost declines. Hydro and geothermal are based on exogenous assumptions of capacity as of 2010 that do not change over time based nor on the scenario hence is their contribution to energy generation constant throughout the results.

The NewReference_Policy scenario shows a distinctly different future of global electric power generation where there is a stringent and globally implemented climate mitigation policy. This scenario is illustrated in Figure 5-14 below. There are three principal differences that stand out in this policy scenario when compared to the Reference scenario. First, nuclear power grows dramatically and dominates power generation with a share of 22% of total energy produced in 2050 increasing to about 42% by 2095. This growth is based on the non-emitting GHG nature of nuclear power and that it is cost competitive against renewable power options. The assumptions used in the projected growth of nuclear power in this GCAM reference projection were developed prior to the Fukushima Daiichi nuclear accident that occurred in March 2011. If more recent prevailing views on nuclear power growth are taken into account there would be less of a growth in nuclear power over the century although developing limits to place on cost-competitive model solution would best be done as a parametric study. The second difference is the introduction of CCS technologies –starting in 2020– on both coal-based and gas-based generation which permit the continued use of fossil fuels by capturing 90% of the emitted CO_2. The amount of energy produced from coal and gas does not change very much over the century but the share from each decreases as non-emitting technologies continue to grow. Coal goes from about 17% in 2050 to less than 10% by 2095 with practically all coal generation requiring CCS as of 2065. Since natural gas has lower CO_2 emissions per unit of energy, its transition to all CCS deployment is more gradual. The share of generation for natural gas is about 22% in 2050 and 12% by 2095 with less than 10% of gas generation running as un-captured by the end of the century. The notable third difference in comparison to the Reference scenario is the appreciable growth in renewable power which is about 32% in 2050 of total generation and continues to 36% by 2095 with almost equal shares for wind, biomass with CCS (a negative emissions technology) and solar power.

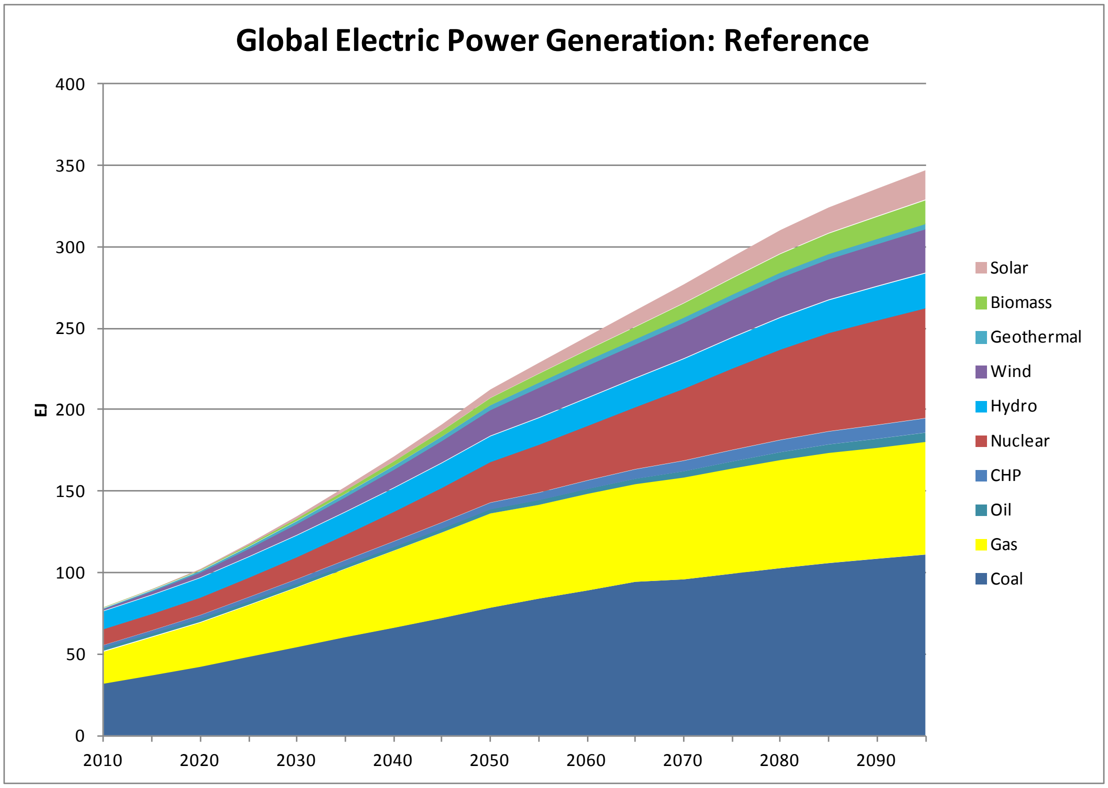

Figure 5-13: Global Power Generation – Reference.

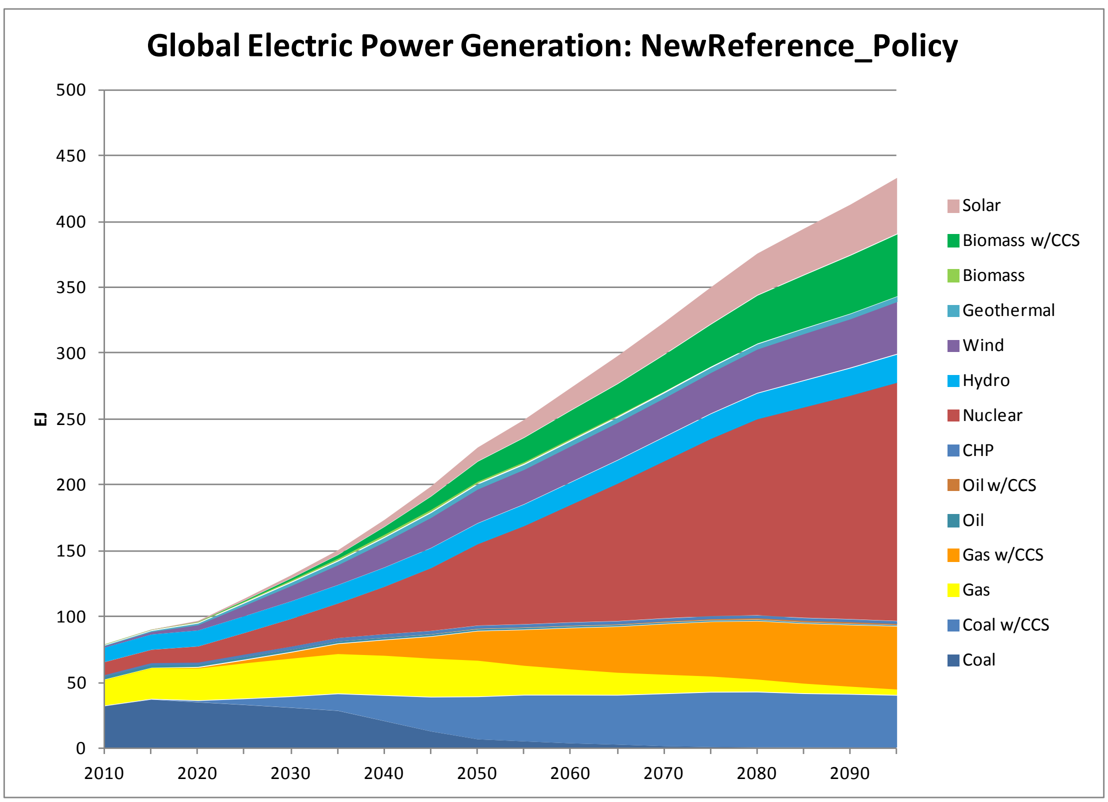

Figure 5-14: Global Power Generation – NewReference Policy.

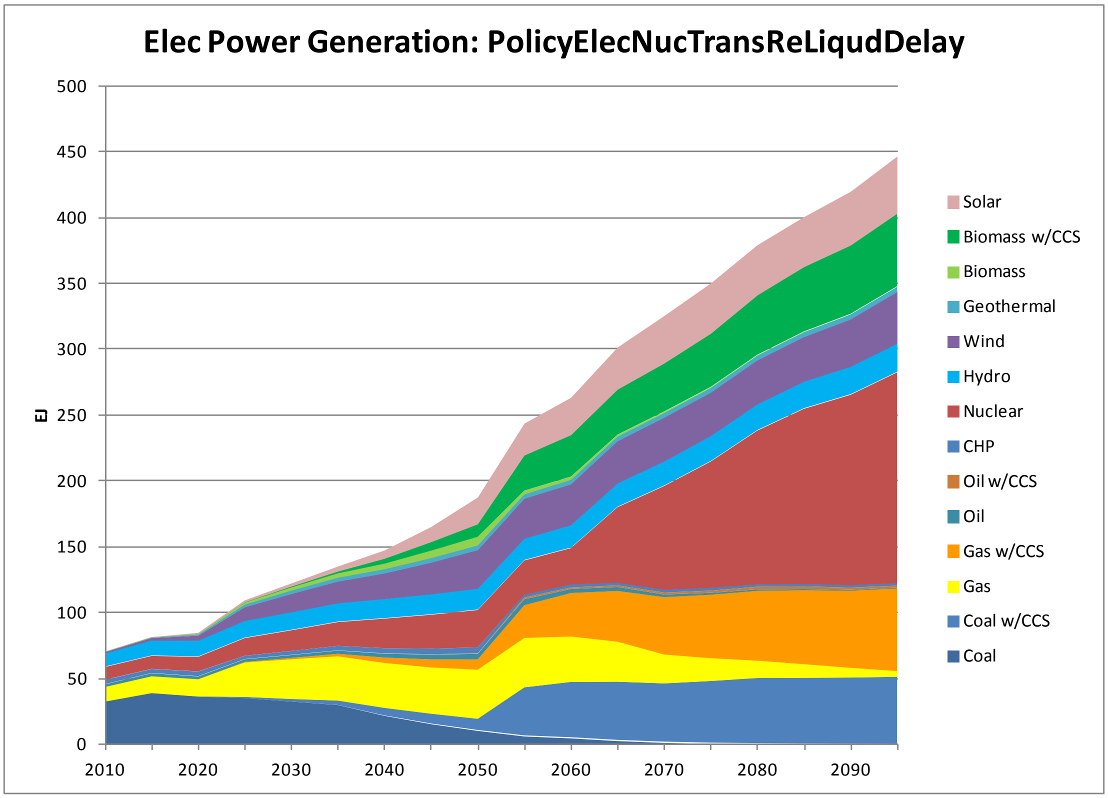

Figure 5-15: Global Power Generation – All Sector Delay.

Finally the picture on global electricity generation in the all-sector delay scenario (PolicyElecNucTransReLiqudDelay – Figure 5-15) shows a clear punctuation in 2050 when most of the energy-related CO_2 mitigation technologies are allowed to be deployed in the low- and middle-income countries, especially the larger countries or regions of China, India, Latin America and Southeast Asia. The lack of technology diffusion for advanced CO_2 mitigation until largely until 2050 yields higher energy costs due to the addition of the carbon tax (see Section 5.9 below for details) which suppresses demand for energy in particular electric energy. In the standard NewReference_Policy scenario, global electric energy generation reaches 150 EJ by about 2030 while in the All Delay scenario this energy level is pushed off until after

2040 and does not come into alignment with the NewReference_Policy levels until 2065 of about 300 EJ. In the All Delay scenario there is a greater reliance on renewable energy at about 46% -mostly wind-- of total generation in 2050 which moderates some to 37% by 2095when the advanced technologies come on line especially biomass with CCS and solar power. Coal generation is approximately 10% in 2050 staying about the same share out to 2095 but switching to coal with CCS mainly as of 2070. With the limitations on technology diffusion mostly lifted on nuclear power as of 2050 its share of generation increases from just over 15% in 2050 to over 35% by 2095 and thereby exhibiting the same pattern of overall mitigation share in the NewReferece_Policy scenario. Lastly natural gas has the same characteristic of coal but shows an even greater expansion after 2050 when its share is about 24%, then abruptly increases starts transitioning to CCS technologies and reaches about 37% of generation by century’s end.

5.8. Regional Energy Sector Projections

Taking a closer look at the main energy and CO_2 mitigation sectors, that is electric power generation and transportation, in the two representative countries the U.S. (for the High Income countries) and China (Low- and Middle-Income) helps to better understand the implications of the technology diffusion changes and associated changes in CO_2 emissions. The trajectories for different realizations of the future for China's electric power generation show three distinct pathways as illustrated in Figure 5-16. The Reference scenario shows continued, increased generation increasing six fold by 2090 when it start to level off. This follows China projected population and economic trajectory with some slower rate of increase due to continue pattern of improvements in energy intensity. The first contrast is to the GCAM un-modified climate mitigation scenario, NewReference_Policy, where there are no changes to the standard assumptions on the availability of advanced technologies, for example coal generation with CCS or renewables with energy storage. In the standard GCAM configuration the level of electric power generation increases significantly due to the imposition of a climate policy target as the Chinese economy increases its electrification. More specifically, it is more cost-effective to decarbonizes the electric power sector and then increase the share of electricity used by the industrial, commercial, residential, and transportation sectors relative to other energy inputs that are more carbon intensive, mainly coal, petroleum, and natural gas. This pattern of increased electrification is a common and robust finding in climate economic models. The second contrast is the pattern exhibited by both of the technology delay cases which cause a divergence from both the Reference and standard policy cases, that is, away from greater electrification. The lack of available advanced technologies in China prevents a move toward more cost-effective forms of energy use in that economy. Under the climate policy target this also has the effect of creating a shortage of cheaper mitigation from one of the largest emitters of CO_2 putting a further burden on other countries.

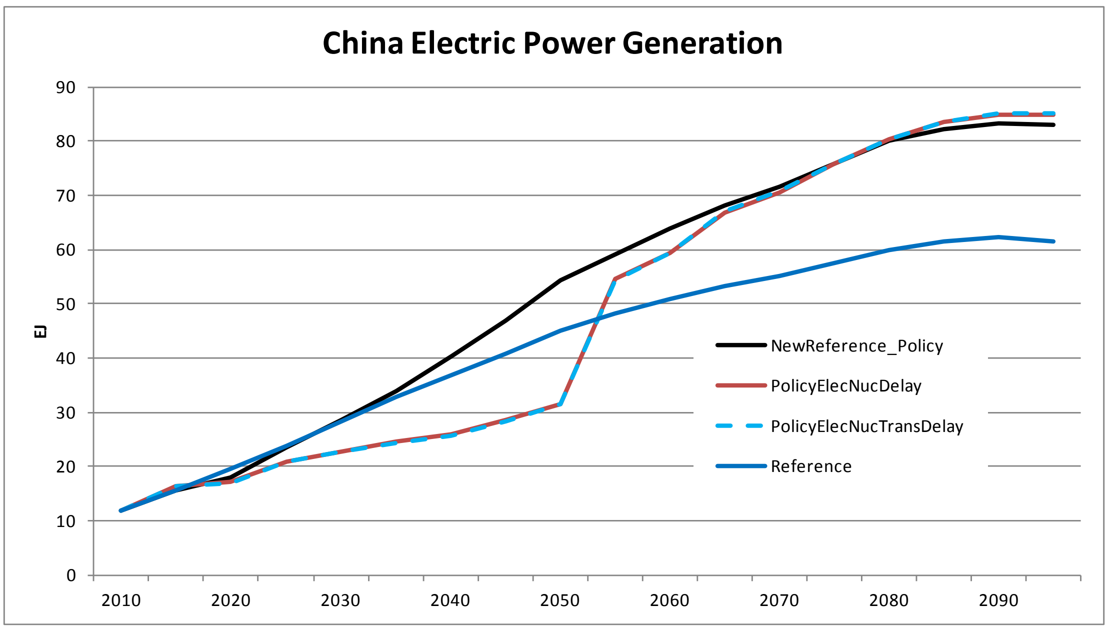

Figure 5-16: China Power Generation.

The U.S. power generation trajectories (Figure 5-17) show similar patterns for the Reference and the un-modified climate mitigation scenario, NewReference_Policy, with increasing electric energy generation over the century and a move toward more electrification and decarbonization of the U.S. economy. As was seen in the emissions projections for the technology delay cases, there will be more of a burden on the U.S. and other High Income countries when the Low- and Middle-Income countries do not have equal and timely access to advanced technologies. This is shown in the uptick of electric power above the standard policy case from 2035 to about 2070.

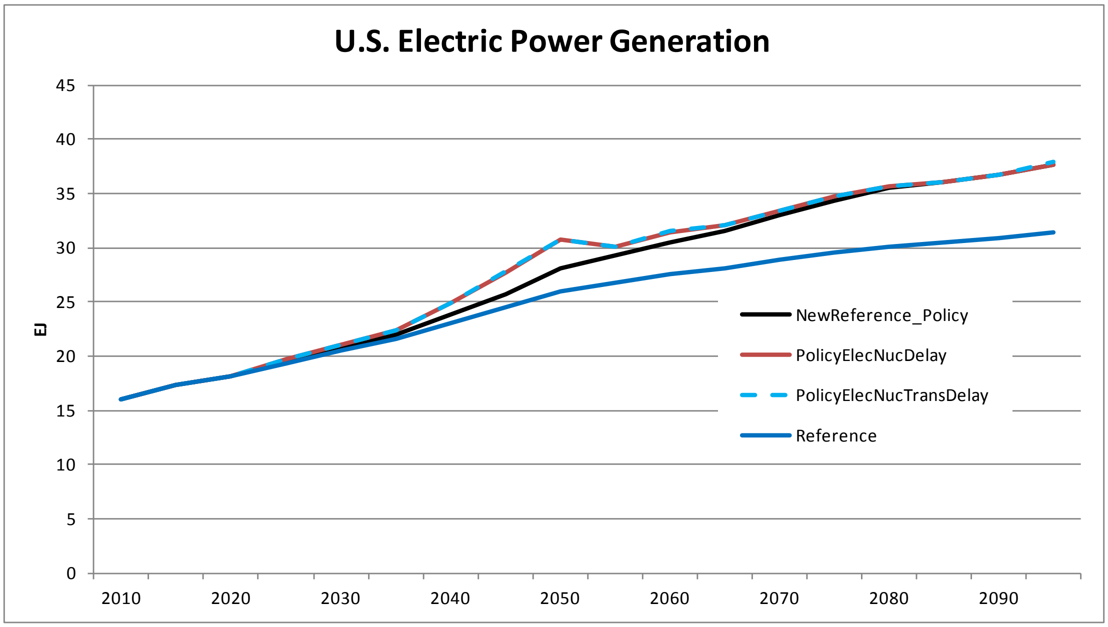

Figure 5-17: U.S. Power Generation.

Switching from energy production to the use of energy for transportation services in the economy we see the opposite patterns for both China and the U.S. in that the climate policy decreases the amount of energy consumed in transportation relative to the no-policy References case. See Figure 5-18 for China's transportation results and Figure 5-19 for the U.S. in energy terms. In both countries the policy cases cause a drop in both passenger transportation and freight transpiration services due to the imposition of the carbon tax. In China where the decreases are more noticeable, Reference scenario passenger transportation is about 7,800 billion passenger-kilometers (pass-km) in 2050 which decreases by 6% in the NewReference_Policy scenario and 10% in the All-Delay case due to the higher carbon tax. By 2095 the projected transportation services in China are just over 13,000 billion pass-km in the Reference scenario. Since the mitigation options are the same in the later periods, both policy scenarios yield the same level of reductions of about 11%. The other part of transportation services modeled in GCAM is freight or cargo which is denominated in ton-km which is the ability to move 1 ton of cargo a distance of 1 km. Reference freight transportation is projected at about 18,700 billion ton-km in 2050 and just over 31,000 billion ton-km in 2095. These are impacted by 23% and 25% reductions in the All-Delay policy case by 2095, respectively, which indicate a greater impact on freight than passenger transportation in China.

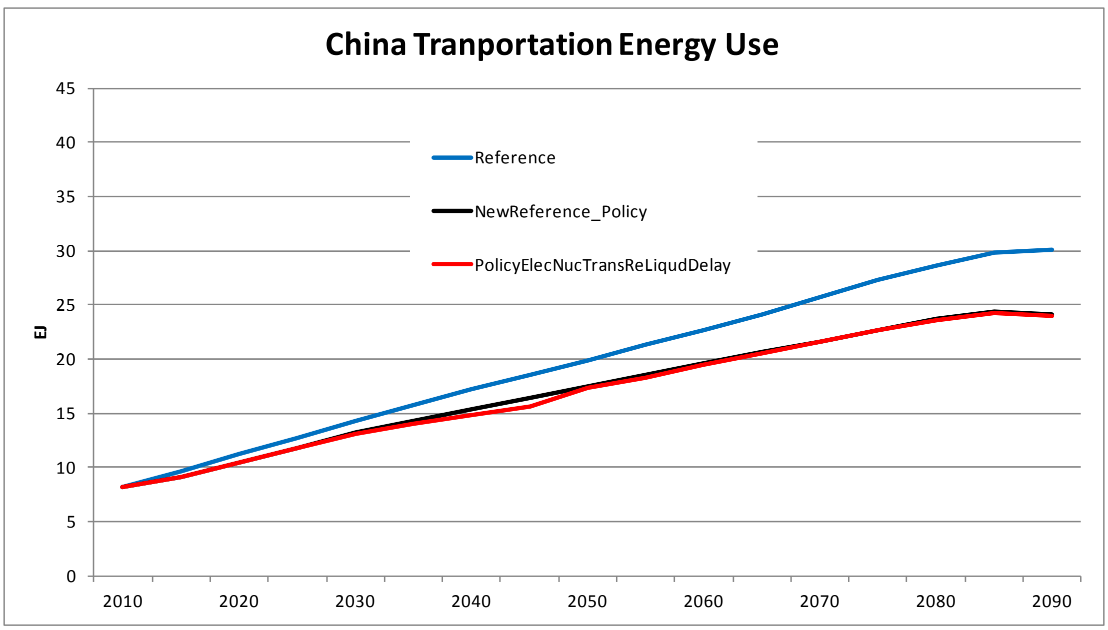

Figure 5-18: China Transportation Energy Use.

The impact on transportation services in the U.S. is not as great as in China for both passenger and freight transportation services although it is useful to note that while the U.S. enjoys much greater transportation services in pass-km and ton-km, at least in the earlier half of the 21st century, China expends more energy for less transportation services owing to the much greater efficiency of the U.S. transportation technologies and system. In 2050, projected Reference scenario U.S. passenger transportation is about 15, 000 billion pass-km and decreases by less than 3% in the climate mitigation cases. By 2095, passenger transportation increase to just over 20,000 billion pass-km in the Reference scenario with just about a 4% decline in the policy cases. Similar to China, freight transportation takes a bigger hit in the policy cases, about a 14% drop from the Reference projection of over 20,000 billion ton-km in 2050 to almost 25% in 2095 of the approximately 30,000 billion ton-km Reference level.

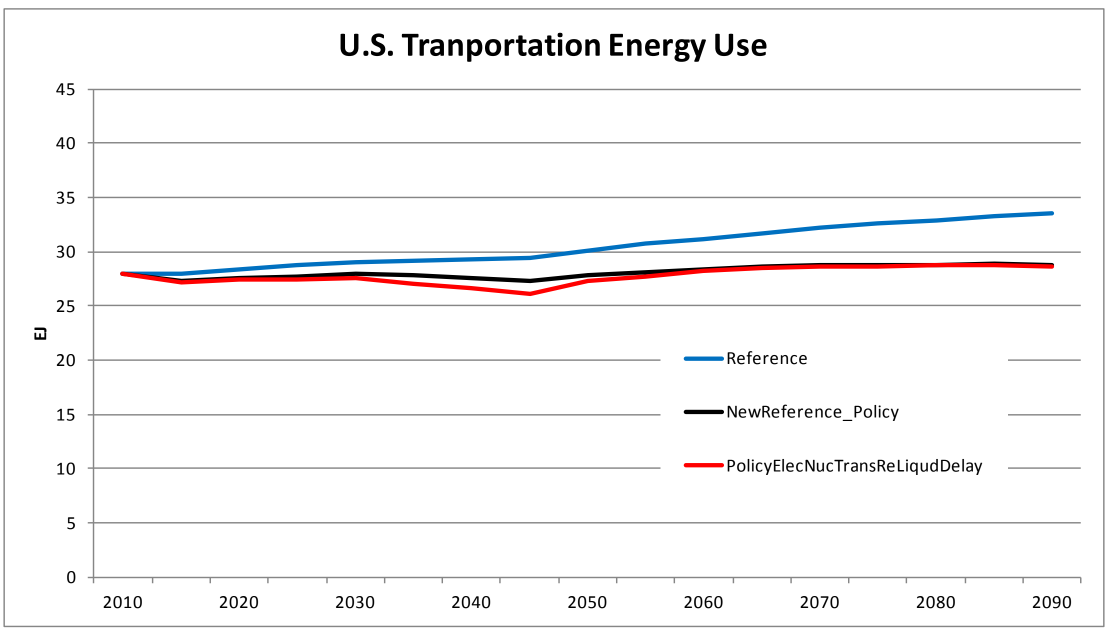

Figure 5-19: U.S. Transportation Energy Use.

5.9. *Scenario Cost Implications*

The results presented so far have shown the implications of changing key assumptions in climate economic modeling including population growth, GDP growth, and economic convergence on regional and global CO_2 emissions projections which are common sensitivity analyses conducted in the modeling community. The new work and main contribution made in this study is the change to assumptions on the rates of diffusion for advanced technologies mainly climate mitigation purposes. In the end, once a specified climate mitigation target is applied it is important to evaluate the feasibility of the modeled outcomes in terms of breath and pace of changes in the global energy system. Part of that evaluation is done by closer examination of the changes to energy production, energy use, and ultimately the cost of those transformations. Even though changing assumptions to population and economic growth rates, while leaving the standard GCAM technology diffusion assumptions in place, lead to different no-policy emissions trajectories, these can be compared to the set of technology delay scenarios given that all of the mitigation scenarios meet the same physical CO_2 emissions limit in the atmosphere.

Another way to think about the scenario comparison is to postulate different "What If" questions? That is, given a concern for climate damages and therefore a physical climate policy target of stabilizing global CO_2 concentrations at 420 ppm by 2100, what are the implications in terms of cost for meeting that target:

- If global population increases more than the central UN forecast?
- If economic growth is higher than estimated or than historical level of growth,

particularly in the Low- and Middle Income countries?

- If, conversely, the Low- and Middle Income countries do not “catch up” to the income levels of the High Income countries rapidly as commonly expected?
- If the rate of technology diffusion is not instantaneous and equally distributed around the globe as commonly expected in many climate economic models?

Figure 5-20 combines all of the policy mitigation scenarios based on the various different assumptions to the examined, key exogenous assumptions by showing the marginal cost as represented by the respective global carbon prices. It is important to note that these values are in 1990 USD per metric ton of carbon not carbon dioxide which is more commonly used. The non-delay mitigation scenarios exhibit the expected carbon prices trajectories starting with the New Reference case –using the standard GCAM assumptions– which steadily increase over time starting just below $110/TC in 2015, hitting about $285/TC in 2050, and ending under $680/TC by 2095. The non-delay scenarios range from the high of the High Population Policy Scenario hitting just under $1,050/TC in 2095 to the lower trajectory of the Low Convergence Scenario --where the Low- and Middle-Income countries have a slower rate of economic growth than the standard policy case—so that the carbon price is estimated at $525/TC in 2095.

They key test for the delay scenarios and a key insight from this study is the impact on the carbon price of the technology delay scenarios. These are clearly identified in Figure 5-20 given their much greater ascent through to 2050 than any of the non-delay scenarios so that the increase over the standard New Reference Policy scenario ranged between 65% and 85% percent in that year (see Figure 5-21 for the percent changes over the New Reference Policy for all the scenarios). This result is a clear indication that the assumptions made on the rates of diffusion for advanced mitigation technologies between High Income and Low and Middle Income countries matter just as much or more than other key assumptions made in climate economic modeling.

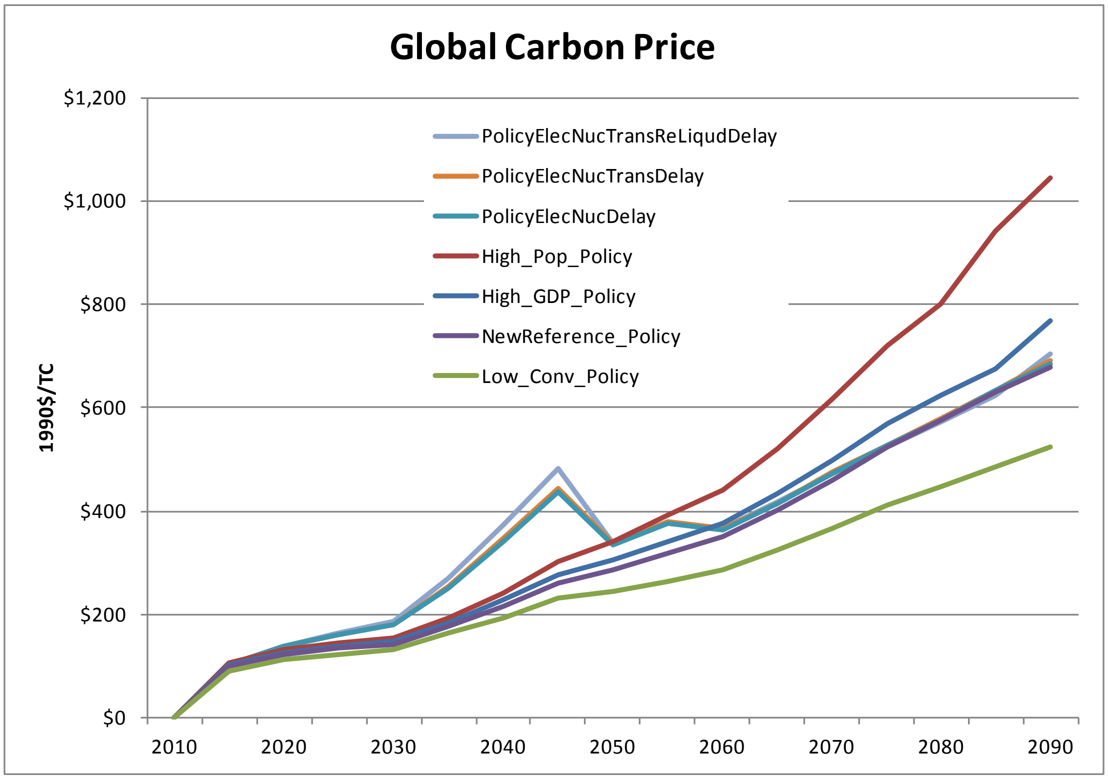

Figure 5-20: Global Mitigation Policy Marginal Costs.

The policy cost of achieving the same global climate target can also be used to compare the scenarios but more caution is needed as policy costs are estimated as the cost of hitting the target versus a baseline case where no policy is implemented and underlying the baseline emissions projection is difference for each set of assumptions.

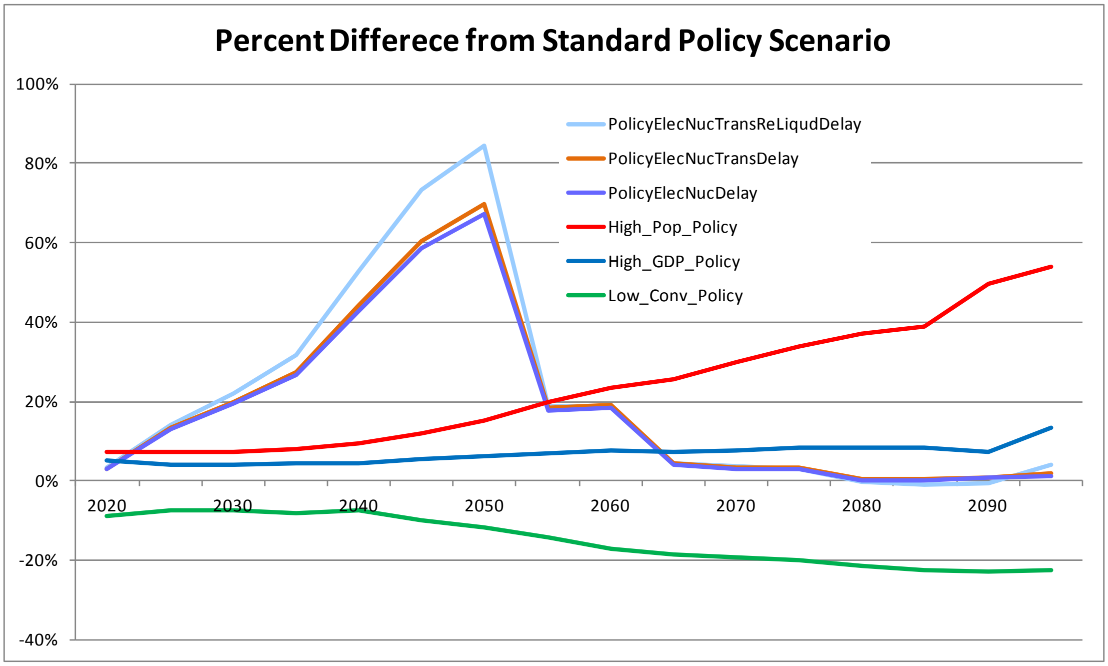

Figure 5-21: Global Mitigation Policy Marginal Costs – percentage.

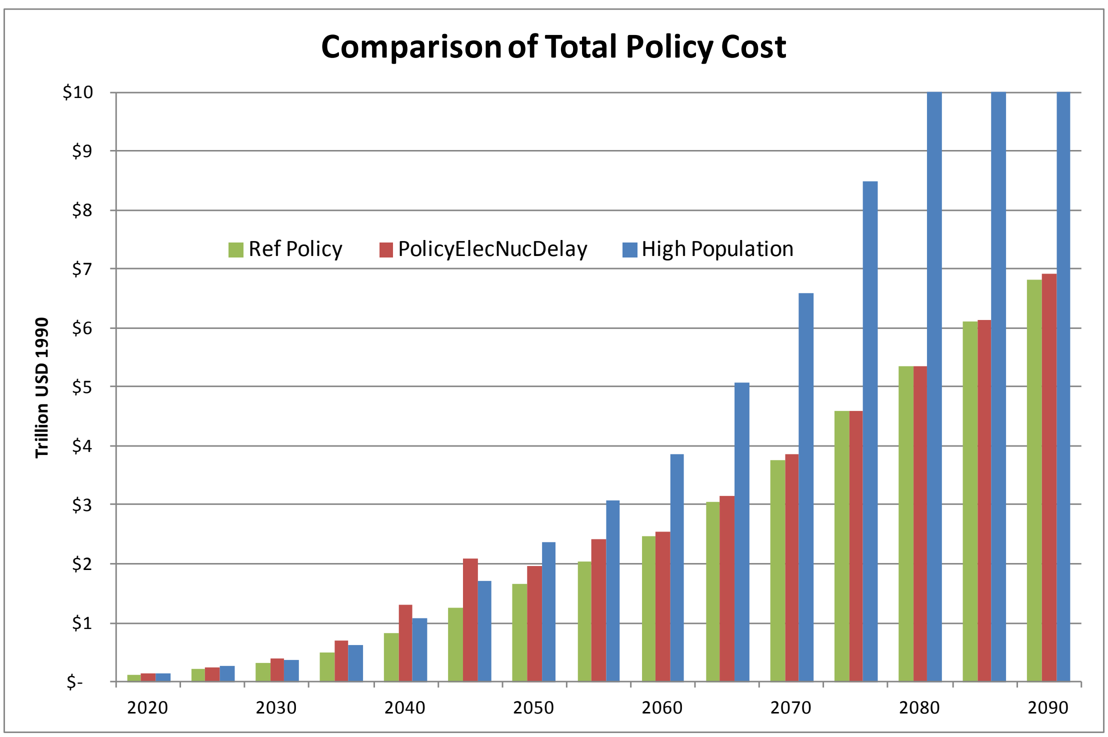

Figure 5-22: Global Mitigation Policy Total Costs.

This can be seen in the comparison of policy costs among the mitigation scenarios (Figure 5-22) corresponding to the High Population scenario, the NewReference scenario, and the delay scenario for the global electric power sector (PolicyElecNucDelay). Similar to the marginal costs shown above, the global total policy cost of the Delay Scenario is greater than the other two from 2030 through 2045 (just over $2 trillion 1990 USD) when most of the technology delay assumptions are in place. Global policy costs in terms of the net present value (NPV) from 2015 to 2050 at 5% is highest for the Delay scenario at $12.9 trillion, versus $9.4 trillion for the standard mitigation approach where all technologies are instantaneously and equally available worldwide. Even the High Population scenario is less at just over $12.5 trillion in NPV. It is over the longer term projection out to 2095 where the much greater CO_2 emissions in the High Population case and the required greater mitigation lead to higher policy cost starting in 2050 on an annual basis. However, this is a very different baseline or no-policy scenario where the same type of experiment on the delay of technology diffusion could be done in the corresponding mitigation scenarios. The NPV estimates of total policy costs out to 2095 do show the High Population scenario much higher at just over $33.3 trillion. The two scenarios that are comparable are the NewReferece Policy scenario at almost $21.0 trillion versus the Delay scenario at over $24.3 trillion which indicates that over the century the additional cost of the assumed delay in technology diffusion from High-Income to Low- and Middle-Income countries is just about 20% greater.

5.10. Alternative Diffusion Scenario

The new scenarios implemented above focus on the question: What are the implications if the rate of technology diffusion is not instantaneous and equally distributed around the globe as commonly expected in many climate economic models? To assess another angle on the technology diffusion question an alternative scenario was constructed where advanced technologies are implemented first in the lower-income countries and later in the high-income countries. This alternative scenario is named "Developing_Advanced" (LDC_Adv) and is defined as follows:

- Same global mitigation target as the existing scenarios.
- Focus on the electric power sector and even more specifically only on advanced fossil generation with CCS and advanced nuclear power;
- Country technology diffusion defined by:
  - Delay deployment in High Income countries by 30 years and then gradually allow deployment by adjustment of the share weight parameters.
  - Allow immediate deployment of advanced technologies in China, India, (rest of) S&E Asia, Former Soviet Union, and Latin America.
  - Keep the deployment to the Middle East and Africa the same as in the current Delay scenario.

Result from this alternative scenario follow below with a focus on evaluating global electric power generation, CO_2 emissions for China and the US, and global carbon prices marginal as the measurement of policy costs.

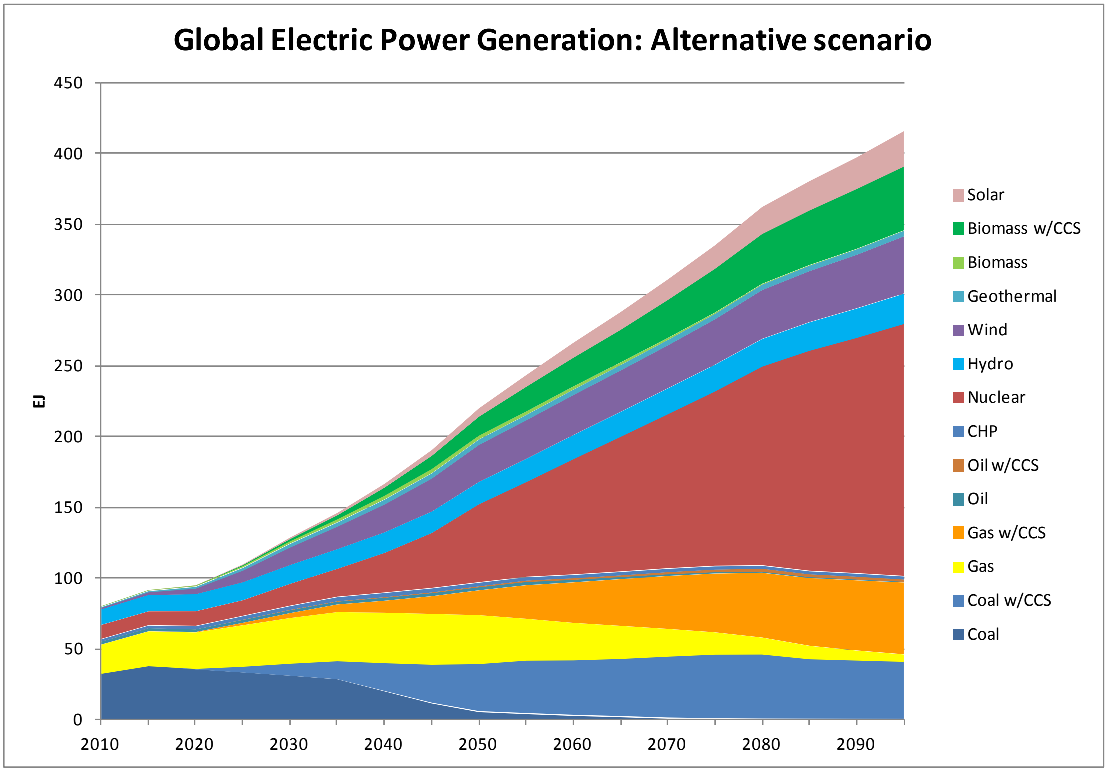

Figure 5-23: Global Electric Power Generation in an Alternative scenario.

In comparing global electric power generation from the "All Delay" scenario (PolicyElecNucTransReLiqudDelay) from Figure 5-15 to the alternative scenario in Figure 5-23 the most notable difference is the absence of the abrupt transition or punctuation around 2050 in the "All Delay" scenario. In a scenario where the lower-income countries (particularly China, India, and Latin America) deploy advanced technologies before the high-income countries, the over global transformation is a smoother transition than the original "All Delay" case. The reason is because the majority of projected GHG emissions over the course of the century are expected from the lower-income countries (See figure 2-1). As a result, more GHG mitigation and advanced technologies are projected to be required in the lower-income countries. Furthermore, figure 5-23 shows that for electricity generation, there is a heavy reliance first on new nuclear power, and then on CCS on both coal and gas plants, and an increasing share of non-hydro renewable power.

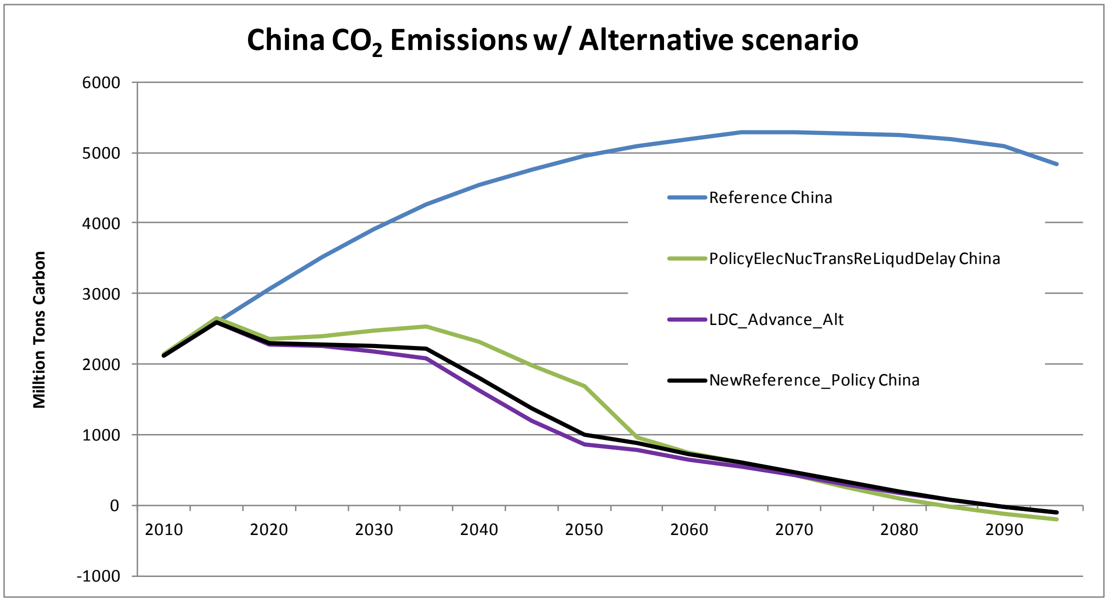

Figure 5-24: China CO_2 Emissions in an Alternative scenario.

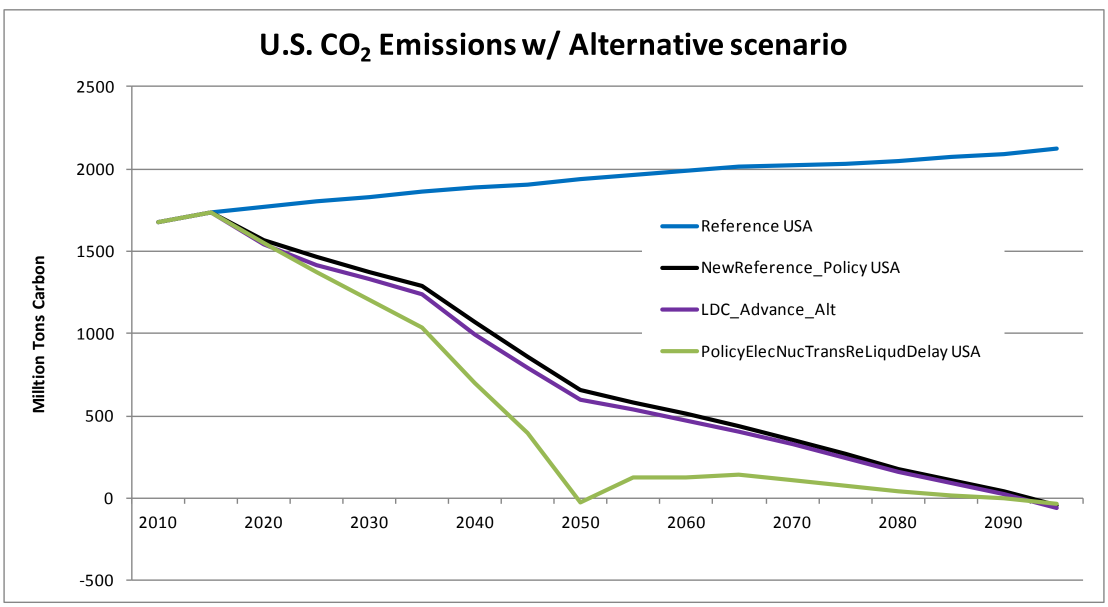

Figure 5-25: U.S. CO_2 Emissions in an Alternative scenario.

The changes from the power sectors in China and the U.S. are reflected in those countries' overall CO_2 emissions as seen in Figures 5-24 and 5-25, respectively, where the Developing_Advanced (LDC_Adv) is compared to the standard main policy scenario, "NewReference_Policy", and the All Delay scenario. As expected the move for China is in the opposite direction as more GHG reductions occurs in the Developing_Advanced scenario. This is indicated by the LDC_Advance line showing greater mitigation than both of the two other scenarios. For the U.S., the alternative scenario shows mitigation effort closer to the standard policy scenario (the purple "LDC_Adavce" line proximity to the black "NewReference_Policy" line). This is also expected since the alternative scenario places constraints on advanced power generation technologies on the U.S. and other high-income countries until later decades whereas the major lower-income countries can deploy those technologies from the start.

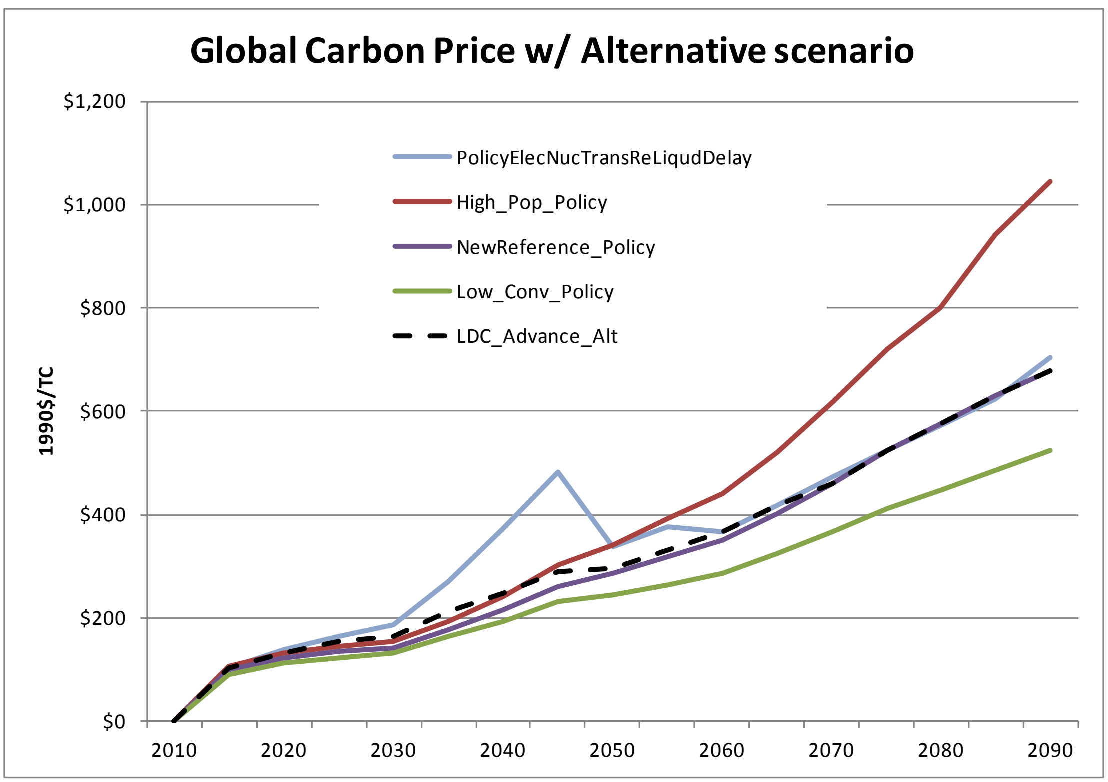

Figure 5-26: Global Mitigation Policy Costs with an Alternative scenario.

The cost implication of the alternative scenario are captured in Figure 5-26 and also compared to the other main scenarios in terms of the global marginal carbon price. The LDC_Advance (black dashed line) scenario initially falls between the All_Delay (light blue) scenario and the standard GCAM policy (purple) scenario and then gradually increases over the standard, all country-technology availability scenario. It is initially surprising that the carbon price of the alternative LDC_Advance does not increase as much as the All_Delay scenario (where delays are in place for the lower-income countries) but this again reflects the requirement that most mitigation occur in the lower-income countries. Since those countries have earlier access to advanced technologies the costs should be lower than the case where they do not. In addition, the high-income countries can still mitigate CO_2 emissions with the available standard set of technologies available in GCAM; it is only the advanced technologies of CCS and next generation nuclear power that are delayed for the high-income countries. Once those advanced technologies are available to the higher-income countries the carbon price start to track similarly to the standard policy mitigation scenario that has no specified delays for either group of counties. The overall insight from this alternative scenario help to further stress the importance, especially in keeping costs down, of incentivizing advanced technology diffusion to the lower-income countries in order to deal with their significant, project growth of emissions.

6. Observation, conclusions, and implication for modeling climate mitigation targets

This final section will cover two sub-sections with observations and implications of this study for climate economic modelers who interpret and use modeling results. Over the last decade there have been over 1,300 global GHG emission scenarios created by the internal modeling community that have covered a plethora of variations on inputs, assumptions, and modeling approaches. There are two main scenario databases —which include baseline and mitigation scenarios— available to the research community for the purposes of maintaining, comparing, and assessing data related to GHG emissions drivers and their results. The first database is the Greenhouse Gas Emissions Scenarios database maintained by the National Institute for Environmental Studies in Japan (NIES, 2012) which contains data of the past IPCC reports, including the Special Report on Emissions Scenarios, Third Assessment Report, and Fourth Assessment Report as well many of the underlying scenarios efforts such as the International Energy Workshop Poll, the Energy Modeling Forum, as well as directly from individual researchers. The second, more recent scenarios database is the Shared Socioeconomic Pathways (SSPs) initiative housed at the International Institute for Applied Systems Analysis (IIASA) in Austria (IIASA, 2013). The objective of the SSP database is to catalogue and document GHG projections from Integrated Assessment Modeling scenarios in order to facilitate research among the broader community including areas of climate change climate impacts, vulnerabilities, adaptation, and mitigation. There also have been recent full assessments of the GHG scenarios literature including the IPCC Fourth

Assessment Report on Mitigation in Chapter 3 (Fisher et al, 2007) and the National Academies of Sciences 2010 report *Limiting the Magnitude of Future Climate Change*, Chapter 2: Goals for Limiting Future Climate Change (de la Chesnaye and Clarke, 2010). (There is also a draft of the IPCC Fifth Assessment Report on Mitigation but that will not be officially approved and published until mid 2014.) While it is not feasible to have reviewed all of the scenarios in the literature, I have reviewed most of the key scenarios studies and major assessments to appreciate the range of main variations on inputs, assumptions, and modeling approaches used by the principal research groups in this field. In the development of reference or no-policy cases the main drivers of GHG emissions, and therefore possibilities of modifications to those drivers, include population growth, economic growth, the type, use, and advancement of technologies, and changes in landuse (not covered in this dissertation). In the development of climate mitigation scenarios, for a given policy target, there are two traditional areas of focus: The first is the how the policy or policies will be realized, e.g., is it a globally comprehensive target with full international participation (similar to what many modeling groups use to reach the 2 degree target)? Or is a globally fragmented set of policies with each nation pledging its own goals and letting the resulting GHG emissions and CO_2 concentrations fallout from that, as is the case reported from the last two UNFCCC international negotiations (Economist, 2013). The second area of focus in the modeling community on mitigation scenarios is on the role or availability of technology, more specifically advanced mitigation technologies to more cost-effectively reduce GHG emissions under various levels of stringency for climate targets.

Just ahead of the IPCC Fifth Assessment Report on Mitigation there is a forthcoming special issue journal in *Climatic Change* (Weyant, 2014) covering the most recent coordinated, international study organized the Energy Modeling Forum at Stanford University on global GHG emissions scenarios. The study (EMF-27) includes 18 climate-economic and integrated assessment modeling team from Europe, Japan and the U.S. that evaluated global technology strategies for climate mitigation under various assumptions on long-term global climate policies and technology availability and their interactions. The synthesis policy paper (Blanford, et al, 2014) provides an overview of the multi-model comparison in the study that included two harmonized long-term climate targets. The first target is to achieve a concentration of 450 ppm CO_2-e by 2100 allowing temporary overshoot of the target. These targets are CO_2-equivilant (CO_2-e) which include other GHGs such as methane and nitrous oxide meaning that they are more stringent than CO_2-only targets since allowance is needed for the radiative forcing of the other gases (IPCC, 2007). As a consequence the 450 ppm CO_2-e target is roughly equivalent to a 370 ppm CO_2 target. The second target is a 550 ppm CO_2-e (or ~ 450 ppm CO_2) which must be exceeded during the 21^{st} century. This second target is consistent with the climate policy scenario run in this dissertation. In the EMF-27 study there also were two fragmented policies based on national and regional emissions targets. The EMF-27 study results stress the importance of international cooperation and an appreciable divergence from the current trajectory of policy commitments if global concentrations anywhere approaching 550 pm CO_2-e are to be achieved. In addition, the study continues to illustrate the heavy dependence on negative emissions in future decades if modeled tight targets are to be met and a consideration for this dependence in the policy debate.

In the same EMF-27 study there is also a technology synthesis paper (Kriegler, et al, 2014) that provides a summary on the role of technology in climate mitigation targets. There are two main findings from the study worth noting here. The first is that an extrapolation of current fragmented policy actions or energy intensity improvement rates are insufficient to keeping emissions from exceeding global concentrations of 550 ppm CO_2-e, however there is considerable uncertainty about the emissions implications of long-term climate targets from the various models. Second, GHG mitigation pathways show significant transformation of the global energy system through increased energy intensity improvements and the electrification of energy end-use coupled with a rapid decarbonization of the electricity sector. The study continues to highlight how important technology is toward meeting achieving climate mitigation targets and helping to transform the energy sectors of principally the developing countries off of their non-policy trajectories. Finally, the broad availability of advanced technologies is re-evaluated with more emphasis on the different between the 450 ppm and the 550 ppm CO_2-e targets where the global costs and even the feasibility of meeting the tighter target depends on technology availability.

In early 2014 edition of *Climatic Change* special issue there are 22 issue-specific papers covering various dimensions of climate change policy and related mitigation technologies plus the two technology and policy overview papers described above. Out of the whole set there are four papers that specifically address technology diffusion (Sano, et al, 2014) or availability (van Vilet, et al, 2014), technology interdependence (Kanudia, et al, 2014), and the value of technology development (Tavoni, et al, 2014). However, the approach taken with respect to differences between countries or regions on technology diffusion is the same standard approach as is customary, that is, there is no modeled difference in rates of technology diffusion between countries. In the Sano, et al, paper (2014), technology diffusion is modeled with a focus on renewable intermittency which is a challenge with a global climate-economic model due to the level of geographic aggregation. The study uses four different representations for renewable intermittency to highlight the importance of advancing the regional specificity of renewable availability for what they term more "realistic evaluations of climate change mitigation scenarios". The study also reinforces the importance or value of CCS technologies to keeping marginal mitigation down with stringent climate targets. Kanudia, et al, paper (2014) also evaluates the importance of dealing with renewable intermittency of renewable power but goes a step further in structuring the analysis to assess the interdependence or timing of various electric sector mitigation technologies. They find that the technology development of the intermittent renewables, that is wind and solar, are more dependent on stable baseload power such as nuclear and fossil generation with CCS than renewable biomass which is not considered intermittent. The potential value of biomass energy can be extended with its connection to CCS technologies resulting in a "negative emissions" option. Examining the importance of limiting climate mitigation technologies is the focus of the van Vilet, et al, paper (2014) which uses the IMAGE integrated model and finds that limits on technologies, from whatever reason, e.g., technological or public acceptance related, exacerbate pressure on near-term mitigation requirements if a long-term target is to be realized. The study further highlights the importance on the negative emissions option of BECS. The IMAGE modeling approach continues to use the same technology diffusion assumptions, just delay equally across all regions, to achieve the long-term globally harmonized climate target. The last paper on technological evolution by Tavoni et al (2014) covers familiar ground on the value of technology availability to confront climate targets and updates the literature from previous coordinated international studies including Weyant 2004 and Clarke et al 2008. In addition, the newer paper includes more recent work on technical change and the connection between technical progress and market failures that prevent clear signals for learning and innovation. This assessment of the most current literature on climate mitigation studies, with some emphasis on technology diffusion or evolution, shows that the standard approach on assumptions on technology diffusion between countries remains the same as in previous research and studies, that is, technology mainly diffuses as the same rate and across all countries at the same time.

Outside the special issues of *Climatic Change* (2014) a GCAM-related paper that explores the modeling of technology diffusion is Iyer et al (2013). This analysis also employs GCAM to evaluate stringent climate mitigation policies under different rates of technology diffusion (or diffusion constraints) based not on an assessment of technology converge as present above but rather on other factors such as limits caused by possible institutional, behavioral, and social issues. The research in this dissertation is also different in how technology diffusion was modeled both in changes to the standard GCAM approach (refer back to Section 4.3) and to geographic granularity of technology diffusion. In the Iyer at al approach, expansion constraints are placed only on technologies in the electric power sector, that is, nuclear power, CCS, and renewables. The approach taken in this dissertation included the power sector but also expanded to cover the modeling of different technology diffusion delays to the transportation and the petroleum refining sectors. In addition, this effort implemented different diffusion rates (delays) for the lower-income countries whereas the Iyer el at analysis imposed diffusion rates on a global level. Even with the different modeling approaches and stated underlying reasons for differences in diffusion rates, the conclusions of both analyses are similar: delay or limits on the diffusion of technology have an appreciable impact on the costs and feasibility of meeting stringent climate mitigation policies. Furthermore, both analyses highlight the importance of deploying advanced technologies in the power sector including nuclear power, CCS, and renewables. Comparing the differences in modeling approaches and implementation would be a useful exercise in further research with GCAM.

Beyond the recent climate economic modeling literature, research on technology diffusion is instructive in evaluating the results of the analytical effort in this dissertation. It is important to recognize that even in rapid pace of globalization that exist in the early part of the 21st century there is not a "global pool of technology" as pointed out in Keller's study (2004) on international technology diffusion even while acknowledging that foreign sources of technology explain a significant fraction of the productivity growth in the lower-income countries. There are distinct patterns of technology diffusion based on existing financial flows (trade, FDI, and private sectors agreements) and motivated by government technology transfer programs (See Section 2.2). In addition, there are also historical-geographic patterns to technology diffusion between higher-income and lower-income regions that should be recognized. More specific to renewable power Pfeiffer and Mulder (2013) evaluated the diffusion of non-hydro renewable energy technologies for electricity generation across 108 developing countries between 1980 and 2010. They found that the positive determinants of technology diffusion include implementation of stabilizing economic reforms and instruments, a diverse portfolio of power generation technologies, higher per capita incomes and education levels, and stable, democratic regimes. Factors that slowed the diffusion of renewable technologies included, in the power sector, growth of electricity consumption and high fossil power generation, and from the policy side, institutional and strategic policy support programs. A World Bank study (2008) on technology diffusion identified comparable issues and stated that most lower-income countries do not possess the same ability as higher-income countries to generate innovations at the technological frontier due to nascent domestic technology sectors, lower education levels, lack of protection for intellectual property rights, and the required infrastructure which is generally weaker, among other factors. These studies reinforce the modeling approach introduced in this dissertation of implementing a delay on technology diffusion based on the classification of countries by their income groups.

The key results from this dissertation show that the cost of meeting the same climate target could be appreciably higher when different assumptions on diffusion rate of climate mitigation technologies between countries are used. Marginal costs, expressed at $/TC start of much higher as soon as the mitigation policy is implemented and reach 65% to 70% above the standard mitigation scenarios for the Electric Sector and Electric and Transportation Sectors Delay scenarios. Marginal costs above the standard mitigation scenario are more than 80% in Delay scenario than combines the Electric, Transportation, and Refining Sectors. In terms of Total Policy Costs, the All Sector Delay scenario more than 30% greater than the standard mitigation scenario through 2050. The scenarios with delays for lower-income groups for technology diffusion and the alternative delay scenario where lower-income countries deploy first all point to the critical importance of incentivizing advanced technology diffusion to the lower-income countries in order to deal with their significant, project growth of emissions over the 21st century.

The assumptions on technical diffusion used in this research are based on historical rates of technological convergence across three main energy-related sectors covering electricity production, petroleum refining and transportation across more than 128 countries. With these results in mind, a few observations and recommendations are offered as areas of inquiry in the climate economic community:

- More detailed work is needed on sectoral and technology specific assessment on a historical basis to develop various rates of technology diffusion. For example, more detailed studies of how power generation technologies diffused in the past to countries at different levels of industrialization and income. Other areas to further explore are the electric power fossil efficiency rates that currently show general 30-year gap between the performance of OECD (higher-income) and non-OECD (lower-income) groups plus the newer experience with renewable power expansion in those two groups.

- Analysis on various factors that drive technology diffusion could help improve forward-looking scenarios in climate economic models. For example, other factors that may influence or retard technology diffusion could be common languages, common industrial standards and practices, historical ties and allegiances (e.g., Latin America and Spain, U.K. and Commonwealth countries), possible the strengths of trade flows between regions (i.e., trade agreements and trade facilitation); and the degree of income equality between different regions.

- For many climate economic models it may be difficult to specify different rates of technology diffusion depending on the level of technology and region detail. Analysts employing these more aggregated, simplified models should evaluate different treatment of technology specification and the levels of technology performance in an effort to simulate different scenarios than the ones where the best, advanced technologies are immediately and equally availably globally.

- Lastly, climate economic modelers should include in their core set of sensitivity analyses different rates of technology diffusion, especially for very advanced technologies that have not been commercially demonstrated at scale, for example carbon capture and storage (CCSW) or even more bio-energy with CCS, that can mean achieving a tight climate mitigation target or not, for example the 2 degree C target that is a principal focus of the international climate negotiations.

- The cost and difficulty of climate mitigation targets are likely underestimated because of the overly optimistic assumptions of technology diffusion in the recent and current round of climate economic studies (IPCC, etc).

- Assumptions on technology diffusion are just as important and influence the estimates of meeting climate targets just as much or more than the assumptions on population growth, GDP growth, and economic convergence. Technology diffusion and more particularly technology transfer could be an important policy option where decision-makers and policymakers could have more direct impact on mitigation and keeping the cost down on meeting tights climate targets. Policies at dealing with population growth are not necessarily in the control of most governments (China as the main exception) and many governments actively encourage greater population growth. Similarly with economic growth as counties continue to promote higher levels of economic growth, and those in the Low- and Middle income countries want to catch up as fast as possible. Globally coordinated policy mitigation policies, as pursued under the UNFCCC do not seem to be making sufficient progress on reducing emissions. Perhaps a strategy of promoting grater technology diffusion could help start reducing emissions in the short-term and also decrease global mitigation costs in the long-term given a particular mitigation policy.

Appendix A -- Data used in Section 3: Testing Technological Convergence

Oil Refining measure KTOE/GDP (2000 USD GDP)

Country	1971	1976	1981	1986	1991	1996	2001	2006	2008
Albania	429.5	448.2	213.0	204.1	248.5	89.7	45.0	52.6	32.1
Algeria	96.1	131.9	303.4	325.7	311.4	267.4	257.2	179.8	197.8
Angola	78.7	92.0	154.4	153.9	156.5	175.0	153.2	78.4	58.7
Argentina	234.2	205.8	225.3	179.3	189.6	161.7	185.9	150.2	131.7
Australia	85.3	102.3	83.8	69.4	72.2	68.0	54.9	40.0	39.5
Austria	56.9	57.6	50.8	42.5	42.1	39.4	33.9	29.2	28.1
Bahrain	4012.9	2058.3	2187.4	2320.8	1894.3	1572.9	1168.5	915.5	797.8
Bangladesh	44.3	53.1	63.2	42.3	39.5	33.8	29.5	22.5	16.8
Belgium	166.8	140.7	127.7	113.3	114.7	115.3	113.8	94.1	94.3
Bolivia	173.5	212.1	212.3	205.0	224.8	227.0	195.8	158.3	179.8
Brazil	108.2	118.9	110.7	103.4	98.3	97.8	111.3	101.0	93.2
Brunei Darussalam	0.0	0.0	0.0	47.5	51.8	62.9	65.4	68.3	73.9
Bulgaria	696.7	679.8	585.3	455.4	195.0	335.9	242.3	235.6	209.2
Cameroon	0.0	0.0	98.5	117.1	80.1	133.0	106.1	112.7	114.6
Canada	177.5	172.6	150.9	110.3	114.4	108.9	97.3	88.7	84.9
Chile	145.1	156.1	112.5	105.4	114.9	103.0	101.0	93.1	77.0
China	212.4	305.1	259.6	196.9	166.9	127.1	118.1	108.9	96.7
Colombia	192.6	146.0	121.9	120.6	129.3	129.9	133.2	97.0	86.3
Congo	0.0	0.0	0.0	132.4	124.2	58.0	102.4	99.4	80.8
Costa Rica	85.1	39.8	64.4	74.4	35.0	48.5	17.5	31.4	25.1
Cote d'Ivoire	136.4	196.5	193.8	177.9	183.8	201.1	190.0	237.7	203.6
Cuba	240.5	263.5	214.5	174.1	138.6	69.2	72.0	46.2	103.2
Cyprus	0.0	107.3	97.4	78.6	80.2	61.8	76.2	0.0	0.0
Czech Republic	105.0	110.1	115.2	97.7	77.0	78.4	60.2	62.3	60.3
Democratic Republic of Congo	63.2	34.3	28.8	6.2	26.5	0.0	0.0	0.0	0.0
Denmark	81.2	57.2	41.5	42.5	43.7	50.0	33.8	30.0	27.9
Dominican Republic	0.0	156.1	125.0	124.3	89.4	68.3	46.5	53.1	39.5
Ecuador	162.2	137.5	230.4	228.7	262.8	259.7	254.0	208.3	204.1
Egypt	375.1	581.2	571.6	522.2	469.9	426.0	360.4	297.7	264.1
El Salvador	60.6	71.4	64.5	72.0	74.8	56.7	62.8	48.0	43.6
Finland	115.8	124.2	107.4	78.2	83.4	91.3	69.6	69.6	70.9
Former USSR	594.1	631.2	581.3	475.0	384.9	334.2	301.6	260.7	238.3
Former Yugoslavia	121.4	144.3	116.9	129.6	112.5	90.9	76.0	63.4	57.9
France	113.9	108.9	76.8	54.6	50.2	50.2	45.8	40.3	40.0
Gabon	304.3	119.6	176.0	92.5	30.5	81.0	59.0	69.8	94.3
Germany	91.8	82.5	69.5	57.0	46.0	47.6	42.6	42.7	39.6
Ghana	192.3	286.0	267.1	194.7	162.8	135.3	131.2	84.0	101.8
Greece	52.4	85.3	108.7	107.7	93.5	118.7	104.4	88.6	82.5
Guatemala	92.0	63.1	51.6	36.7	33.7	36.7	34.4	2.4	1.7
Honduras	212.9	136.6	57.6	40.1	68.2	0.0	0.0	0.0	0.0
Hungary	127.5	148.0	128.9	112.5	106.8	101.8	80.4	75.3	73.5
India	133.2	132.7	142.5	171.1	147.3	131.7	173.8	162.9	156.9
Indonesia	222.0	183.7	184.6	233.6	234.3	195.7	215.6	161.6	140.7
Iran	395.9	295.2	311.0	318.8	401.4	483.3	497.3	394.3	365.6
Iraq	561.7	682.6	606.0	1491.7	1229.1	1394.5	1538.2	833.2	924.1
Ireland	78.7	43.7	13.0	24.8	22.9	20.5	20.8	15.3	15.0

Source: IEA. 2010a.IEA. 2010b.

Israel	165.4	159.0	133.5	122.0	116.9	101.8	90.1	82.8	78.0
Italy	147.2	107.9	82.0	69.6	62.2	58.0	56.2	55.5	52.9
Jamaica	209.3	138.3	101.6	100.0	99.0	60.5	92.5	87.6	100.0
Japan	106.1	100.7	75.2	51.0	49.2	51.6	48.7	43.7	41.7
Jordan	219.4	398.4	379.2	361.0	404.0	404.1	388.0	309.0	235.9
Kenya	464.4	393.7	308.0	186.1	159.5	121.5	106.3	86.1	73.8
Korea	176.3	181.8	168.0	120.2	148.7	182.3	174.2	142.0	129.4
Korea, DPR	0.0	0.0	144.5	98.3	124.5	79.0	47.7	28.2	34.1
Kuwait	283.4	390.5	391.4	783.2	119.4	739.2	592.1	525.1	472.9
Lebanon	125.4	341.0	149.5	68.5	40.9	0.0	0.0	0.0	0.0
Libya	24.1	83.7	155.8	389.2	418.2	476.6	465.9	297.9	295.4
Malaysia	248.2	234.9	165.9	197.0	177.9	197.6	212.3	160.8	163.2
Mexico	89.2	99.5	113.4	123.3	118.0	108.6	87.8	80.1	73.9
Morocco	96.2	129.3	170.0	140.9	139.4	127.2	135.3	98.0	81.8
Mozambique	437.3	160.2	198.6	0.0	0.0	0.0	0.0	0.0	0.0
Myanmar	653.7	484.7	405.3	335.0	207.7	165.5	123.5	61.3	48.3
Netherlands + Antilles	373.4	283.7	220.0	199.9	181.0	184.4	157.1	141.9	99.2
New Zealand	60.1	59.9	48.2	39.4	70.0	56.4	53.8	46.5	46.5
Nicaragua	145.8	157.7	180.5	151.8	219.9	187.5	232.0	168.2	140.8
Nigeria	49.5	52.6	147.4	151.8	255.9	186.7	158.7	48.7	35.9
Norway	57.8	66.2	49.1	41.5	66.3	62.6	52.5	55.1	48.0
Oman	0.0	0.0	0.0	182.7	175.5	155.4	117.3	129.6	137.8
Pakistan	165.1	124.9	132.7	120.8	107.5	80.0	110.3	98.0	86.6
Panama	957.6	643.7	224.2	125.1	133.6	199.6	167.8	0.0	0.0
Paraguay	92.5	73.2	57.1	44.9	47.8	23.6	14.8	0.0	0.0
Peru	123.7	127.4	150.3	161.1	168.4	125.6	123.0	96.2	84.0
Philippines	288.1	219.2	179.3	152.3	174.5	250.0	178.8	97.2	75.3
Poland	66.1	88.5	78.3	72.0	69.5	71.5	70.9	66.1	61.4
Portugal	60.5	67.5	78.3	78.6	71.7	80.6	70.5	71.5	63.2
Qatar	2.9	32.1	33.4	125.1	180.6	192.1	102.6	129.7	90.1
Romania	425.1	362.5	286.6	257.7	191.6	161.7	154.6	137.2	116.8
Saudi Arabia	370.8	171.2	148.7	324.6	331.1	352.3	316.3	311.4	296.0
Senegal	175.9	178.9	179.5	107.7	105.7	116.7	131.0	36.6	82.9
Singapore	1507.5	1422.7	1510.3	1051.6	876.7	667.1	415.0	394.2	380.0
Slovakia	276.8	277.7	266.1	208.6	199.5	157.1	164.8	124.2	108.8
South Africa	116.5	97.7	87.1	92.4	107.5	127.3	128.7	91.8	88.1
Spain	85.8	97.0	84.2	82.7	73.7	67.3	58.4	52.7	49.7
Sri Lanka	287.6	232.4	202.7	156.2	124.5	126.3	106.7	81.0	62.9
Sudan	79.9	80.7	65.2	73.8	71.9	35.8	92.3	123.8	90.2
Sweden	64.6	71.2	64.7	61.3	69.0	78.5	65.6	51.8	53.0
Switzerland	22.8	21.6	15.9	15.7	15.4	16.9	14.2	14.6	12.8
Syria	437.2	310.7	738.8	806.5	856.6	602.9	551.6	428.5	371.7
Thailand	235.5	250.1	180.2	146.7	124.4	225.2	262.7	239.4	229.1
Trinidad and Tobago	3741.0	2521.3	892.0	550.0	724.5	625.2	685.6	427.3	393.9
Tunisia	202.3	139.7	142.2	128.7	108.8	97.0	77.6	55.7	53.0
Turkey	74.5	83.0	78.8	87.8	82.7	78.1	69.9	51.0	45.2
United Arab Emirates	0.0	0.0	51.1	234.4	179.1	169.4	167.7	117.5	94.3
United Kingdom	103.5	86.1	66.0	58.3	60.3	56.2	40.5	36.0	34.0

Source: IEA. 2010a.IEA. 2010b.

United Republic of Tanzania	199.9	152.4	104.6	101.2	84.8	63.3	0.0	0.0	0.0
United States	143.1	147.0	118.7	101.0	94.0	85.3	74.4	66.9	64.9
Uruguay	187.0	175.8	127.4	87.0	95.9	100.7	105.0	100.1	99.3
Venezuela	1048.9	607.9	477.4	486.6	489.7	461.7	448.2	366.3	324.9
Yemen	1535.7	470.4	641.8	561.0	612.2	299.3	252.0	176.9	200.1
Zambia	0.0	173.0	139.0	108.1	104.4	81.5	36.4	50.3	54.0
Std Dev	579.6	357.6	289.7	304.9	257.5	238.1	218.0	151.1	144.3
Mean	288.4	236.3	212.0	209.4	191.5	181.2	165.3	128.5	120.2
Coefficient of	2.0	1.5	1.4	1.5	1.3	1.3	1.3	1.2	1.2
Moving Avg	2.0	1.6	1.3	1.4	1.4	1.4	1.3	1.2	1.2

Source: IEA. 2010a.IEA. 2010b.

Chemical & Petrochemical measure KTOE/GDP (2000 USD GDP)

Country	1971	1976	1981	1986	1991	1996	2001	2006	2008
Albania	0.0	0.0	0.0	0.0	0.0	1.3	2.5	4.3	3.9
Algeria	0.0	0.4	9.2	12.0	1.8	1.4	1.3	1.1	1.1
Australia	1.5	4.6	4.3	3.7	3.7	3.1	3.2	3.2	2.9
Austria	3.3	3.1	1.7	1.5	2.3	2.4	2.8	3.0	2.8
Bahrain	0.0	0.0	0.0	143.6	138.2	102.8	97.3	76.4	76.0
Bangladesh	0.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Belgium	14.6	11.1	9.6	8.5	7.7	8.2	8.6	8.8	8.6
Botswana	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Brazil	5.6	5.7	7.2	6.9	6.9	7.2	8.0	7.8	6.9
Bulgaria	47.8	45.4	0.0	0.0	108.2	106.4	47.4	32.6	26.5
Canada	5.1	4.8	8.6	7.9	7.1	6.8	4.6	4.0	3.6
Chile	0.4	0.8	0.5	0.3	0.5	0.5	0.7	0.5	0.4
China	13.7	16.0	141.5	65.9	61.3	60.2	31.8	29.9	28.8
Colombia	1.3	6.8	12.5	10.3	10.4	9.7	10.6	8.8	9.6
Costa Rica	0.0	0.0	0.0	0.0	0.7	3.1	3.6	2.2	1.9
Cote d'Ivoire	0.2	0.1	0.4	0.0	0.0	0.0	1.2	1.0	0.3
Cuba	0.0	0.2	0.5	1.1	0.9	0.9	0.8	0.5	0.5
Cyprus	0.1	0.2	0.3	0.4	0.4	0.3	0.1	0.1	0.1
Czech Republic	16.2	9.5	7.8	7.8	7.1	8.5	12.0	13.2	9.1
Denmark	2.5	2.1	1.7	1.3	1.1	1.2	1.1	0.9	0.9
Finland	6.5	7.1	6.1	7.6	7.0	7.0	3.4	3.8	4.7
Former USSR	74.4	90.1	63.8	60.8	20.2	36.8	38.0	27.7	22.4
Former Yugoslavia	13.9	8.7	11.9	14.6	11.1	8.3	4.5	7.6	4.6
France	6.1	5.2	4.6	4.6	3.9	3.4	4.0	3.2	3.2
Gabon	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Germany	13.3	12.1	10.4	9.2	5.4	4.5	3.7	3.2	3.7
Greece	2.6	2.1	1.4	1.4	1.4	1.7	1.2	1.1	1.0
Hungary	13.5	14.8	14.1	14.6	12.1	10.5	8.6	5.5	5.4
Iceland	0.0	0.0	1.1	1.3	1.5	1.1	0.5	0.1	0.1
India	10.3	14.6	18.0	18.5	18.5	16.1	10.1	5.7	4.9
Indonesia	4.6	6.7	5.6	4.5	3.5	3.5	4.4	2.6	2.0
Iran	31.9	21.4	1.5	1.8	20.8	16.2	26.5	22.0	34.5
Iraq	10.9	8.0	0.0	0.0	43.9	34.9	38.7	20.9	23.2
Ireland	0.7	0.8	2.5	2.5	2.6	2.5	2.2	1.8	1.4
Israel	0.0	0.0	0.0	1.8	1.7	1.8	2.2	2.0	2.0
Italy	13.5	11.2	5.7	4.7	4.4	4.1	3.1	3.4	2.8
Japan	8.2	6.1	3.6	3.2	4.6	4.3	4.2	4.0	3.5
Jordan	0.0	0.0	0.0	1.9	2.1	2.0	0.8	1.0	0.6
Korea	2.4	2.5	9.8	6.7	11.1	10.0	8.9	8.6	8.3
Kuwait	7.4	10.1	9.6	16.1	0.1	9.8	24.9	15.8	15.8
Luxembourg	7.0	9.8	7.5	5.8	2.3	1.6	0.8	0.8	0.5
Mexico	5.6	7.1	9.8	15.1	13.1	7.5	5.2	3.2	3.1
Morocco	0.6	0.8	1.6	0.9	0.6	0.7	1.3	1.3	1.1
Myanmar	1.0	3.4	4.2	9.0	0.0	2.4	0.0	0.0	0.0
Netherlands	16.1	11.0	17.9	14.9	11.3	10.8	9.2	7.1	6.5
New Zealand	0.3	0.3	0.3	0.5	1.0	1.1	0.2	0.4	0.4

Source: IEA. 2010a.IEA. 2010b.

Nigeria	0.0	0.0	0.0	2.9	5.4	5.0	4.9	5.0	4.4
Norway	7.4	6.2	6.1	4.6	3.6	3.5	4.0	4.4	4.4
Pakistan	11.4	14.1	1.8	1.0	1.3	12.1	11.2	13.9	9.1
Philippines	3.2	5.1	2.5	2.5	3.0	5.7	4.3	3.7	2.5
Poland	30.1	28.0	29.1	23.0	23.2	19.8	14.5	11.8	10.1
Portugal	3.4	3.3	3.9	4.2	3.2	2.6	3.4	2.8	2.8
Qatar	0.0	10.1	41.7	89.5	84.9	78.9	58.0	52.1	36.9
Romania	64.5	39.1	29.4	114.9	68.9	50.7	33.0	20.9	20.6
Saudi Arabia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9
Senegal	0.0	0.0	0.0	0.0	0.0	0.0	1.7	1.0	1.1
Singapore	0.8	0.8	1.1	2.3	1.2	0.6	0.6	0.6	0.5
Slovakia	0.0	0.0	11.1	10.3	20.3	20.7	15.3	8.0	8.3
South Africa	6.0	6.4	6.3	6.2	5.6	7.4	4.6	8.2	7.1
Spain	4.7	5.5	5.8	4.5	4.5	3.8	3.7	3.8	3.5
Sweden	5.0	4.7	3.7	3.6	5.6	7.1	5.3	2.1	1.9
Switzerland	0.7	1.3	1.5	2.1	1.7	1.9	1.9	2.2	1.9
Syria	0.0	0.0	0.0	0.0	9.5	14.2	24.5	17.5	16.8
Thailand	0.8	5.4	4.0	4.5	6.0	9.4	8.3	8.2	7.3
Togo	1.3	1.7	1.7	2.2	2.5	3.8	0.0	0.0	0.0
Tunisia	0.0	0.0	3.5	5.8	0.8	0.6	0.7	4.8	4.3
Turkey	3.4	3.1	3.8	2.8	4.3	3.7	3.5	4.4	2.0
United Arab Emirates	50.5	34.4	50.9	156.3	209.9	230.2	143.4	81.7	96.3
United Kingdom	7.8	7.6	6.9	4.6	3.7	3.3	3.4	2.4	2.2
United States	4.3	5.1	4.1	3.3	8.5	8.2	7.8	5.8	5.7
Venezuela	0.6	13.5	14.1	20.6	26.5	46.0	38.3	32.0	27.9
Zambia	11.8	9.2	6.6	7.3	0.0	0.0	0.0	0.0	0.0
Std Dev	14.3	13.3	19.5	30.2	33.8	33.4	22.5	15.3	15.8
Mean	8.1	7.9	9.1	13.5	14.8	14.8	11.7	9.0	8.6
Coefficient of	1.8	1.7	2.1	2.2	2.3	2.3	1.9	1.7	1.8
Moving Avg	1.8	1.7	2.0	2.1	2.2	2.2	2.0	1.7	1.8

Source: IEA. 2010a.IEA. 2010b.

Electricity consumption/GDP (kWh per 2000 USD)

Country	1971	1976	1981	1986	1991	1996	2001	2006	2008
Albania	0.6795	0.9713	1.0227	1.2969	0.5579	0.9108	0.9158	0.6054	0.7629
Algeria	0.1137	0.1327	0.1982	0.2501	0.3069	0.3415	0.3967	0.4089	0.437
Angola	0.0834	0.0727	0.0802	0.0814	0.0798	0.0988	0.1487	0.1429	0.1396
Argentina	0.1266	0.1499	0.1696	0.2029	0.2171	0.2306	0.291	0.2945	0.2813
Australia	0.297	0.3665	0.4232	0.4685	0.5231	0.4863	0.4978	0.4697	0.4655
Austria	0.272	0.2879	0.296	0.3046	0.3196	0.312	0.3067	0.3132	0.3029
Bahrain	0.3263	0.2978	0.4809	0.7693	0.6119	0.7145	0.744	0.8078	0.7811
Bangladesh	0.0398	0.0716	0.088	0.1382	0.1748	0.2522	0.3021	0.4295	0.4499
Belgium	0.2733	0.3019	0.3176	0.3396	0.3506	0.3735	0.3631	0.3546	0.3397
Benin	0.0391	0.0725	0.1023	0.0991	0.1279	0.1478	0.1837	0.2126	0.2124
Bolivia	0.185	0.1884	0.2637	0.2927	0.3221	0.3888	0.4096	0.4231	0.478
Brazil	0.2108	0.2317	0.3068	0.3814	0.4425	0.4658	0.4739	0.5078	0.5019
Brunei Darussalam	0.0819	0.0559	0.0978	0.1593	0.2401	0.3599	0.3685	0.4497	0.4737
Bulgaria	3.047	3.0457	2.9618	2.8701	2.7418	3.0568	2.3565	1.9069	1.7877
Cameroon	0.2921	0.2895	0.2375	0.2049	0.276	0.2758	0.25	0.3588	0.3737
Canada	0.6982	0.7191	0.7707	0.83	0.8524	0.8173	0.708	0.6459	0.653
Chile	0.3285	0.4051	0.3627	0.4137	0.4049	0.4255	0.5235	0.544	0.5331
Chinese Taipei	0.4141	0.476	0.4662	0.4838	0.5053	0.5206	0.5741	0.574	0.5516
Colombia	0.2841	0.2782	0.3304	0.4054	0.3918	0.3691	0.3635	0.3413	0.3261
Congo	0.0761	0.0781	0.0623	0.1406	0.1565	0.1442	0.1008	0.1115	0.1237
Costa Rica	0.249	0.2697	0.3238	0.3828	0.3656	0.359	0.3719	0.3738	0.3585
Cote d'Ivoire	0.1022	0.1316	0.1983	0.1933	0.2211	0.2465	0.2949	0.3249	0.3518
Cuba	0.2922	0.3312	0.373	0.348	0.3858	0.4386	0.4451	0.3464	0.3414
Cyprus	0.287	0.3226	0.2854	0.2904	0.3113	0.3126	0.3425	0.3901	0.4008
Czech Republic	0.878	0.9458	0.9879	1.0424	1.1087	1.0783	1.0359	0.9184	0.8514
Democratic Republic of	0.4679	0.532	0.5108	0.5744	0.6424	0.8616	1.0977	1.0273	0.9666
Denmark	0.1825	0.2058	0.2348	0.2374	0.2553	0.2446	0.2157	0.2106	0.1998
Dominican Republic	0.182	0.2313	0.2394	0.2668	0.2171	0.2762	0.3712	0.3985	0.3799
Ecuador	0.153	0.1771	0.2801	0.3204	0.3801	0.4599	0.4975	0.5456	0.6515
Egypt	0.3431	0.3905	0.4646	0.5455	0.6015	0.628	0.6982	0.8076	0.7989
El Salvador	0.0892	0.1159	0.16	0.2032	0.2311	0.259	0.2776	0.3187	0.3562
Ethiopia	0.1306	0.1124	0.1325	0.1569	0.1879	0.1959	0.2044	0.2375	0.2232
Finland	0.4345	0.4903	0.5479	0.6051	0.6699	0.7053	0.6537	0.6254	0.5654
Former Soviet Union	1.8063	1.8786	1.9021	2.0053	2.8073	3.3212	2.7807	2.2323	2.0295
Former Yugoslavia	0.7762	0.899	1.0237	1.2051	1.4392	1.1985	1.1501	0.9963	0.9388
France	0.2285	0.2565	0.2922	0.3296	0.3377	0.3529	0.3333	0.3252	0.326
Gabon	0.059	0.0617	0.1562	0.2181	0.194	0.1823	0.2195	0.2548	0.2786
Germany	0.3349	0.3698	0.371	0.3782	0.3238	0.3019	0.2895	0.2927	0.2802
Ghana	1.0302	1.6126	1.8265	1.2502	1.4859	1.4993	1.2762	0.9765	0.8194
Gibraltar	0.119	0.1188	0.1224	0.1228	0.1521	0.1703	0.1673	0.1768	0.1846
Greece	0.1634	0.202	0.2376	0.2849	0.323	0.3703	0.3871	0.3691	0.3719
Guatemala	0.0925	0.1119	0.1194	0.1352	0.1573	0.1885	0.2162	0.2919	0.2848
Haiti	0.0181	0.0372	0.0624	0.0807	0.0706	0.0751	0.0796	0.0916	0.0571
Honduras	0.1423	0.1669	0.2051	0.2775	0.3377	0.372	0.4583	0.4707	0.4932
Hong Kong, China	0.2029	0.1803	0.1758	0.2003	0.208	0.2045	0.2192	0.182	0.1696
Hungary	0.69	0.7079	0.726	0.7984	0.8629	0.8271	0.7089	0.6462	0.6511

Source: IEA. 2010a.IEA. 2010b.

Iceland	0.4572	0.5459	0.554	0.6071	0.6086	0.65	0.8497	0.85	1.3271
India	0.4662	0.576	0.6433	0.7731	0.9352	0.9313	0.8594	0.81	0.7814
Indonesia	0.0639	0.0747	0.1212	0.1843	0.2712	0.3469	0.5159	0.5387	0.5436
Iraq	0.0527	0.0682	0.177	0.4243	1.2042	2.1438	1.2411	1.5657	1.5611
Ireland	0.2539	0.2783	0.2772	0.3008	0.2777	0.264	0.2232	0.2039	0.2042
Islamic Republic of Iran	0.1723	0.2126	0.4126	0.5929	0.7248	0.8909	1.0346	1.1623	1.0875
Israel	0.2168	0.227	0.2365	0.2472	0.2594	0.2948	0.3305	0.324	0.3226
Italy	0.2246	0.2371	0.2348	0.239	0.2519	0.2624	0.2757	0.2898	0.288
Jamaica	0.2416	0.2369	0.2383	0.2375	0.2198	0.5883	0.6673	0.6413	0.6725
Japan	0.1905	0.2069	0.194	0.1927	0.1946	0.207	0.2127	0.2075	0.1995
Jordan	0.1146	0.2149	0.2351	0.4032	0.6486	0.7402	0.7753	0.8114	0.8661
Kenya	0.2271	0.2538	0.2502	0.2756	0.2862	0.3159	0.2915	0.3382	0.337
Korea	0.1411	0.2046	0.2769	0.2956	0.3466	0.423	0.5389	0.5573	0.5731
Korea, DPR	4.4565	3.2231	2.1961	1.6801	1.6155	1.5508	1.6156	1.6413	1.682
Kuwait	0.0757	0.1658	0.408	0.6549	0.6749	0.6696	0.8174	0.7048	0.6831
Lebanon	0.0977	0.3371	0.2588	0.275	0.2415	0.4292	0.4541	0.4254	0.4012
Libyan Arab Jamahiriya	0.0116	0.0524	0.0953	0.1164	0.2228	0.2735	0.3401	0.4794	0.4646
Luxembourg	0.6683	0.5911	0.5324	0.4709	0.4047	0.3965	0.3231	0.3039	0.2857
Malaysia	0.2635	0.2974	0.3505	0.4282	0.4636	0.5661	0.734	0.6902	0.6775
Malta	0.4927	0.3454	0.3312	0.4178	0.5149	0.4435	0.4405	0.4737	0.4484
Mexico	0.1295	0.1489	0.1562	0.2121	0.2176	0.2552	0.2707	0.2877	0.2792
Morocco	0.1602	0.1908	0.2608	0.276	0.2995	0.3449	0.384	0.4168	0.4206
Mozambique	0.1672	0.282	0.1691	0.2537	0.2835	0.23	1.0631	1.388	1.3003
Myanmar	0.2114	0.2782	0.2529	0.3281	0.3837	0.4057	0.3258	0.2584	0.2518
Nepal	0.0433	0.0622	0.0942	0.1569	0.2011	0.2228	0.2727	0.3351	0.3517
Netherlands	0.2392	0.2683	0.2725	0.2707	0.278	0.2827	0.272	0.2713	0.2645
New Zealand	0.4669	0.5548	0.5978	0.6506	0.7632	0.6816	0.6767	0.6225	0.6117
Nicaragua	0.1869	0.2188	0.285	0.3314	0.4416	0.4249	0.4305	0.4945	0.5045
Nigeria	0.0724	0.1189	0.1405	0.2821	0.2388	0.2305	0.1999	0.2423	0.2595
Norway	0.9016	0.8804	0.8599	0.8265	0.8414	0.7123	0.673	0.5848	0.5902
Oman	0.0035	0.047	0.1468	0.2527	0.304	0.338	0.3813	0.4242	0.4423
Pakistan	0.3215	0.3492	0.4042	0.5099	0.6236	0.6854	0.7101	0.7619	0.6437
Panama	0.1814	0.2294	0.236	0.2741	0.2854	0.3184	0.3365	0.3179	0.295
Paraguay	0.1019	0.1306	0.1772	0.2591	0.3742	0.5414	0.6547	0.647	0.6611
People's Republic of	1.1877	1.4224	1.476	1.2301	1.301	1.1462	1.0484	1.2663	1.2496
Peru	0.1895	0.1975	0.2248	0.2607	0.3499	0.2978	0.3472	0.3519	0.3532
Philippines	0.3078	0.3625	0.334	0.3766	0.402	0.4619	0.5352	0.5011	0.48
Poland	0.7189	0.8055	0.9666	1.0129	1.0749	0.8728	0.7193	0.6456	0.5991
Portugal	0.1748	0.2073	0.2469	0.2957	0.3014	0.3366	0.3715	0.4259	0.4217
Qatar	0.0349	0.0681	0.2414	0.4402	0.5037	0.5812	0.5046	0.5595	0.5327
Romania	1.779	1.6542	1.6006	1.5368	1.5134	1.3379	1.1679	0.9827	0.8761
Saudi Arabia	0.0374	0.0457	0.144	0.3665	0.4397	0.5509	0.6655	0.7161	0.7408
Senegal	0.1432	0.1579	0.216	0.2132	0.2241	0.2506	0.2547	0.301	0.2985
Singapore	0.2317	0.278	0.2938	0.3325	0.3363	0.3151	0.3437	0.3018	0.2924
Slovak Republic	0.9559	1.0418	1.3634	1.3965	1.6793	1.4993	1.2818	0.9852	0.8632
South Africa	0.7101	0.889	1.0725	1.3788	1.4344	1.4973	1.4362	1.3534	1.2673
Spain	0.2172	0.2636	0.3061	0.3175	0.3111	0.3288	0.368	0.3978	0.3883
Sri Lanka	0.1713	0.1952	0.2229	0.2591	0.2691	0.2833	0.3421	0.3717	0.3407
Sudan	0.0935	0.1139	0.1132	0.1989	0.1665	0.1471	0.1423	0.1825	0.1812

Source: IEA. 2010a.IEA. 2010b.

Sweden	0.4609	0.5228	0.5713	0.6805	0.6891	0.6454	0.5743	0.4772	0.4613
Switzerland	0.1726	0.1955	0.2115	0.2297	0.2322	0.2312	0.2299	0.2264	0.218
Syrian Arab Republic	0.2864	0.2353	0.369	0.6414	0.7069	0.7315	0.9436	1.1397	1.1439
Thailand	0.2268	0.3231	0.3661	0.4494	0.5262	0.634	0.7625	0.7969	0.7859
Togo	0.2201	0.2303	0.2028	0.2682	0.3086	0.3872	0.3775	0.4066	0.403
Trinidad and Tobago	0.2189	0.2375	0.2918	0.5088	0.5313	0.6152	0.6145	0.4938	0.5255
Tunisia	0.1715	0.2023	0.3044	0.3812	0.4263	0.4508	0.497	0.4846	0.4704
Turkey	0.1109	0.1537	0.1991	0.2307	0.2821	0.3387	0.4119	0.4209	0.4538
United Arab Emirates	0.0214	0.0691	0.1379	0.3555	0.3396	0.415	0.5582	0.5782	0.6137
United Kingdom	0.3207	0.3116	0.2967	0.2763	0.276	0.2635	0.2399	0.2189	0.2099
United Republic of	0.1189	0.127	0.1456	0.1669	0.2057	0.244	0.2182	0.2075	0.2315
United States	0.4037	0.4323	0.4342	0.4015	0.4357	0.417	0.3715	0.354	0.3539
Uruguay	0.1613	0.1594	0.1781	0.22	0.24	0.2448	0.2957	0.2706	0.2724
Venezuela	0.1807	0.2092	0.4017	0.4649	0.4901	0.5313	0.556	0.5583	0.5155
Vietnam	0.2223	0.2659	0.3308	0.3619	0.431	0.5616	0.7912	1.1268	1.2351
Yemen	0.1586	0.1415	0.1369	0.2015	0.292	0.2493	0.2646	0.3346	0.3917
Zambia	1.8518	2.105	2.2426	2.2843	2.0079	2.123	1.9473	2.018	1.5552
Zimbabwe	1.0174	1.6021	1.4747	1.4583	1.2868	1.2689	1.4444	2.3371	2.7009
Std Dev	0.6	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4
Mean	0.4	0.4	0.4	0.5	0.5	0.6	0.6	0.6	0.6
Coefficient of	1.5	1.3	1.1	0.9	0.9	0.9	0.8	0.7	0.7
Moving Avg	1.5	1.3	1.1	1.0	0.9	0.9	0.8	0.7	0.7

Source: IEA. 2010a.IEA. 2010b.

Appendix B -- GCAM Configuration modifications and data changes

MODIFIED GCAM FILE FOR REFINING SECTOR DELAY SCENARIO

Shareweights
INPUT_TABLE
Variable ID
2006

				sharewt								
region	supplysector	subsector	technology	1975	1990	2005	2020	2035	2050	2065	2080	2095
Africa	refined liquids enduse	coal to liquids	coal to liquids CCS Level 1	0	0	0	0	0	0	0.25	0.5	1
Africa	refined liquids industrial	coal to liquids	coal to liquids CCS Level 1	0	0	0	0	0	0	0.25	0.5	1
Africa	refined liquids enduse	coal to liquids	coal to liquids CCS Level 2	0	0	0	0	0	0	0.25	0.5	1
Africa	refined liquids industrial	coal to liquids	coal to liquids CCS Level 2	0	0	0	0	0	0	0.25	0.5	1
Africa	refined liquids enduse	biomass liquids	biomass liquids-ethanol CCS Level 1	0	0	0	0	0	0	0.333	0.5	1
Africa	refined liquids enduse	biomass liquids	biomass liquids-FT CCS Level 1	0	0	0	0	0	0	0.333	0.5	1
Africa	refined liquids industrial	biomass liquids	biomass liquids-ethanol CCS Level 1	0	0	0	0	0	0	0.333	0.5	1
Africa	refined liquids industrial	biomass liquids	biomass liquids-FT CCS Level 1	0	0	0	0	0	0	0.333	0.5	1
Africa	refined liquids enduse	biomass liquids	biomass liquids-ethanol CCS Level 2	0	0	0	0	0	0	0.333	0.5	1
Africa	refined liquids enduse	biomass liquids	biomass liquids-FT CCS Level 2	0	0	0	0	0	0	0.333	0.5	1
Africa	refined liquids industrial	biomass liquids	biomass liquids-ethanol CCS Level 2	0	0	0	0	0	0	0.333	0.5	1
Africa	refined liquids industrial	biomass liquids	biomass liquids-FT CCS Level 2	0	0	0	0	0	0	0.333	0.5	1
Australia_NZ	refined liquids enduse	coal to liquids	coal to liquids CCS Level 1	0	0	0	0.333	1	1	1	1	1
Australia_NZ	refined liquids industrial	coal to liquids	coal to liquids CCS Level 1	0	0	0	0.333	1	1	1	1	1
Australia_NZ	refined liquids enduse	coal to liquids	coal to liquids CCS Level 2	0	0	0	0.333	1	1	1	1	1
Australia_NZ	refined liquids industrial	coal to liquids	coal to liquids CCS Level 2	0	0	0	0.333	1	1	1	1	1
Australia_NZ	refined liquids enduse	biomass liquids	biomass liquids-ethanol CCS Level 1	0	0	0	0.333	1	1	1	1	1
Australia_NZ	refined liquids enduse	biomass liquids	biomass liquids-FT CCS Level 1	0	0	0	0.333	1	1	1	1	1
Australia_NZ	refined liquids industrial	biomass liquids	biomass liquids-ethanol CCS Level 1	0	0	0	0.333	1	1	1	1	1
Australia_NZ	refined liquids industrial	biomass liquids	biomass liquids-FT CCS Level 1	0	0	0	0.333	1	1	1	1	1
Australia_NZ	refined liquids enduse	biomass liquids	biomass liquids-ethanol CCS Level 2	0	0	0	0.333	1	1	1	1	1
Australia_NZ	refined liquids enduse	biomass liquids	biomass liquids-FT CCS Level 2	0	0	0	0.333	1	1	1	1	1
Australia_NZ	refined liquids industrial	biomass liquids	biomass liquids-ethanol CCS Level 2	0	0	0	0.333	1	1	1	1	1
Australia_NZ	refined liquids industrial	biomass liquids	biomass liquids-FT CCS Level 2	0	0	0	0.333	1	1	1	1	1
Latin America	refined liquids enduse	coal to liquids	coal to liquids CCS Level 1	0	0	0	0	0	0	0.25	0.5	1
Latin America	refined liquids industrial	coal to liquids	coal to liquids CCS Level 1	0	0	0	0	0	0	0.25	0.5	1
Latin America	refined liquids enduse	coal to liquids	coal to liquids CCS Level 2	0	0	0	0	0	0	0.25	0.5	1
Latin America	refined liquids industrial	coal to liquids	coal to liquids CCS Level 2	0	0	0	0	0	0	0.25	0.5	1
Latin America	refined liquids enduse	biomass liquids	biomass liquids-ethanol CCS Level 1	0	0	0	0	0	0	0.333	0.5	1
Latin America	refined liquids enduse	biomass liquids	biomass liquids-FT CCS Level 1	0	0	0	0	0	0	0.333	0.5	1
Latin America	refined liquids industrial	biomass liquids	biomass liquids-ethanol CCS Level 1	0	0	0	0	0	0	0.333	0.5	1
Latin America	refined liquids industrial	biomass liquids	biomass liquids-FT CCS Level 1	0	0	0	0	0	0	0.333	0.5	1
Latin America	refined liquids enduse	biomass liquids	biomass liquids-ethanol CCS Level 2	0	0	0	0	0	0	0.333	0.5	1
Latin America	refined liquids enduse	biomass liquids	biomass liquids-FT CCS Level 2	0	0	0	0	0	0	0.333	0.5	1
Latin America	refined liquids industrial	biomass liquids	biomass liquids-ethanol CCS Level 2	0	0	0	0	0	0	0.333	0.5	1
Latin America	refined liquids industrial	biomass liquids	biomass liquids-FT CCS Level 2	0	0	0	0	0	0	0.333	0.5	1
Southeast Asia	refined liquids enduse	coal to liquids	coal to liquids CCS Level 1	0	0	0	0	0	0	0.25	0.5	1
Southeast Asia	refined liquids industrial	coal to liquids	coal to liquids CCS Level 1	0	0	0	0	0	0	0.25	0.5	1
Southeast Asia	refined liquids enduse	coal to liquids	coal to liquids CCS Level 2	0	0	0	0	0	0	0.25	0.5	1
Southeast Asia	refined liquids industrial	coal to liquids	coal to liquids CCS Level 2	0	0	0	0	0	0	0.25	0.5	1
Southeast Asia	refined liquids enduse	biomass liquids	biomass liquids-ethanol CCS Level 1	0	0	0	0	0	0	0.333	0.5	1
Southeast Asia	refined liquids enduse	biomass liquids	biomass liquids-FT CCS Level 1	0	0	0	0	0	0	0.333	0.5	1

Southeast Asia	refined liquids industrial	biomass liquids	biomass liquids-ethanol CCS Level 1	0	0	0	0	0	0	0.333	0.5	1
Southeast Asia	refined liquids industrial	biomass liquids	biomass liquids-FT CCS Level 1	0	0	0	0	0	0	0.333	0.5	1
Southeast Asia	refined liquids enduse	biomass liquids	biomass liquids-ethanol CCS Level 2	0	0	0	0	0	0	0.333	0.5	1
Southeast Asia	refined liquids enduse	biomass liquids	biomass liquids-FT CCS Level 2	0	0	0	0	0	0	0.333	0.5	1
Southeast Asia	refined liquids industrial	biomass liquids	biomass liquids-ethanol CCS Level 2	0	0	0	0	0	0	0.333	0.5	1
Southeast Asia	refined liquids industrial	biomass liquids	biomass liquids-FT CCS Level 2	0	0	0	0	0	0	0.333	0.5	1
Japan	refined liquids enduse	coal to liquids	coal to liquids CCS Level 1	0	0	0	0.333	1	1	1	1	1
Japan	refined liquids industrial	coal to liquids	coal to liquids CCS Level 1	0	0	0	0.333	1	1	1	1	1
Japan	refined liquids enduse	coal to liquids	coal to liquids CCS Level 2	0	0	0	0.333	1	1	1	1	1
Japan	refined liquids industrial	coal to liquids	coal to liquids CCS Level 2	0	0	0	0.333	1	1	1	1	1
Japan	refined liquids enduse	biomass liquids	biomass liquids-ethanol CCS Level 1	0	0	0	0.333	1	1	1	1	1
Japan	refined liquids enduse	biomass liquids	biomass liquids-FT CCS Level 1	0	0	0	0.333	1	1	1	1	1
Japan	refined liquids industrial	biomass liquids	biomass liquids-ethanol CCS Level 1	0	0	0	0.333	1	1	1	1	1
Japan	refined liquids industrial	biomass liquids	biomass liquids-FT CCS Level 1	0	0	0	0.333	1	1	1	1	1
Japan	refined liquids enduse	biomass liquids	biomass liquids-ethanol CCS Level 2	0	0	0	0.333	1	1	1	1	1
Japan	refined liquids enduse	biomass liquids	biomass liquids-FT CCS Level 2	0	0	0	0.333	1	1	1	1	1
Japan	refined liquids industrial	biomass liquids	biomass liquids-ethanol CCS Level 2	0	0	0	0.333	1	1	1	1	1
Japan	refined liquids industrial	biomass liquids	biomass liquids-FT CCS Level 2	0	0	0	0.333	1	1	1	1	1
India	refined liquids enduse	coal to liquids	coal to liquids CCS Level 1	0	0	0	0	0	0	0.25	0.5	1
India	refined liquids industrial	coal to liquids	coal to liquids CCS Level 1	0	0	0	0	0	0	0.25	0.5	1
India	refined liquids enduse	coal to liquids	coal to liquids CCS Level 2	0	0	0	0	0	0	0.25	0.5	1
India	refined liquids industrial	coal to liquids	coal to liquids CCS Level 2	0	0	0	0	0	0	0.25	0.5	1
India	refined liquids enduse	biomass liquids	biomass liquids-ethanol CCS Level 1	0	0	0	0	0	0	0.333	0.5	1
India	refined liquids enduse	biomass liquids	biomass liquids-FT CCS Level 1	0	0	0	0	0	0	0.333	0.5	1
India	refined liquids industrial	biomass liquids	biomass liquids-ethanol CCS Level 1	0	0	0	0	0	0	0.333	0.5	1
India	refined liquids industrial	biomass liquids	biomass liquids-FT CCS Level 1	0	0	0	0	0	0	0.333	0.5	1
India	refined liquids enduse	biomass liquids	biomass liquids-ethanol CCS Level 2	0	0	0	0	0	0	0.333	0.5	1
India	refined liquids enduse	biomass liquids	biomass liquids-FT CCS Level 2	0	0	0	0	0	0	0.333	0.5	1
India	refined liquids industrial	biomass liquids	biomass liquids-ethanol CCS Level 2	0	0	0	0	0	0	0.333	0.5	1
India	refined liquids industrial	biomass liquids	biomass liquids-FT CCS Level 2	0	0	0	0	0	0	0.333	0.5	1
Canada	refined liquids enduse	coal to liquids	coal to liquids CCS Level 1	0	0	0	0.333	1	1	1	1	1
Canada	refined liquids industrial	coal to liquids	coal to liquids CCS Level 1	0	0	0	0.333	1	1	1	1	1
Canada	refined liquids enduse	coal to liquids	coal to liquids CCS Level 2	0	0	0	0.333	1	1	1	1	1
Canada	refined liquids industrial	coal to liquids	coal to liquids CCS Level 2	0	0	0	0.333	1	1	1	1	1
Canada	refined liquids enduse	biomass liquids	biomass liquids-ethanol CCS Level 1	0	0	0	0.333	1	1	1	1	1
Canada	refined liquids enduse	biomass liquids	biomass liquids-FT CCS Level 1	0	0	0	0.333	1	1	1	1	1
Canada	refined liquids industrial	biomass liquids	biomass liquids-ethanol CCS Level 1	0	0	0	0.333	1	1	1	1	1
Canada	refined liquids industrial	biomass liquids	biomass liquids-FT CCS Level 1	0	0	0	0.333	1	1	1	1	1
Canada	refined liquids enduse	biomass liquids	biomass liquids-ethanol CCS Level 2	0	0	0	0.333	1	1	1	1	1
Canada	refined liquids enduse	biomass liquids	biomass liquids-FT CCS Level 2	0	0	0	0.333	1	1	1	1	1
Canada	refined liquids industrial	biomass liquids	biomass liquids-ethanol CCS Level 2	0	0	0	0.333	1	1	1	1	1
Canada	refined liquids industrial	biomass liquids	biomass liquids-FT CCS Level 2	0	0	0	0.333	1	1	1	1	1
China	refined liquids enduse	coal to liquids	coal to liquids CCS Level 1	0	0	0	0	0	0	0.25	0.5	1
China	refined liquids industrial	coal to liquids	coal to liquids CCS Level 1	0	0	0	0	0	0	0.25	0.5	1
China	refined liquids enduse	coal to liquids	coal to liquids CCS Level 2	0	0	0	0	0	0	0.25	0.5	1
China	refined liquids industrial	coal to liquids	coal to liquids CCS Level 2	0	0	0	0	0	0	0.25	0.5	1
China	refined liquids enduse	biomass liquids	biomass liquids-ethanol CCS Level 1	0	0	0	0	0	0	0.333	0.5	1
China	refined liquids enduse	biomass liquids	biomass liquids-FT CCS Level 1	0	0	0	0	0	0	0.333	0.5	1
China	refined liquids industrial	biomass liquids	biomass liquids-ethanol CCS Level 1	0	0	0	0	0	0	0.333	0.5	1

China	refined liquids industrial	biomass liquids	biomass liquids-FT CCS Level 1	0	0	0	0	0	0	0.333	0.5	1
China	refined liquids enduse	biomass liquids	biomass liquids-ethanol CCS Level 2	0	0	0	0	0	0	0.333	0.5	1
China	refined liquids enduse	biomass liquids	biomass liquids-FT CCS Level 2	0	0	0	0	0	0	0.333	0.5	1
China	refined liquids industrial	biomass liquids	biomass liquids-ethanol CCS Level 2	0	0	0	0	0	0	0.333	0.5	1
China	refined liquids industrial	biomass liquids	biomass liquids-FT CCS Level 2	0	0	0	0	0	0	0.333	0.5	1
Korea	refined liquids enduse	coal to liquids	coal to liquids CCS Level 1	0	0	0	0.333	1	1	1	1	1
Korea	refined liquids industrial	coal to liquids	coal to liquids CCS Level 1	0	0	0	0.333	1	1	1	1	1
Korea	refined liquids enduse	coal to liquids	coal to liquids CCS Level 2	0	0	0	0.333	1	1	1	1	1
Korea	refined liquids industrial	coal to liquids	coal to liquids CCS Level 2	0	0	0	0.333	1	1	1	1	1
Korea	refined liquids enduse	biomass liquids	biomass liquids-ethanol CCS Level 1	0	0	0	0.333	1	1	1	1	1
Korea	refined liquids enduse	biomass liquids	biomass liquids-FT CCS Level 1	0	0	0	0.333	1	1	1	1	1
Korea	refined liquids industrial	biomass liquids	biomass liquids-ethanol CCS Level 1	0	0	0	0.333	1	1	1	1	1
Korea	refined liquids industrial	biomass liquids	biomass liquids-FT CCS Level 1	0	0	0	0.333	1	1	1	1	1
Korea	refined liquids enduse	biomass liquids	biomass liquids-ethanol CCS Level 2	0	0	0	0.333	1	1	1	1	1
Korea	refined liquids enduse	biomass liquids	biomass liquids-FT CCS Level 2	0	0	0	0.333	1	1	1	1	1
Korea	refined liquids industrial	biomass liquids	biomass liquids-ethanol CCS Level 2	0	0	0	0.333	1	1	1	1	1
Korea	refined liquids industrial	biomass liquids	biomass liquids-FT CCS Level 2	0	0	0	0.333	1	1	1	1	1
Eastern Europe	refined liquids enduse	coal to liquids	coal to liquids CCS Level 1	0	0	0	0.333	1	1	1	1	1
Eastern Europe	refined liquids industrial	coal to liquids	coal to liquids CCS Level 1	0	0	0	0.333	1	1	1	1	1
Eastern Europe	refined liquids enduse	coal to liquids	coal to liquids CCS Level 2	0	0	0	0.333	1	1	1	1	1
Eastern Europe	refined liquids industrial	coal to liquids	coal to liquids CCS Level 2	0	0	0	0.333	1	1	1	1	1
Eastern Europe	refined liquids enduse	biomass liquids	biomass liquids-ethanol CCS Level 1	0	0	0	0.333	1	1	1	1	1
Eastern Europe	refined liquids enduse	biomass liquids	biomass liquids-FT CCS Level 1	0	0	0	0.333	1	1	1	1	1
Eastern Europe	refined liquids industrial	biomass liquids	biomass liquids-ethanol CCS Level 1	0	0	0	0.333	1	1	1	1	1
Eastern Europe	refined liquids industrial	biomass liquids	biomass liquids-FT CCS Level 1	0	0	0	0.333	1	1	1	1	1
Eastern Europe	refined liquids enduse	biomass liquids	biomass liquids-ethanol CCS Level 2	0	0	0	0.333	1	1	1	1	1
Eastern Europe	refined liquids enduse	biomass liquids	biomass liquids-FT CCS Level 2	0	0	0	0.333	1	1	1	1	1
Eastern Europe	refined liquids industrial	biomass liquids	biomass liquids-ethanol CCS Level 2	0	0	0	0.333	1	1	1	1	1
Eastern Europe	refined liquids industrial	biomass liquids	biomass liquids-FT CCS Level 2	0	0	0	0.333	1	1	1	1	1
Western Europe	refined liquids enduse	coal to liquids	coal to liquids CCS Level 1	0	0	0	0.333	1	1	1	1	1
Western Europe	refined liquids industrial	coal to liquids	coal to liquids CCS Level 1	0	0	0	0.333	1	1	1	1	1
Western Europe	refined liquids enduse	coal to liquids	coal to liquids CCS Level 2	0	0	0	0.333	1	1	1	1	1
Western Europe	refined liquids industrial	coal to liquids	coal to liquids CCS Level 2	0	0	0	0.333	1	1	1	1	1
Western Europe	refined liquids enduse	biomass liquids	biomass liquids-ethanol CCS Level 1	0	0	0	0.333	1	1	1	1	1
Western Europe	refined liquids enduse	biomass liquids	biomass liquids-FT CCS Level 1	0	0	0	0.333	1	1	1	1	1
Western Europe	refined liquids industrial	biomass liquids	biomass liquids-ethanol CCS Level 1	0	0	0	0.333	1	1	1	1	1
Western Europe	refined liquids industrial	biomass liquids	biomass liquids-FT CCS Level 1	0	0	0	0.333	1	1	1	1	1
Western Europe	refined liquids enduse	biomass liquids	biomass liquids-ethanol CCS Level 2	0	0	0	0.333	1	1	1	1	1
Western Europe	refined liquids enduse	biomass liquids	biomass liquids-FT CCS Level 2	0	0	0	0.333	1	1	1	1	1
Western Europe	refined liquids industrial	biomass liquids	biomass liquids-ethanol CCS Level 2	0	0	0	0.333	1	1	1	1	1
Western Europe	refined liquids industrial	biomass liquids	biomass liquids-FT CCS Level 2	0	0	0	0.333	1	1	1	1	1
Middle East	refined liquids enduse	coal to liquids	coal to liquids CCS Level 1	0	0	0	0	0	0	0.25	0.5	1
Middle East	refined liquids industrial	coal to liquids	coal to liquids CCS Level 1	0	0	0	0	0	0	0.25	0.5	1
Middle East	refined liquids enduse	coal to liquids	coal to liquids CCS Level 2	0	0	0	0	0	0	0.25	0.5	1
Middle East	refined liquids industrial	coal to liquids	coal to liquids CCS Level 2	0	0	0	0	0	0	0.25	0.5	1
Middle East	refined liquids enduse	biomass liquids	biomass liquids-ethanol CCS Level 1	0	0	0	0	0	0	0.333	0.5	1
Middle East	refined liquids enduse	biomass liquids	biomass liquids-FT CCS Level 1	0	0	0	0	0	0	0.333	0.5	1
Middle East	refined liquids industrial	biomass liquids	biomass liquids-ethanol CCS Level 1	0	0	0	0	0	0	0.333	0.5	1
Middle East	refined liquids industrial	biomass liquids	biomass liquids-FT CCS Level 1	0	0	0	0	0	0	0.333	0.5	1

Middle East	refined liquids enduse	biomass liquids	biomass liquids-ethanol CCS Level 2	0	0	0	0	0	0	0.333	0.5	1
Middle East	refined liquids enduse	biomass liquids	biomass liquids-FT CCS Level 2	0	0	0	0	0	0	0.333	0.5	1
Middle East	refined liquids industrial	biomass liquids	biomass liquids-ethanol CCS Level 2	0	0	0	0	0	0	0.333	0.5	1
Middle East	refined liquids industrial	biomass liquids	biomass liquids-FT CCS Level 2	0	0	0	0	0	0	0.333	0.5	1
USA	refined liquids enduse	coal to liquids	coal to liquids CCS Level 1	0	0	0	0.333	1	1	1	1	1
USA	refined liquids industrial	coal to liquids	coal to liquids CCS Level 1	0	0	0	0.333	1	1	1	1	1
USA	refined liquids enduse	coal to liquids	coal to liquids CCS Level 2	0	0	0	0.333	1	1	1	1	1
USA	refined liquids industrial	coal to liquids	coal to liquids CCS Level 2	0	0	0	0.333	1	1	1	1	1
USA	refined liquids enduse	biomass liquids	biomass liquids-ethanol CCS Level 1	0	0	0	0.333	1	1	1	1	1
USA	refined liquids enduse	biomass liquids	biomass liquids-FT CCS Level 1	0	0	0	0.333	1	1	1	1	1
USA	refined liquids industrial	biomass liquids	biomass liquids-ethanol CCS Level 1	0	0	0	0.333	1	1	1	1	1
USA	refined liquids industrial	biomass liquids	biomass liquids-FT CCS Level 1	0	0	0	0.333	1	1	1	1	1
USA	refined liquids enduse	biomass liquids	biomass liquids-ethanol CCS Level 2	0	0	0	0.333	1	1	1	1	1
USA	refined liquids enduse	biomass liquids	biomass liquids-FT CCS Level 2	0	0	0	0.333	1	1	1	1	1
USA	refined liquids industrial	biomass liquids	biomass liquids-ethanol CCS Level 2	0	0	0	0.333	1	1	1	1	1
USA	refined liquids industrial	biomass liquids	biomass liquids-FT CCS Level 2	0	0	0	0.333	1	1	1	1	1
Former Soviet Union	refined liquids enduse	coal to liquids	coal to liquids CCS Level 1	0	0	0	0	0	0	0.25	0.5	1
Former Soviet Union	refined liquids industrial	coal to liquids	coal to liquids CCS Level 1	0	0	0	0	0	0	0.25	0.5	1
Former Soviet Union	refined liquids enduse	coal to liquids	coal to liquids CCS Level 2	0	0	0	0	0	0	0.25	0.5	1
Former Soviet Union	refined liquids industrial	coal to liquids	coal to liquids CCS Level 2	0	0	0	0	0	0	0.25	0.5	1
Former Soviet Union	refined liquids enduse	biomass liquids	biomass liquids-ethanol CCS Level 1	0	0	0	0	0	0	0.333	0.5	1
Former Soviet Union	refined liquids enduse	biomass liquids	biomass liquids-FT CCS Level 1	0	0	0	0	0	0	0.333	0.5	1
Former Soviet Union	refined liquids industrial	biomass liquids	biomass liquids-ethanol CCS Level 1	0	0	0	0	0	0	0.333	0.5	1
Former Soviet Union	refined liquids industrial	biomass liquids	biomass liquids-FT CCS Level 1	0	0	0	0	0	0	0.333	0.5	1
Former Soviet Union	refined liquids enduse	biomass liquids	biomass liquids-ethanol CCS Level 2	0	0	0	0	0	0	0.333	0.5	1
Former Soviet Union	refined liquids enduse	biomass liquids	biomass liquids-FT CCS Level 2	0	0	0	0	0	0	0.333	0.5	1
Former Soviet Union	refined liquids industrial	biomass liquids	biomass liquids-ethanol CCS Level 2	0	0	0	0	0	0	0.333	0.5	1
Former Soviet Union	refined liquids industrial	biomass liquids	biomass liquids-FT CCS Level 2	0	0	0	0	0	0	0.333	0.5	1
Korea	refined liquids enduse	coal to liquids	coal to liquids CCS Level 1	0	0	0	0	0	0	0.25	0.5	1
Korea	refined liquids industrial	coal to liquids	coal to liquids CCS Level 1	0	0	0	0	0	0	0.25	0.5	1
Korea	refined liquids enduse	coal to liquids	coal to liquids CCS Level 2	0	0	0	0	0	0	0.25	0.5	1
Korea	refined liquids industrial	coal to liquids	coal to liquids CCS Level 2	0	0	0	0	0	0	0.25	0.5	1
Korea	refined liquids enduse	biomass liquids	biomass liquids-ethanol CCS Level 1	0	0	0	0	0	0	0.333	0.5	1
Korea	refined liquids enduse	biomass liquids	biomass liquids-FT CCS Level 1	0	0	0	0	0	0	0.333	0.5	1
Korea	refined liquids industrial	biomass liquids	biomass liquids-ethanol CCS Level 1	0	0	0	0	0	0	0.333	0.5	1
Korea	refined liquids industrial	biomass liquids	biomass liquids-FT CCS Level 1	0	0	0	0	0	0	0.333	0.5	1
Korea	refined liquids enduse	biomass liquids	biomass liquids-ethanol CCS Level 2	0	0	0	0	0	0	0.333	0.5	1
Korea	refined liquids enduse	biomass liquids	biomass liquids-FT CCS Level 2	0	0	0	0	0	0	0.333	0.5	1
Korea	refined liquids industrial	biomass liquids	biomass liquids-ethanol CCS Level 2	0	0	0	0	0	0	0.333	0.5	1
Korea	refined liquids industrial	biomass liquids	biomass liquids-FT CCS Level 2	0	0	0	0	0	0	0.333	0.5	1

MODIFIED GCAM FILE FOR TRANSPORTATION SECTOR DELAY SCENARIO

TranTechnology calibrated energy consumption and shareweight path
GENERIC SHAREWEIGHT PATH FOR TECHS THAT DO NOT EXIST IN THE BASE YEAR

	2020	2035	2050	2065	2080	2095
elec and other	0.1	0.25	0.5	0.5	0.5	0.5
H2	0	0.1	0.25	0.25	0.25	0.25
CNG	0.01	0.1	0.25	0.25	0.25	0.25

INPUT_TABLE
Variable ID
1010

					calibrated-value		share-weight								
region	supplysect	tranSubsec	tranTechno	minicam-e	1990	2005	1975	1990	2005	2020	2035	2050	2065	2080	2095
USA	trn_freight	air	air	refined liqu	0.493404	0.543212	1	1	1	1	1	1	1	1	1
USA	trn_freight	rail	rail ICE	refined liqu	0.432782	0.497982	1	1	1	1	1	1	1	1	1
USA	trn_freight	rail	rail electric	elect_td_tr	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5	0.5
USA	trn_freight	road	truck ICE	refined liqu	3.483727	4.701163	1	1	1	1	1	1	1	1	1
USA	trn_freight	domestic sl	domestic sl	refined liqu	0.161957	0.166223	1	1	1	1	1	1	1	1	1
USA	trn_passen	air	air	refined liqu	2.731653	3.007405	1	1	1	1	1	1	1	1	1
USA	trn_passen	high speed	high speed	elect_td_tr	0	0	0	0	0	1	1	1	1	1	1
USA	trn_passen	rail	rail ICE	refined liqu	0.014442	0.016618	1	1	1	1	1	1	1	1	1
USA	trn_passen	rail	rail electric	elect_td_tr	0.014851	0.026851	1	1	1	1	1	1	1	1	1
USA	trn_shippir	internation	internation	refined liqu	1.207795	1.085956	1	1	1	1	1	1	1	1	1
USA	trn_pass_r	LDV	LDV ICE	refined liqu	12.90182	17.41053	1	1	1	1	1	1	1	1	1
USA	trn_pass_r	LDV	LDV electri	elect_td_tr	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5	0.5
USA	trn_pass_r	LDV	LDV gas	delivered g	0	0	0	0	0	0.01	0.1	0.25	0.25	0.25	0.25
USA	trn_pass_r	LDV	LDV fuel ce	H2 Enduse	0	0	0	0	0	0	0.1	0.25	0.25	0.25	0.25
USA	trn_pass_r	bus	bus ICE	refined liqu	0.133974	0.180794	1	1	1	1	1	1	1	1	1
USA	trn_pass_r	bus	bus electric	elect_td_tr	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5	0.5
USA	trn_pass_r	bus	bus gas	delivered g	0	0.02175	0	0	1	1	1	1	1	1	1
USA	trn_pass_r	bus	bus fuel ce	H2 Enduse	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5	0.5
Canada	trn_freight	air	air	refined liqu	0.009192	0.012399	1	1	1	1	1	1	1	1	1
Canada	trn_freight	rail	rail ICE	refined liqu	0.084132	0.074193	1	1	1	1	1	1	1	1	1
Canada	trn_freight	rail	rail electric	elect_td_tr	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5	0.5
Canada	trn_freight	road	truck ICE	refined liqu	0.407764	0.523267	1	1	1	1	1	1	1	1	1
Canada	trn_freight	domestic sl	domestic sl	refined liqu	0.061864	0.079336	1	1	1	1	1	1	1	1	1
Canada	trn_passen	air	air	refined liqu	0.174654	0.235581	1	1	1	1	1	1	1	1	1
Canada	trn_passen	high speed	high speed	elect_td_tr	0	0	0	0	0	1	1	1	1	1	1
Canada	trn_passen	rail	rail ICE	refined liqu	0.002058	0.001815	1	1	1	1	1	1	1	1	1
Canada	trn_passen	rail	rail electric	elect_td_tr	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5	0.5
Canada	trn_shippir	internation	internation	refined liqu	0.037999	0.024681	1	1	1	1	1	1	1	1	1
Canada	trn_pass_r	LDV	LDV ICE	refined liqu	0.95981	1.231683	1	1	1	1	1	1	1	1	1
Canada	trn_pass_r	LDV	LDV electri	elect_td_tr	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5	0.5
Canada	trn_pass_r	LDV	LDV gas	delivered g	0	0	0	0	0	0.01	0.1	0.25	0.25	0.25	0.25
Canada	trn_pass_r	LDV	LDV fuel ce	H2 Enduse	0	0	0	0	0	0	0.1	0.25	0.25	0.25	0.25
Canada	trn_pass_r	bus	bus ICE	refined liqu	0.016523	0.021204	1	1	1	1	1	1	1	1	1
Canada	trn_pass_r	bus	bus electric	elect_td_tr	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5	0.5
Canada	trn_pass_r	bus	bus gas	delivered g	0.001495	0.001691	1	1	1	1	1	1	1	1	1

Canada	trn_pass_r	bus	bus fuel ce	H2 Enduse	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5	0.5

INPUT_TABLE
Variable ID
1015

				interpolation-rule			
region	supplysect	tranSubsec	tranTechn	apply-to	from-year	to-year	interpolation-function
USA	trn_passen	rail	rail ICE	share-weig	2005	2095	fixed
USA	trn_passen	rail	rail electric	share-weig	2005	2095	fixed
USA	trn_pass_r	bus	bus ICE	share-weig	2005	2095	fixed
USA	trn_pass_r	bus	bus gas	share-weig	2005	2095	fixed
Canada	trn_pass_r	bus	bus ICE	share-weig	2005	2095	fixed
Canada	trn_pass_r	bus	bus gas	share-weig	2005	2095	fixed

INPUT_TABLE
Variable ID
1010

					calibrated-value		share-weight								
region	supplysect	tranSubsec	tranTechn	minicam-e	1990	2005	1975	1990	2005	2020	2035	2050	2065	2080	2095
Western Eu	trn_freight	air	air	refined liqu	0.149891	0.258533	1	1	1	1	1	1	1	1	1
Western Eu	trn_freight	rail	rail ICE	refined liqu	0.115544	0.106229	1	1	1	1	1	1	1	1	1
Western Eu	trn_freight	rail	rail electric	elect_td_tr	0.008124	0.01085	1	1	1	1	1	1	1	1	1
Western Eu	trn_freight	road	truck ICE	refined liqu	3.951857	4.892998	1	1	1	1	1	1	1	1	1
Western Eu	trn_freight	domestic sl	domestic sl	refined liqu	0.290589	0.278275	1	1	1	1	1	1	1	1	1
Western Eu	trn_passen	air	air	refined liqu	1.182472	2.03954	1	1	1	1	1	1	1	1	1
Western Eu	trn_passen	high speed	high speed	elect_td_tr	0.012401	0.030674	1	1	1	1	1	1	1	1	1
Western Eu	trn_passen	rail	rail ICE	refined liqu	0.01842	0.016935	1	1	1	1	1	1	1	1	1
Western Eu	trn_passen	rail	rail electric	elect_td_tr	0.160002	0.199587	1	1	1	1	1	1	1	1	1
Western Eu	trn_shippir	internation	internation	refined liqu	1.48447	2.234537	1	1	1	1	1	1	1	1	1
Western Eu	trn_pass_r	LDV	LDV ICE	refined liqu	5.442247	6.738327	1	1	1	1	1	1	1	1	1
Western Eu	trn_pass_r	LDV	LDV electri	elect_td_tr	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5	0.5
Western Eu	trn_pass_r	LDV	LDV gas	delivered g	0	0	0	0	0	0.01	0.1	0.25	0.25	0.25	0.25
Western Eu	trn_pass_r	LDV	LDV fuel ce	H2 Enduse	0	0	0	0	0	0	0.1	0.25	0.25	0.25	0.25
Western Eu	trn_pass_r	bus	bus ICE	refined liqu	0.388547	0.48108	1	1	1	1	1	1	1	1	1
Western Eu	trn_pass_r	bus	bus electri	elect_td_tr	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5	0.5
Western Eu	trn_pass_r	bus	bus gas	delivered g	0.008729	0.020172	1	1	1	1	1	1	1	1	1
Western Eu	trn_pass_r	bus	bus fuel ce	H2 Enduse	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5	0.5
Japan	trn_freight	air	air	refined liqu	0.013113	0.02063	1	1	1	1	1	1	1	1	1
Japan	trn_freight	rail	rail ICE	refined liqu	0.00715	0.005029	1	1	1	1	1	1	1	1	1
Japan	trn_freight	rail	rail electric	elect_td_tr	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5	0.5
Japan	trn_freight	road	truck ICE	refined liqu	1.067463	1.273318	1	1	1	1	1	1	1	1	1
Japan	trn_freight	domestic sl	domestic sl	refined liqu	0.169787	0.163708	1	1	1	1	1	1	1	1	1
Japan	trn_passen	air	air	refined liqu	0.277656	0.436812	1	1	1	1	1	1	1	1	1
Japan	trn_passen	high speed	high speed	elect_td_tr	0.008143	0.008143	1	1	1	1	1	1	1	1	1
Japan	trn_passen	rail	rail ICE	refined liqu	0.00585	0.004115	1	1	1	1	1	1	1	1	1
Japan	trn_passen	rail	rail electric	elect_td_tr	0.052522	0.060623	1	1	1	1	1	1	1	1	1

Japan	trn_shippir	internation	internation	refined liqu	0.220301	0.245313	1	1	1	1	1	1	1	1	1
Japan	trn_pass_r	LDV	LDV ICE	refined liqu	1.507931	1.798728	1	1	1	1	1	1	1	1	1
Japan	trn_pass_r	LDV	LDV electri	elect_td_tr	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5	0.5
Japan	trn_pass_r	LDV	LDV gas	delivered g	0	0	0	0	0	0.01	0.1	0.25	0.25	0.25	0.25
Japan	trn_pass_r	LDV	LDV fuel ce	H2 Enduse	0	0	0	0	0	0	0.1	0.25	0.25	0.25	0.25
Japan	trn_pass_r	bus	bus ICE	refined liqu	0.103355	0.123286	1	1	1	1	1	1	1	1	1
Japan	trn_pass_r	bus	bus electri	elect_td_tr	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5	0.5
Japan	trn_pass_r	bus	bus gas	delivered g	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5	0.5
Japan	trn_pass_r	bus	bus fuel ce	H2 Enduse	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5	0.5

INPUT_TABLE
Variable ID
1015

				interpolation-rule			
region	supplysect	tranSubsec	tranTechno	apply-to	from-year	to-year	interpolation-function
Western E	trn_freight	rail	rail ICE	share-weig	2005	2095	fixed
Western E	trn_freight	rail	rail electric	share-weig	2005	2095	fixed
Western E	trn_passen	rail	rail ICE	share-weig	2005	2095	fixed
Western E	trn_passen	rail	rail electric	share-weig	2005	2095	fixed
Western E	trn_pass_r	bus	bus ICE	share-weig	2005	2095	fixed
Western E	trn_pass_r	bus	bus gas	share-weig	2005	2095	fixed
Japan	trn_passen	rail	rail ICE	share-weig	2005	2095	fixed
Japan	trn_passen	rail	rail electric	share-weig	2005	2095	fixed

INPUT_TABLE
Variable ID
1010

					calibrated-value		share-weight								
region	supplysect	tranSubsec	tranTechno	minicam-en	1990	2005	1975	1990	2005	2020	2035	2050	2065	2080	2095
Australia_N	trn_freight	air	air	refined liqu	0.006781	0.012126	1	1	1	1	1	1	1	1	1
Australia_N	trn_freight	rail	rail ICE	refined liqu	0.02143	0.026221	1	1	1	1	1	1	1	1	1
Australia_N	trn_freight	rail	rail electric	elect_td_tr	0.001682	0.002652	1	1	1	1	1	1	1	1	1
Australia_N	trn_freight	road	truck ICE	refined liqu	0.359378	0.475715	1	1	1	1	1	1	1	1	1
Australia_N	trn_freight	domestic s	domestic s	refined liqu	0.022509	0.010515	1	1	1	1	1	1	1	1	1
Australia_N	trn_passen	air	air	refined liqu	0.128841	0.230396	1	1	1	1	1	1	1	1	1
Australia_N	trn_passen	high speed	high speed	elect_td_tr	0	0	0	0	0	1	1	1	1	1	1
Australia_N	trn_passen	rail	rail ICE	refined liqu	0.002381	0.002913	1	1	1	1	1	1	1	1	1
Australia_N	trn_passen	rail	rail electric	elect_td_tr	0.005046	0.007955	1	1	1	1	1	1	1	1	1
Australia_N	trn_shippir	internation	internation	refined liqu	0.040531	0.044595	1	1	1	1	1	1	1	1	1
Australia_N	trn_pass_r	LDV	LDV ICE	refined liqu	0.516597	0.683828	1	1	1	1	1	1	1	1	1
Australia_N	trn_pass_r	LDV	LDV electri	elect_td_tr	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5	0.5
Australia_N	trn_pass_r	LDV	LDV gas	delivered g	0	0	0	0	0	0.01	0.1	0.25	0.25	0.25	0.25
Australia_N	trn_pass_r	LDV	LDV fuel ce	H2 Enduse	0	0	0	0	0	0	0.1	0.25	0.25	0.25	0.25
Australia_N	trn_pass_r	bus	bus ICE	refined liqu	0.022843	0.030238	1	1	1	1	1	1	1	1	1
Australia_N	trn_pass_r	bus	bus electri	elect_td_tr	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5	0.5
Australia_N	trn_pass_r	bus	bus gas	delivered g	0.002797	0.00188	1	1	1	1	1	1	1	1	1

Australia_N	trn_pass_r	bus	bus fuel ce	H2 Enduse	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5	0.5
Former Sov	trn_freight	air	air	refined liqu	0.128424	0.066867	1	1	1	1	1	1	1	1	1
Former Sov	trn_freight	rail	rail ICE	refined liqu	0.320558	0.124636	1	1	1	1	1	1	1	1	1
Former Sov	trn_freight	rail	rail electric	elect_td_tr	0.035954	0.026636	1	1	1	1	1	1	1	1	1
Former Sov	trn_freight	road	truck ICE	refined liqu	1.837872	1.206893	1	1	1	1	1	1	1	1	1
Former Sov	trn_freight	domestic sl	domestic sl	refined liqu	0.20579	0.058984	1	1	1	1	1	1	1	1	1
Former Sov	trn_passen	air	air	refined liqu	0.878477	0.457401	1	1	1	1	1	1	1	1	1
Former Sov	trn_passen	high speed	high speed	elect_td_tr	0	0	0	0	0	0.5	0.75	1	1	1	1
Former Sov	trn_passen	rail	rail ICE	refined liqu	0.038467	0.014956	1	1	1	1	1	1	1	1	1
Former Sov	trn_passen	rail	rail electric	elect_td_tr	0.314594	0.233068	1	1	1	1	1	1	1	1	1
Former Sov	trn_shippir	internation	internation	refined liqu	0.115775	0.022034	1	1	1	1	1	1	1	1	1
Former Sov	trn_pass_r	LDV	LDV ICE	refined liqu	1.834607	1.204749	1	1	1	1	1	1	1	1	1
Former Sov	trn_pass_r	LDV	LDV electri	elect_td_tr	0	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5
Former Sov	trn_pass_r	LDV	LDV gas	delivered g	0	0	0	0	0	0	0.007	0.1	0.2	0.25	0.25
Former Sov	trn_pass_r	LDV	LDV fuel ce	H2 Enduse	0	0	0	0	0	0	0	0	0.1	0.25	0.25
Former Sov	trn_pass_r	bus	bus ICE	refined liqu	0.064428	0.042308	1	1	1	1	1	1	1	1	1
Former Sov	trn_pass_r	bus	bus electric	elect_td_tr	0	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5
Former Sov	trn_pass_r	bus	bus gas	delivered g	0.057661	0.0104	1	1	1	1	1	1	1	1	1
Former Sov	trn_pass_r	bus	bus fuel ce	H2 Enduse	0	0	0	0	0	0	0	0	0.1	0.25	0.25

INPUT_TABLE

Variable ID

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				interpolation-rule			
region	supplysecto	tranSubsec	tranTechno	apply-to	from-year	to-year	interpolation-function
Australia_N	trn_freight	rail	rail ICE	share-weig	2005	2095	fixed
Australia_N	trn_freight	rail	rail electric	share-weig	2005	2095	fixed
Australia_N	trn_passen	rail	rail ICE	share-weig	2005	2095	fixed
Australia_N	trn_passen	rail	rail electric	share-weig	2005	2095	fixed
Australia_N	trn_pass_r	bus	bus ICE	share-weig	2005	2095	fixed
Australia_N	trn_pass_r	bus	bus gas	share-weig	2005	2095	fixed
Former Sov	trn_freight	rail	rail ICE	share-weig	2005	2095	fixed
Former Sov	trn_freight	rail	rail electric	share-weig	2005	2095	fixed
Former Sov	trn_passen	rail	rail ICE	share-weig	2005	2095	fixed
Former Sov	trn_passen	rail	rail electric	share-weig	2005	2095	fixed
Former Sov	trn_pass_r	bus	bus ICE	share-weig	2005	2095	fixed
Former Sov	trn_pass_r	bus	bus gas	share-weig	2005	2095	fixed

INPUT_TABLE

Variable ID

1010

					calibrated-value		share-weight								
region	supplysecto	tranSubsec	tranTechno	minicam-en	1990	2005	1975	1990	2005	2020	2035	2050	2065	2080	2095
China	trn_freight	air	air	refined liqu	0.006244	0.065546	1	1	1	1	1	1	1	1	1
China	trn_freight	rail	rail coal	delivered c	0.332938	0.137796	1	1	1	1	1	0	0	0	0
China	trn_freight	rail	rail ICE	refined liqu	0.07389	0.308626	1	1	1	1	1	1	1	1	1

China	trn_freight	rail	rail electric	elect_td_tr	0.003325	0.011225	1	1	1	1	1	1	1	1	1
China	trn_freight	road	truck ICE	refined liqu	0.700185	2.406322	1	1	1	1	1	1	1	1	1
China	trn_freight	domestic sl	domestic s	refined liqu	0.114707	0.388276	1	1	1	1	1	1	1	1	1
China	trn_passen	air	air	refined liqu	0.034306	0.360106	1	1	1	1	1	1	1	1	1
China	trn_passen	high speed	high speed	elect_td_tr	0	0	0	0	0	0.5	0.75	1	1	1	1
China	trn_passen	rail	rail coal	delivered c	0.083234	0.034449	1	1	1	1	1	0	0	0	0
China	trn_passen	rail	rail ICE	refined liqu	0.018473	0.077157	1	1	1	1	1	1	1	1	1
China	trn_passen	rail	rail electric	elect_td_tr	0.018839	0.063608	1	1	1	1	1	1	1	1	1
China	trn_shippir	internation	internation	refined liqu	0.060182	0.320767	1	1	1	1	1	1	1	1	1
China	trn_pass_r	LDV	LDV ICE	refined liqu	0.130548	0.448655	1	1	1	1	1	1	1	1	1
China	trn_pass_r	LDV	LDV electri	elect_td_tr	0	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5
China	trn_pass_r	LDV	LDV gas	delivered g	0	0	0	0	0	0	0.007	0.1	0.2	0.25	0.25
China	trn_pass_r	LDV	LDV fuel ce	H2 Enduse	0	0	0	0	0	0	0	0	0.1	0.25	0.25
China	trn_pass_r	bus	bus ICE	refined liqu	0.18404	0.63249	1	1	1	1	1	1	1	1	1
China	trn_pass_r	bus	bus electric	elect_td_tr	0	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5
China	trn_pass_r	bus	bus gas	delivered g	0	0.002918	0	0	1	1	1	1	1	1	1
China	trn_pass_r	bus	bus fuel ce	H2 Enduse	0	0	0	0	0	0	0	0	0.1	0.25	0.25
Middle Eas	trn_freight	air	air	refined liqu	0.061597	0.074723	1	1	1	1	1	1	1	1	1
Middle Eas	trn_freight	rail	rail ICE	refined liqu	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5	0.5
Middle Eas	trn_freight	rail	rail electric	elect_td_tr	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5	0.5
Middle Eas	trn_freight	road	truck ICE	refined liqu	0.520117	0.987755	1	1	1	1	1	1	1	1	1
Middle Eas	trn_freight	domestic sl	domestic s	refined liqu	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5	0.5
Middle Eas	trn_passen	air	air	refined liqu	0.349052	0.423433	1	1	1	1	1	1	1	1	1
Middle Eas	trn_passen	high speed	high speed	elect_td_tr	0	0	0	0	0	0.5	0.75	1	1	1	1
Middle Eas	trn_passen	rail	rail ICE	refined liqu	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5	0.5
Middle Eas	trn_passen	rail	rail electric	elect_td_tr	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5	0.5
Middle Eas	trn_shippir	internation	internation	refined liqu	0.37816	0.561608	1	1	1	1	1	1	1	1	1
Middle Eas	trn_pass_r	LDV	LDV ICE	refined liqu	1.447779	2.749479	1	1	1	1	1	1	1	1	1
Middle Eas	trn_pass_r	LDV	LDV electri	elect_td_tr	0	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5
Middle Eas	trn_pass_r	LDV	LDV gas	delivered g	0	0	0	0	0	0	0.007	0.1	0.2	0.25	0.25
Middle Eas	trn_pass_r	LDV	LDV fuel ce	H2 Enduse	0	0	0	0	0	0	0	0	0.1	0.25	0.25
Middle Eas	trn_pass_r	bus	bus ICE	refined liqu	0.112572	0.213785	1	1	1	1	1	1	1	1	1
Middle Eas	trn_pass_r	bus	bus electric	elect_td_tr	0	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5
Middle Eas	trn_pass_r	bus	bus gas	delivered g	0	0.010764	0	0	1	1	1	1	1	1	1
Middle Eas	trn_pass_r	bus	bus fuel ce	H2 Enduse	0	0	0	0	0	0	0	0	0.1	0.25	0.25

INPUT_TABLE

Variable ID

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				interpolation-rule			
region	supplysect	tranSubsec	tranTechno	apply-to	from-year	to-year	interpolation-function
China	trn_freight	rail	rail coal	share-weig	2005	2095	linear
China	trn_freight	rail	rail ICE	share-weig	2005	2095	fixed
China	trn_freight	rail	rail electric	share-weig	2005	2095	fixed
China	trn_passen	rail	rail coal	share-weig	2005	2095	linear
China	trn_passen	rail	rail ICE	share-weig	2005	2095	fixed

China	trn_passen	rail	rail electric	share-weig	2005	2095	fixed
China	trn_pass_r	bus	bus ICE	share-weig	2005	2095	fixed
China	trn_pass_r	bus	bus gas	share-weig	2005	2095	fixed
Middle Eas	trn_pass_r	bus	bus ICE	share-weig	2005	2095	fixed
Middle Eas	trn_pass_r	bus	bus gas	share-weig	2005	2095	fixed

INPUT_TABLE
Variable ID
1010

					calibrated-value		share-weight								
region	supplysect	tranSubsec	tranTechnc	minicam-er	1990	2005	1975	1990	2005	2020	2035	2050	2065	2080	2095
Africa	trn_freight	air	air	refined liqu	0.010317	0.016404	1	1	1	1	1	1	1	1	1
Africa	trn_freight	rail	rail ICE	refined liqu	0.003112	0.004486	1	1	1	1	1	1	1	1	1
Africa	trn_freight	rail	rail electric	elect_td_tr	0.002977	0.004132	1	1	1	1	1	1	1	1	1
Africa	trn_freight	road	truck ICE	refined liqu	0.461131	0.767684	1	1	1	1	1	1	1	1	1
Africa	trn_freight	domestic sl	domestic s	refined liqu	0.005514	0.036229	1	1	1	1	1	1	1	1	1
Africa	trn_passen	air	air	refined liqu	0.196021	0.311682	1	1	1	1	1	1	1	1	1
Africa	trn_passen	high speed	high speed	elect_td_tr	0	0	0	0	0	0.5	0.75	1	1	1	1
Africa	trn_passen	rail	rail ICE	refined liqu	0.006279	0.00905	1	1	1	1	1	1	1	1	1
Africa	trn_passen	rail	rail electric	elect_td_tr	0.013876	0.019255	1	1	1	1	1	1	1	1	1
Africa	trn_shippir	internation	internation	refined liqu	0.220854	0.26893	1	1	1	1	1	1	1	1	1
Africa	trn_pass_r	LDV	LDV ICE	refined liqu	0.461104	0.767639	1	1	1	1	1	1	1	1	1
Africa	trn_pass_r	LDV	LDV electri	elect_td_tr	0	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5
Africa	trn_pass_r	LDV	LDV gas	delivered g	0	0	0	0	0	0	0.007	0.1	0.2	0.25	0.25
Africa	trn_pass_r	LDV	LDV fuel ce	H2 Enduse	0	0	0	0	0	0	0	0	0.1	0.25	0.25
Africa	trn_pass_r	bus	bus ICE	refined liqu	0.485953	0.809007	1	1	1	1	1	1	1	1	1
Africa	trn_pass_r	bus	bus electri	elect_td_tr	0	0.000103	0	0	1	0	0.1	0.25	0.5	0.5	0.5
Africa	trn_pass_r	bus	bus gas	delivered g	0	0.010371	0	0	1	1	1	1	1	1	1
Africa	trn_pass_r	bus	bus fuel ce	H2 Enduse	0	0	0	0	0	0	0	0	0.1	0.25	0.25
Latin Amer	trn_freight	air	air	refined liqu	0.045128	0.068535	1	1	1	1	1	1	1	1	1
Latin Amer	trn_freight	rail	rail ICE	refined liqu	0.043934	0.043438	1	1	1	1	1	1	1	1	1
Latin Amer	trn_freight	rail	rail electric	elect_td_tr	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5	0.5
Latin Amer	trn_freight	road	truck ICE	refined liqu	2.5707	3.885869	1	1	1	1	1	1	1	1	1
Latin Amer	trn_freight	domestic sl	domestic s	refined liqu	0.079436	0.125823	1	1	1	1	1	1	1	1	1
Latin Amer	trn_passen	air	air	refined liqu	0.289152	0.439129	1	1	1	1	1	1	1	1	1
Latin Amer	trn_passen	high speed	high speed	elect_td_tr	0	0	0	0	0	0.5	0.75	1	1	1	1
Latin Amer	trn_passen	rail	rail ICE	refined liqu	0.009319	0.009214	1	1	1	1	1	1	1	1	1
Latin Amer	trn_passen	rail	rail electric	elect_td_tr	0.010211	0.012495	1	1	1	1	1	1	1	1	1
Latin Amer	trn_shippir	internation	internation	refined liqu	0.230882	0.440533	1	1	1	1	1	1	1	1	1
Latin Amer	trn_pass_r	LDV	LDV ICE	refined liqu	1.113678	1.683436	1	1	1	1	1	1	1	1	1
Latin Amer	trn_pass_r	LDV	LDV electri	elect_td_tr	0	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5
Latin Amer	trn_pass_r	LDV	LDV gas	delivered g	0	0	0	0	0	0	0.007	0.1	0.2	0.25	0.25
Latin Amer	trn_pass_r	LDV	LDV fuel ce	H2 Enduse	0	0	0	0	0	0	0	0	0.1	0.25	0.25
Latin Amer	trn_pass_r	bus	bus ICE	refined liqu	0.365668	0.552744	1	1	1	1	1	1	1	1	1
Latin Amer	trn_pass_r	bus	bus electri	elect_td_tr	0.000312	0.000639	1	1	1	0	0.1	0.25	0.5	0.5	0.5
Latin Amer	trn_pass_r	bus	bus gas	delivered g	0.008424	0.235512	1	1	1	1	1	1	1	1	1

Latin Amer	trn_pass_r	bus	bus fuel ce	H2 Enduse	0	0	0	0	0	0	0	0	0.1	0.25	0.25

INPUT_TABLE
Variable ID
1015

				interpolation-rule			
region	supplysect	tranSubsec	tranTechn	apply-to	from-year	to-year	interpolation-function
Africa	trn_freight	rail	rail ICE	share-weig	2005	2095	fixed
Africa	trn_freight	rail	rail electric	share-weig	2005	2095	fixed
Africa	trn_passen	rail	rail ICE	share-weig	2005	2095	fixed
Africa	trn_passen	rail	rail electric	share-weig	2005	2095	fixed
Africa	trn_pass_r	bus	bus ICE	share-weig	2005	2095	fixed
Africa	trn_pass_r	bus	bus electri	share-weig	2005	2095	fixed
Africa	trn_pass_r	bus	bus gas	share-weig	2005	2095	fixed
Latin Amer	trn_passen	rail	rail ICE	share-weig	2005	2095	fixed
Latin Amer	trn_passen	rail	rail electric	share-weig	2005	2095	fixed
Latin Amer	trn_pass_r	bus	bus ICE	share-weig	2005	2095	fixed
Latin Amer	trn_pass_r	bus	bus electri	share-weig	2005	2095	fixed
Latin Amer	trn_pass_r	bus	bus gas	share-weig	2005	2095	fixed

INPUT_TABLE
Variable ID
1010

					calibrated-value		share-weight								
region	supplysect	tranSubsec	tranTechn	minicam-e	1990	2005	1975	1990	2005	2020	2035	2050	2065	2080	2095
Southeast A	trn_freight	air	air	refined liqu	0.032036	0.070013	1	1	1	1	1	1	1	1	1
Southeast A	trn_freight	rail	rail ICE	refined liqu	0.001861	0.003821	1	1	1	1	1	1	1	1	1
Southeast A	trn_freight	rail	rail electric	elect_td_tr	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5	0.5
Southeast A	trn_freight	road	truck ICE	refined liqu	0.2896	0.645892	1	1	1	1	1	1	1	1	1
Southeast A	trn_freight	domestic s	domestic s	refined liqu	0.076183	0.133602	1	1	1	1	1	1	1	1	1
Southeast A	trn_passen	air	air	refined liqu	0.368415	0.805152	1	1	1	1	1	1	1	1	1
Southeast A	trn_passen	high speed	high speed	elect_td_tr	0	0	0	0	0	0.5	0.75	1	1	1	1
Southeast A	trn_passen	rail	rail ICE	refined liqu	0.018956	0.038926	1	1	1	1	1	1	1	1	1
Southeast A	trn_passen	rail	rail electric	elect_td_tr	0.001927	0.005138	1	1	1	1	1	1	1	1	1
Southeast A	trn_shippir	internation	internation	refined liqu	0.640618	1.471942	1	1	1	1	1	1	1	1	1
Southeast A	trn_pass_r	LDV	LDV ICE	refined liqu	0.449036	1.001479	1	1	1	1	1	1	1	1	1
Southeast A	trn_pass_r	LDV	LDV electri	elect_td_tr	0	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5
Southeast A	trn_pass_r	LDV	LDV gas	delivered g	0	0	0	0	0	0	0.007	0.1	0.2	0.25	0.25
Southeast A	trn_pass_r	LDV	LDV fuel ce	H2 Enduse	0	0	0	0	0	0	0	0	0.1	0.25	0.25
Southeast A	trn_pass_r	bus	bus ICE	refined liqu	0.978927	2.183287	1	1	1	1	1	1	1	1	1
Southeast A	trn_pass_r	bus	bus electri	elect_td_tr	0	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5
Southeast A	trn_pass_r	bus	bus gas	delivered g	5.44E-05	0.006155	1	1	1	1	1	1	1	1	1
Southeast A	trn_pass_r	bus	bus fuel ce	H2 Enduse	0	0	0	0	0	0	0	0	0.1	0.25	0.25
Eastern Eu	trn_freight	air	air	refined liqu	0.001736	0.001862	1	1	1	1	1	1	1	1	1
Eastern Eu	trn_freight	rail	rail ICE	refined liqu	0.030691	0.016681	1	1	1	1	1	1	1	1	1
Eastern Eu	trn_freight	rail	rail electric	elect_td_tr	0.002664	0.002034	1	1	1	1	1	1	1	1	1

Eastern Eu	trn_freight	road	truck ICE	refined liqu	0.405498	0.649996	1	1	1	1	1	1	1	1	1
Eastern Eu	trn_freight	domestic s	domestic s	refined liqu	0.023444	0.005309	1	1	1	1	1	1	1	1	1
Eastern Eu	trn_passen	air	air	refined liqu	0.063382	0.067971	1	1	1	1	1	1	1	1	1
Eastern Eu	trn_passen	high speed	high speed	elect_td_tr	0	0	0	0	0	1	1	1	1	1	1
Eastern Eu	trn_passen	rail	rail ICE	refined liqu	0.007419	0.004032	1	1	1	1	1	1	1	1	1
Eastern Eu	trn_passen	rail	rail electric	elect_td_tr	0.050609	0.038636	1	1	1	1	1	1	1	1	1
Eastern Eu	trn_shippir	internation	internation	refined liqu	0.02226	0.019348	1	1	1	1	1	1	1	1	1
Eastern Eu	trn_pass_r	LDV	LDV ICE	refined liqu	0.482207	0.772958	1	1	1	1	1	1	1	1	1
Eastern Eu	trn_pass_r	LDV	LDV electri	elect_td_tr	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5	0.5
Eastern Eu	trn_pass_r	LDV	LDV gas	delivered g	0	0	0	0	0	0.01	0.1	0.25	0.25	0.25	0.25
Eastern Eu	trn_pass_r	LDV	LDV fuel ce	H2 Enduse	0	0	0	0	0	0	0.1	0.25	0.25	0.25	0.25
Eastern Eu	trn_pass_r	bus	bus ICE	refined liqu	0.069641	0.111631	1	1	1	1	1	1	1	1	1
Eastern Eu	trn_pass_r	bus	bus electric	elect_td_tr	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5	0.5
Eastern Eu	trn_pass_r	bus	bus gas	delivered g	4.19E-06	0.00162	1	1	1	1	1	1	1	1	1
Eastern Eu	trn_pass_r	bus	bus fuel ce	H2 Enduse	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5	0.5

INPUT_TABLE

Variable ID

1015

				interpolation-rule			
region	supplysecto	tranSubsec	tranTechno	apply-to	from-year	to-year	interpolation-function
Southeast	trn_passen	rail	rail ICE	share-weig	2005	2095	fixed
Southeast	trn_passen	rail	rail electric	share-weig	2005	2095	fixed
Southeast	trn_pass_r	bus	bus ICE	share-weig	2005	2095	fixed
Southeast	trn_pass_r	bus	bus gas	share-weig	2005	2095	fixed
Eastern Eu	trn_freight	rail	rail ICE	share-weig	2005	2095	fixed
Eastern Eu	trn_freight	rail	rail electric	share-weig	2005	2095	fixed
Eastern Eu	trn_passen	rail	rail ICE	share-weig	2005	2095	fixed
Eastern Eu	trn_passen	rail	rail electric	share-weig	2005	2095	fixed
Eastern Eu	trn_pass_r	bus	bus ICE	share-weig	2005	2095	fixed
Eastern Eu	trn_pass_r	bus	bus gas	share-weig	2005	2095	fixed

INPUT_TABLE

Variable ID

1010

					calibrated-value		share-weight								
region	supplysecto	tranSubsec	tranTechno	minicam-en	1990	2005	1975	1990	2005	2020	2035	2050	2065	2080	2095
Korea	trn_freight	air	air	refined liqu	0.018557	0.031075	1	1	1	1	1	1	1	1	1
Korea	trn_freight	rail	rail ICE	refined liqu	0.002423	0.002236	1	1	1	1	1	1	1	1	1
Korea	trn_freight	rail	rail electric	elect_td_tr	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5	0.5
Korea	trn_freight	road	truck ICE	refined liqu	0.12583	0.309981	1	1	1	1	1	1	1	1	1
Korea	trn_freight	domestic s	domestic s	refined liqu	0.066403	0.03513	1	1	1	1	1	1	1	1	1
Korea	trn_passen	air	air	refined liqu	0.074227	0.1243	1	1	1	1	1	1	1	1	1
Korea	trn_passen	high speed	high speed	elect_td_tr	0	0.001159	0	0	1	0.5	0.75	1	1	1	1
Korea	trn_passen	rail	rail ICE	refined liqu	0.009693	0.008942	1	1	1	1	1	1	1	1	1
Korea	trn_passen	rail	rail electric	elect_td_tr	0.003642	0.006258	1	1	1	1	1	1	1	1	1

Korea	trn_shippir	internation	internation	refined liqu	0.066181	0.416219	1	1	1	1	1	1	1	1	1
Korea	trn_pass_r	LDV	LDV ICE	refined liqu	0.276638	0.681494	1	1	1	1	1	1	1	1	1
Korea	trn_pass_r	LDV	LDV electri	elect_td_tr	0	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5
Korea	trn_pass_r	LDV	LDV gas	delivered g	0	0	0	0	0	0	0.007	0.1	0.2	0.25	0.25
Korea	trn_pass_r	LDV	LDV fuel ce	H2 Enduse	0	0	0	0	0	0	0	0	0.1	0.25	0.25
Korea	trn_pass_r	bus	bus ICE	refined liqu	0.047601	0.117264	1	1	1	1	1	1	1	1	1
Korea	trn_pass_r	bus	bus electri	elect_td_tr	0	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5
Korea	trn_pass_r	bus	bus gas	delivered g	0	0.013557	0	0	1	1	1	1	1	1	1
Korea	trn_pass_r	bus	bus fuel ce	H2 Enduse	0	0	0	0	0	0	0	0	0.1	0.25	0.25
India	trn_freight	air	air	refined liqu	0.011229	0.022038	1	1	1	1	1	1	1	1	1
India	trn_freight	rail	rail ICE	refined liqu	0.019228	0.020151	1	1	1	1	1	1	1	1	1
India	trn_freight	rail	rail electric	elect_td_tr	0.00147	0.003739	1	1	1	1	1	1	1	1	1
India	trn_freight	road	truck ICE	refined liqu	0.181746	0.249938	1	1	1	1	1	1	1	1	1
India	trn_freight	domestic s	domestic s	refined liqu	0.023351	0.020159	1	1	1	1	1	1	1	1	1
India	trn_passen	air	air	refined liqu	0.063631	0.124885	1	1	1	1	1	1	1	1	1
India	trn_passen	high speed	high speed	elect_td_tr	0	0	0	0	0	0.5	0.75	1	1	1	1
India	trn_passen	rail	rail ICE	refined liqu	0.044864	0.047018	1	1	1	1	1	1	1	1	1
India	trn_passen	rail	rail electric	elect_td_tr	0.013234	0.033652	1	1	1	1	1	1	1	1	1
India	trn_shippir	internation	internation	refined liqu	0.006212	0.001231	1	1	1	1	1	1	1	1	1
India	trn_pass_r	LDV	LDV ICE	refined liqu	0.188725	0.259536	1	1	1	1	1	1	1	1	1
India	trn_pass_r	LDV	LDV electri	elect_td_tr	0	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5
India	trn_pass_r	LDV	LDV gas	delivered g	0	0	0	0	0	0	0.007	0.1	0.2	0.25	0.25
India	trn_pass_r	LDV	LDV fuel ce	H2 Enduse	0	0	0	0	0	0	0	0	0.1	0.25	0.25
India	trn_pass_r	bus	bus ICE	refined liqu	0.538258	0.740215	1	1	1	1	1	1	1	1	1
India	trn_pass_r	bus	bus electri	elect_td_tr	0	0	0	0	0	0	0.1	0.25	0.5	0.5	0.5
India	trn_pass_r	bus	bus gas	delivered g	0	0.027645	0	0	1	1	1	1	1	1	1
India	trn_pass_r	bus	bus fuel ce	H2 Enduse	0	0	0	0	0	0	0	0	0.1	0.25	0.25

INPUT_TABLE
Variable ID
1015

				interpolation-rule			
region	supplysect	tranSubsec	tranTechn	apply-to	from-year	to-year	interpolation-function
Korea	trn_passen	rail	rail ICE	share-weig	2005	2095	fixed
Korea	trn_passen	rail	rail electric	share-weig	2005	2095	fixed
Korea	trn_pass_r	bus	bus ICE	share-weig	2005	2095	fixed
Korea	trn_pass_r	bus	bus gas	share-weig	2005	2095	fixed
India	trn_freight	rail	rail ICE	share-weig	2005	2095	fixed
India	trn_freight	rail	rail electric	share-weig	2005	2095	fixed
India	trn_passen	rail	rail ICE	share-weig	2005	2095	fixed
India	trn_passen	rail	rail electric	share-weig	2005	2095	fixed
India	trn_pass_r	bus	bus ICE	share-weig	2005	2095	fixed
India	trn_pass_r	bus	bus gas	share-weig	2005	2095	fixed

INPUT_TABLE

MODIFIED GCAM FILE FOR ELECTRIC SECTOR DELAY SCENARIO

Variable ID

37a

Fossil - Reference - share-weight (tech level)

region	technology	share-weight 1975	1990	2005	2020	2035	2050	2065	2080	2095
Africa	Coal (existing)	1	1	1	0	0	0	0	0	0
Africa	Coal (conv pul)	0	0	0	1	1	1	1	1	1
Africa	Coal (IGCC)	0	0	0	0	0	1	1	1	1
Africa	Coal (IGCC)_CCS	0	0	0	0	0	0	0.25	0.5	1
Africa	Gas (existing)	1	1	1	0	0	0	0	0	0
Africa	Gas (peak load conv)	0	0	0	1	1	1	1	1	1
Africa	Gas (base load conv)	0	0	0	0	0	0	0	0	0
Africa	Gas (CC)	0	0	0	0	0.25	0.333	0.5	1	1
Africa	Gas (CC)_CCS	0	0	0	0	0	0	0.333	0.5	1
Africa	Oil (existing)	1	1	1	0	0	0	0	0	0
Africa	Oil (peak load conv)	0	0	0	1	1	1	1	1	1
Africa	Oil (base load conv)	0	0	0	0	0	0	0	0	0
Africa	Oil (IGCC)	0	0	0	0	0	1	1	1	1
Africa	Oil (IGCC)_CCS	0	0	0	0	0	0	0.25	0.5	1
Africa	Biomass (existing)	1	1	1	0	0	0	0	0	0
Africa	Biomass (conv)	0	0	0	1	1	1	1	1	1
Africa	Biomass (IGCC)	0	0	0	0	0	0	0.25	0.333	0.5
Africa	Biomass (IGCC)_CCS	0	0	0	0	0	0	0.25	0.333	0.5
Latin America	Coal (existing)	1	1	1	0	0	0	0	0	0
Latin America	Coal (conv pul)	0	0	0	1	1	1	1	1	1
Latin America	Coal (IGCC)	0	0	0	0	0	1	1	1	1
Latin America	Coal (IGCC)_CCS	0	0	0	0	0	0	0.25	0.5	1
Latin America	Gas (existing)	1	1	1	0	0	0	0	0	0
Latin America	Gas (peak load conv)	0	0	0	1	1	1	1	1	1
Latin America	Gas (base load conv)	0	0	0	0	0	0	0	0	0
Latin America	Gas (CC)	0	0	0	0	0.25	0.333	0.5	1	1
Latin America	Gas (CC)_CCS	0	0	0	0	0	0	0.333	0.5	1
Latin America	Oil (existing)	1	1	1	0	0	0	0	0	0
Latin America	Oil (peak load conv)	0	0	0	1	1	1	1	1	1
Latin America	Oil (base load conv)	0	0	0	0	0	0	0	0	0

Latin America	Oil (IGCC)	0	0	0	0	0	1	1	1	1
Latin America	Oil (IGCC)_CCS	0	0	0	0	0	0	0.25	0.5	1
Latin America	Biomass (existing)	1	1	1	0	0	0	0	0	0
Latin America	Biomass (conv)	0	0	0	1	1	1	1	1	1
Latin America	Biomass (IGCC)	0	0	0	0	0	0	0.25	0.333	0.5
Latin America	Biomass (IGCC)_CCS	0	0	0	0	0	0	0.25	0.333	0.5
Southeast Asia	Coal (existing)	1	1	1	0	0	0	0	0	0
Southeast Asia	Coal (conv pul)	0	0	0	1	1	1	1	1	1
Southeast Asia	Coal (IGCC)	0	0	0	0	0	1	1	1	1
Southeast Asia	Coal (IGCC)_CCS	0	0	0	0	0	0	0.25	0.5	1
Southeast Asia	Gas (existing)	1	1	1	0	0	0	0	0	0
Southeast Asia	Gas (peak load conv)	0	0	0	1	1	1	1	1	1
Southeast Asia	Gas (base load conv)	0	0	0	0	0	0	0	0	0
Southeast Asia	Gas (CC)	0	0	0	0	0.25	0.333	0.5	1	1
Southeast Asia	Gas (CC)_CCS	0	0	0	0	0	0	0.333	0.5	1
Southeast Asia	Oil (existing)	1	1	1	0	0	0	0	0	0
Southeast Asia	Oil (peak load conv)	0	0	0	1	1	1	1	1	1
Southeast Asia	Oil (base load conv)	0	0	0	0	0	0	0	0	0
Southeast Asia	Oil (IGCC)	0	0	0	0	0	1	1	1	1
Southeast Asia	Oil (IGCC)_CCS	0	0	0	0	0	0	0.25	0.5	1
Southeast Asia	Biomass (existing)	1	1	1	0	0	0	0	0	0
Southeast Asia	Biomass (conv)	0	0	0	1	1	1	1	1	1
Southeast Asia	Biomass (IGCC)	0	0	0	0	0	0	0.25	0.333	0.5
Southeast Asia	Biomass (IGCC)_CCS	0	0	0	0	0	0	0.25	0.333	0.5
Middle East	Coal (existing)	1	1	1	0	0	0	0	0	0
Middle East	Coal (conv pul)	0	0	0	1	1	1	1	1	1
Middle East	Coal (IGCC)	0	0	0	0	0	1	1	1	1
Middle East	Coal (IGCC)_CCS	0	0	0	0	0	0	0.25	0.5	1
Middle East	Gas (existing)	1	1	1	0	0	0	0	0	0
Middle East	Gas (peak load conv)	0	0	0	1	1	1	1	1	1
Middle East	Gas (base load conv)	0	0	0	0	0	0	0	0	0
Middle East	Gas (CC)	0	0	0	0	0.25	0.333	0.5	1	1
Middle East	Gas (CC)_CCS	0	0	0	0	0	0	0.333	0.5	1
Middle East	Oil (existing)	1	1	1	0	0	0	0	0	0
Middle East	Oil (peak load conv)	0	0	0	1	1	1	1	1	1
Middle East	Oil (base load conv)	0	0	0	0	0	0	0	0	0

Middle East	Oil (IGCC)	0	0	0	0	0	1	1	1	1
Middle East	Oil (IGCC)_CCS	0	0	0	0	0	0	0.25	0.5	1
Middle East	Biomass (existing)	1	1	1	0	0	0	0	0	0
Middle East	Biomass (conv)	0	0	0	1	1	1	1	1	1
Middle East	Biomass (IGCC)	0	0	0	0	0	0	0.25	0.333	0.5
Middle East	Biomass (IGCC)_CCS	0	0	0	0	0	0	0.25	0.333	0.5
India	Coal (existing)	1	1	1	0	0	0	0	0	0
India	Coal (conv pul)	0	0	0	1	1	1	1	1	1
India	Coal (IGCC)	0	0	0	0	0	1	1	1	1
India	Coal (IGCC)_CCS	0	0	0	0	0	0	0.25	0.5	1
India	Gas (existing)	1	1	1	0	0	0	0	0	0
India	Gas (peak load conv)	0	0	0	1	1	1	1	1	1
India	Gas (base load conv)	0	0	0	0	0	0	0	0	0
India	Gas (CC)	0	0	0	0	0.25	0.333	0.5	1	1
India	Gas (CC)_CCS	0	0	0	0	0	0	0.333	0.5	1
India	Oil (existing)	1	1	1	0	0	0	0	0	0
India	Oil (peak load conv)	0	0	0	1	1	1	1	1	1
India	Oil (base load conv)	0	0	0	0	0	0	0	0	0
India	Oil (IGCC)	0	0	0	0	0	1	1	1	1
India	Oil (IGCC)_CCS	0	0	0	0	0	0	0.25	0.5	1
India	Biomass (existing)	1	1	1	0	0	0	0	0	0
India	Biomass (conv)	0	0	0	1	1	1	1	1	1
India	Biomass (IGCC)	0	0	0	0	0	0	0.25	0.333	0.5
India	Biomass (IGCC)_CCS	0	0	0	0	0	0	0.25	0.333	0.5
China	Coal (existing)	1	1	1	0	0	0	0	0	0
China	Coal (conv pul)	0	0	0	1	1	1	1	1	1
China	Coal (IGCC)	0	0	0	0	0	1	1	1	1
China	Coal (IGCC)_CCS	0	0	0	0	0	0	0.25	0.5	1
China	Gas (existing)	1	1	1	0	0	0	0	0	0
China	Gas (peak load conv)	0	0	0	1	1	1	1	1	1
China	Gas (base load conv)	0	0	0	0	0	0	0	0	0
China	Gas (CC)	0	0	0	0	0.25	0.333	0.5	1	1
China	Gas (CC)_CCS	0	0	0	0	0	0	0.333	0.5	1
China	Oil (existing)	1	1	1	0	0	0	0	0	0
China	Oil (peak load conv)	0	0	0	1	1	1	1	1	1
China	Oil (base load conv)	0	0	0	0	0	0	0	0	0

China	Oil (IGCC)	0	0	0	0	0	1	1	1	1
China	Oil (IGCC)_CCS	0	0	0	0	0	0	0.25	0.5	1
China	Biomass (existing)	1	1	1	0	0	0	0	0	0
China	Biomass (conv)	0	0	0	1	1	1	1	1	1
China	Biomass (IGCC)	0	0	0	0	0	0	0.25	0.333	0.5
China	Biomass (IGCC)_CCS	0	0	0	0	0	0	0.25	0.333	0.5
Former Soviet Union	Coal (existing)	1	1	1	0	0	0	0	0	0
Former Soviet Union	Coal (conv pul)	0	0	0	1	1	1	1	1	1
Former Soviet Union	Coal (IGCC)	0	0	0	0	0	1	1	1	1
Former Soviet Union	Coal (IGCC)_CCS	0	0	0	0	0	0	0.25	0.5	1
Former Soviet Union	Gas (existing)	1	1	1	0	0	0	0	0	0
Former Soviet Union	Gas (peak load conv)	0	0	0	1	1	1	1	1	1
Former Soviet Union	Gas (base load conv)	0	0	0	0	0	0	0	0	0
Former Soviet Union	Gas (CC)	0	0	0	0	0.25	0.333	0.5	1	1
Former Soviet Union	Gas (CC)_CCS	0	0	0	0	0	0	0.333	0.5	1
Former Soviet Union	Oil (existing)	1	1	1	0	0	0	0	0	0
Former Soviet Union	Oil (peak load conv)	0	0	0	1	1	1	1	1	1
Former Soviet Union	Oil (base load conv)	0	0	0	0	0	0	0	0	0
Former Soviet Union	Oil (IGCC)	0	0	0	0	0	1	1	1	1
Former Soviet Union	Oil (IGCC)_CCS	0	0	0	0	0	0	0.25	0.5	1
Former Soviet Union	Biomass (existing)	1	1	1	0	0	0	0	0	0
Former Soviet Union	Biomass (conv)	0	0	0	1	1	1	1	1	1
Former Soviet Union	Biomass (IGCC)	0	0	0	0	0	0	0.25	0.333	0.5
Former Soviet Union	Biomass (IGCC)_CCS	0	0	0	0	0	0	0.25	0.333	0.5
Eastern Europe	Coal (existing)	1	1	1	0	0	0	0	0	0
Eastern Europe	Coal (conv pul)	0	0	0	1	1	1	1	1	1
Eastern Europe	Coal (IGCC)	0	0	0	1	1	1	1	1	1
Eastern Europe	Coal (IGCC)_CCS	0	0	0	0.25	0.333	0.5	1	1	1
Eastern Europe	Gas (existing)	1	1	1	0	0	0	0	0	0
Eastern Europe	Gas (peak load conv)	0	0	0	1	1	1	1	1	1
Eastern Europe	Gas (base load conv)	0	0	0	0	0	0	0	0	0
Eastern Europe	Gas (CC)	0	0	0	1	1	1	1	1	1
Eastern Europe	Gas (CC)_CCS	0	0	0	*0.25*	0.333	0.5	1	1	1
Eastern Europe	Oil (existing)	1	1	1	0	0	0	0	0	0
Eastern Europe	Oil (peak load conv)	0	0	0	1	1	1	1	1	1
Eastern Europe	Oil (base load conv)	0	0	0	0	0	0	0	0	0

Eastern Europe	Oil (IGCC)	0	0	0	1	1	1	1	1	1
Eastern Europe	Oil (IGCC)_CCS	0	0	0	0.25	0.333	0.5	1	1	1
Eastern Europe	Biomass (existing)	1	1	1	0	0	0	0	0	0
Eastern Europe	Biomass (conv)	0	0	0	1	1	1	1	1	1
Eastern Europe	Biomass (IGCC)	0	0	0	1	1	1	1	1	1
Eastern Europe	Biomass (IGCC)_CCS	0	0	0	0.25	0.333	0.5	1	1	1
Korea	Coal (existing)	1	1	1	0	0	0	0	0	0
Korea	Coal (conv pul)	0	0	0	1	1	1	1	1	1
Korea	Coal (IGCC)	0	0	0	1	1	1	1	1	1
Korea	Coal (IGCC)_CCS	0	0	0	0.25	0.333	0.5	1	1	1
Korea	Gas (existing)	1	1	1	0	0	0	0	0	0
Korea	Gas (peak load conv)	0	0	0	1	1	1	1	1	1
Korea	Gas (base load conv)	0	0	0	0	0	0	0	0	0
Korea	Gas (CC)	0	0	0	1	1	1	1	1	1
Korea	Gas (CC)_CCS	0	0	0	0.25	0.333	0.5	1	1	1
Korea	Oil (existing)	1	1	1	0	0	0	0	0	0
Korea	Oil (peak load conv)	0	0	0	1	1	1	1	1	1
Korea	Oil (base load conv)	0	0	0	0	0	0	0	0	0
Korea	Oil (IGCC)	0	0	0	1	1	1	1	1	1
Korea	Oil (IGCC)_CCS	0	0	0	0.25	0.333	0.5	1	1	1
Korea	Biomass (existing)	1	1	1	0	0	0	0	0	0
Korea	Biomass (conv)	0	0	0	1	1	1	1	1	1
Korea	Biomass (IGCC)	0	0	0	1	1	1	1	1	1
Korea	Biomass (IGCC)_CCS	0	0	0	0.25	0.333	0.5	1	1	1
Australia_NZ	Coal (existing)	1	1	1	0	0	0	0	0	0
Australia_NZ	Coal (conv pul)	0	0	0	1	1	1	1	1	1
Australia_NZ	Coal (IGCC)	0	0	0	1	1	1	1	1	1
Australia_NZ	Coal (IGCC)_CCS	0	0	0	0.333	1	1	1	1	1
Australia_NZ	Gas (existing)	1	1	1	0	0	0	0	0	0
Australia_NZ	Gas (peak load conv)	0	0	0	1	1	1	1	1	1
Australia_NZ	Gas (base load conv)	0	0	0	0	0	0	0	0	0
Australia_NZ	Gas (CC)	0	0	0	1	1	1	1	1	1
Australia_NZ	Gas (CC)_CCS	0	0	0	0.333	1	1	1	1	1
Australia_NZ	Oil (existing)	1	1	1	0	0	0	0	0	0
Australia_NZ	Oil (peak load conv)	0	0	0	1	1	1	1	1	1
Australia_NZ	Oil (base load conv)	0	0	0	0	0	0	0	0	0

Australia_NZ	Oil (IGCC)	0	0	0	1	1	1	1	1	1
Australia_NZ	Oil (IGCC)_CCS	0	0	0	0.333	1	1	1	1	1
Australia_NZ	Biomass (existing)	1	1	1	0	0	0	0	0	0
Australia_NZ	Biomass (conv)	0	0	0	1	1	1	1	1	1
Australia_NZ	Biomass (IGCC)	0	0	0	1	1	1	1	1	1
Australia_NZ	Biomass (IGCC)_CCS	0	0	0	0.333	1	1	1	1	1
Canada	Coal (existing)	1	1	1	0	0	0	0	0	0
Canada	Coal (conv pul)	0	0	0	1	1	1	1	1	1
Canada	Coal (IGCC)	0	0	0	1	1	1	1	1	1
Canada	Coal (IGCC)_CCS	0	0	0	0.333	1	1	1	1	1
Canada	Gas (existing)	1	1	1	0	0	0	0	0	0
Canada	Gas (peak load conv)	0	0	0	1	1	1	1	1	1
Canada	Gas (base load conv)	0	0	0	0	0	0	0	0	0
Canada	Gas (CC)	0	0	0	1	1	1	1	1	1
Canada	Gas (CC)_CCS	0	0	0	0.333	1	1	1	1	1
Canada	Oil (existing)	1	1	1	0	0	0	0	0	0
Canada	Oil (peak load conv)	0	0	0	1	1	1	1	1	1
Canada	Oil (base load conv)	0	0	0	0	0	0	0	0	0
Canada	Oil (IGCC)	0	0	0	1	1	1	1	1	1
Canada	Oil (IGCC)_CCS	0	0	0	0.333	1	1	1	1	1
Canada	Biomass (existing)	1	1	1	0	0	0	0	0	0
Canada	Biomass (conv)	0	0	0	1	1	1	1	1	1
Canada	Biomass (IGCC)	0	0	0	1	1	1	1	1	1
Canada	Biomass (IGCC)_CCS	0	0	0	0.333	1	1	1	1	1
Japan	Coal (existing)	1	1	1	0	0	0	0	0	0
Japan	Coal (conv pul)	0	0	0	1	1	1	1	1	1
Japan	Coal (IGCC)	0	0	0	1	1	1	1	1	1
Japan	Coal (IGCC)_CCS	0	0	0	0.333	1	1	1	1	1
Japan	Gas (existing)	1	1	1	0	0	0	0	0	0
Japan	Gas (peak load conv)	0	0	0	1	1	1	1	1	1
Japan	Gas (base load conv)	0	0	0	0	0	0	0	0	0
Japan	Gas (CC)	0	0	0	1	1	1	1	1	1
Japan	Gas (CC)_CCS	0	0	0	0.333	1	1	1	1	1
Japan	Oil (existing)	1	1	1	0	0	0	0	0	0
Japan	Oil (peak load conv)	0	0	0	1	1	1	1	1	1
Japan	Oil (base load conv)	0	0	0	0	0	0	0	0	0

Japan	Oil (IGCC)	0	0	0	1	1	1	1	1	1
Japan	Oil (IGCC)_CCS	0	0	0	0.333	1	1	1	1	1
Japan	Biomass (existing)	1	1	1	0	0	0	0	0	0
Japan	Biomass (conv)	0	0	0	1	1	1	1	1	1
Japan	Biomass (IGCC)	0	0	0	1	1	1	1	1	1
Japan	Biomass (IGCC)_CCS	0	0	0	0.333	1	1	1	1	1
Western Europe	Coal (existing)	1	1	1	0	0	0	0	0	0
Western Europe	Coal (conv pul)	0	0	0	1	1	1	1	1	1
Western Europe	Coal (IGCC)	0	0	0	1	1	1	1	1	1
Western Europe	Coal (IGCC)_CCS	0	0	0	0.333	1	1	1	1	1
Western Europe	Gas (existing)	1	1	1	0	0	0	0	0	0
Western Europe	Gas (peak load conv)	0	0	0	1	1	1	1	1	1
Western Europe	Gas (base load conv)	0	0	0	0	0	0	0	0	0
Western Europe	Gas (CC)	0	0	0	1	1	1	1	1	1
Western Europe	Gas (CC)_CCS	0	0	0	0.333	1	1	1	1	1
Western Europe	Oil (existing)	1	1	1	0	0	0	0	0	0
Western Europe	Oil (peak load conv)	0	0	0	1	1	1	1	1	1
Western Europe	Oil (base load conv)	0	0	0	0	0	0	0	0	0
Western Europe	Oil (IGCC)	0	0	0	1	1	1	1	1	1
Western Europe	Oil (IGCC)_CCS	0	0	0	0.333	1	1	1	1	1
Western Europe	Biomass (existing)	1	1	1	0	0	0	0	0	0
Western Europe	Biomass (conv)	0	0	0	1	1	1	1	1	1
Western Europe	Biomass (IGCC)	0	0	0	1	1	1	1	1	1
Western Europe	Biomass (IGCC)_CCS	0	0	0	0.333	1	1	1	1	1
Africa	PV_storage	0	0	0	0	0.25	0.333	0.5	1	1
Latin America	PV_storage	0	0	0	0	0.25	0.333	0.5	1	1
Southeast Asia	PV_storage	0	0	0	0	0.25	0.333	0.5	1	1
India	PV_storage	0	0	0	0	0.25	0.333	0.5	1	1
Middle East	PV_storage	0	0	0	0	0.25	0.333	0.5	1	1
China	PV_storage	0	0	0	0	0.25	0.333	0.5	1	1
Former Soviet Union	PV_storage	0	0	0	0	0.25	0.333	0.5	1	1
Eastern Europe	PV_storage	0	0	0	0.25	0.333	0.5	1	1	1
Korea	PV_storage	0	0	0	0.25	0.333	0.5	1	1	1
Canada	PV_storage	0	0	0	1	1	1	1	1	1
Western Europe	PV_storage	0	0	0	1	1	1	1	1	1
Japan	PV_storage	0	0	0	1	1	1	1	1	1

Australia_NZ	PV_storage	0	0	0	1	1	1	1	1	1
USA	PV_storage	0	0	0	1	1	1	1	1	1
Africa	CSP_storage	0	0	0	0	0.25	0.333	0.5	1	1
Latin America	CSP_storage	0	0	0	0	0.25	0.333	0.5	1	1
Southeast Asia	CSP_storage	0	0	0	0	0.25	0.333	0.5	1	1
India	CSP_storage	0	0	0	0	0.25	0.333	0.5	1	1
Middle East	CSP_storage	0	0	0	0	0.25	0.333	0.5	1	1
China	CSP_storage	0	0	0	0	0.25	0.333	0.5	1	1
Former Soviet Union	CSP_storage	0	0	0	0	0.25	0.333	0.5	1	1
Eastern Europe	CSP_storage	0	0	0	0.25	0.333	0.5	1	1	1
Korea	CSP_storage	0	0	0	0.25	0.333	0.5	1	1	1
Canada	CSP_storage	0	0	0	1	1	1	1	1	1
Western Europe	CSP_storage	0	0	0	1	1	1	1	1	1
Japan	CSP_storage	0	0	0	1	1	1	1	1	1
Australia_NZ	CSP_storage	0	0	0	1	1	1	1	1	1
USA	CSP_storage	0	0	0	1	1	1	1	1	1
Africa	wind_storage	0	0	0	0	0.25	0.333	0.5	1	1
Latin America	wind_storage	0	0	0	0	0.25	0.333	0.5	1	1
Southeast Asia	wind_storage	0	0	0	0	0.25	0.333	0.5	1	1
India	wind_storage	0	0	0	0	0.25	0.333	0.5	1	1
Middle East	wind_storage	0	0	0	0	0.25	0.333	0.5	1	1
China	wind_storage	0	0	0	0	0.25	0.333	0.5	1	1
Former Soviet Union	wind_storage	0	0	0	0	0.25	0.333	0.5	1	1
Eastern Europe	wind_storage	0	0	0	0.25	0.333	0.5	1	1	1
Korea	wind_storage	0	0	0	0.25	0.333	0.5	1	1	1
Canada	wind_storage	0	0	0	1	1	1	1	1	1
Western Europe	wind_storage	0	0	0	1	1	1	1	1	1
Japan	wind_storage	0	0	0	1	1	1	1	1	1
Australia_NZ	wind_storage	0	0	0	1	1	1	1	1	1
USA	wind_storage	0	0	0	1	1	1	1	1	1
USA	Gen_III	0	0	0	1	1	1	1	1	1
Canada	Gen_III	0	0	0	1	1	1	1	1	1
Western Europe	Gen_III	0	0	0	1	1	1	1	1	1
Japan	Gen_III	0	0	0	1	1	1	1	1	1
Australia_NZ	Gen_III	0	0	0	1	1	1	1	1	1
Eastern Europe	Gen_III	0	0	0	0	0.25	0.3	0.5	0.75	1

Korea	Gen_III	0	0	0	0	0.25	0.3	0.5	0.75	1
Former Soviet Union	Gen_III	0	0	0	0	0	0	0.25	0.5	1
China	Gen_III	0	0	0	0	0	0	0.25	0.5	1
Middle East	Gen_III	0	0	0	0	0	0	0.25	0.5	1
Africa	Gen_III	0	0	0	0	0	0	0.25	0.5	1
Latin America	Gen_III	0	0	0	0	0	0	0.25	0.5	1
Southeast Asia	Gen_III	0	0	0	0	0	0	0.25	0.5	1
India	Gen_III	0	0	0	0	0	0	0.25	0.5	1

MODIFIED SOCIO-ECON FILE FOR "HIGH GDP SCENARIO"

Population
INPUT_TABLE
Variable ID
10

	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop
region	1975	1990	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095
Africa	412028	630697	919484	1032840	1134742	1225761	1319913	1404323	1493557	1559406	1630097	1683839	1755813	1809448	1864499	1893855	1922680	1937867	1948830	1944503	1928285
Australia_I	16909	20532	24548	25835	27057	28226	29387	30430	31400	32164	32819	33278	33647	33809	33832	33652	33363	32961	32509	32029	31592
Canada	23139	27698	32318	33896	35040	35934	36799	37386	37910	38126	38344	38425	38630	38755	38938	39070	39283	39521	39813	40094	40343
China	980561	1223291	1426771	1469426	1511917	1544737	1564310	1574451	1574778	1564877	1548112	1523878	1500563	1473884	1449614	1422749	1399717	1376916	1355263	1328750	1293598
Eastern Eu	112678	122883	119100	118410	117147	115835	114477	112907	110998	109156	106905	104655	101539	98436	94866	91661	88225	85111	82267	80347	79646
Former Sov	254228	289091	284342	283390	283487	284059	284080	284395	283991	284128	283238	282204	279466	276550	272704	269095	264977	261167	257763	255727	255638
India	606142	849515	1094583	1214464	1291722	1352178	1412225	1456108	1494751	1521585	1544450	1561583	1569149	1569662	1559181	1544504	1519125	1487947	1449540	1411441	1377394
Japan	111469	123478	127773	126995	126369	125521	124121	122841	121335	120020	118428	116732	114698	112501	110071	107461	104726	101995	99478	97414	96155
Korea	35278	42869	48138	48501	48866	48896	48574	48264	47965	47528	47119	46495	46156	45559	45025	44054	43149	42102	41194	40297	39629
Latin Amer	319222	436676	549919	584391	619954	654891	686786	717081	743913	770226	793205	815184	833139	850658	866087	881779	895362	907541	916824	923083	924592
Middle Eas	76657	131495	188106	210542	232198	253011	273172	292929	312247	330563	347974	363789	378471	390958	401515	409339	415117	418699	420752	421589	422203
Southeast /	474445	666169	875769	955566	1033074	1108389	1180396	1247683	1308968	1364412	1412063	1452295	1482438	1504280	1516383	1520705	1515847	1503409	1483694	1458934	1430679
USA	215079	250181	299730	321704	336265	349627	365110	379007	393314	407363	421860	437135	450656	464450	476574	489725	501034	512070	521816	532323	544015
Western Eu	402474	434467	473526	485073	490863	493372	496156	495666	495146	489924	485052	477411	471984	464058	456467	446389	437248	428119	420708	414689	411450

Labor Force Participation Rate
INPUT_TABLE
Variable ID
20

	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce
region	1975	1990	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095
Africa	0.425	0.44	0.419	0.434	0.446	0.457	0.466	0.475	0.48	0.491	0.497	0.505	0.502	0.5	0.491	0.486	0.475	0.464	0.452	0.446	0.446
Australia_I	0.446	0.499	0.51	0.508	0.5	0.491	0.48	0.472	0.464	0.462	0.46	0.46	0.458	0.458	0.455	0.454	0.449	0.445	0.44	0.437	0.44
Canada	0.453	0.542	0.527	0.533	0.53	0.524	0.514	0.503	0.491	0.482	0.472	0.466	0.456	0.449	0.44	0.434	0.427	0.42	0.413	0.408	0.406
China	0.522	0.574	0.609	0.609	0.614	0.62	0.62	0.615	0.603	0.586	0.564	0.541	0.515	0.493	0.474	0.463	0.457	0.456	0.457	0.457	0.448
Eastern Eu	0.506	0.489	0.515	0.514	0.505	0.493	0.477	0.464	0.45	0.445	0.439	0.44	0.434	0.434	0.43	0.432	0.431	0.43	0.427	0.427	0.43
Former Sov	0.502	0.498	0.515	0.509	0.502	0.493	0.485	0.477	0.47	0.462	0.456	0.45	0.447	0.443	0.44	0.436	0.433	0.43	0.429	0.428	0.43
India	0.432	0.43	0.447	0.458	0.468	0.476	0.483	0.488	0.491	0.492	0.49	0.486	0.482	0.475	0.467	0.457	0.447	0.437	0.428	0.422	0.418
Japan	0.502	0.518	0.525	0.515	0.503	0.489	0.476	0.464	0.453	0.446	0.44	0.437	0.434	0.433	0.433	0.434	0.434	0.435	0.435	0.435	0.435
Korea	0.383	0.458	0.606	0.575	0.547	0.522	0.5	0.481	0.465	0.455	0.446	0.44	0.432	0.427	0.42	0.416	0.41	0.405	0.398	0.394	0.393
Latin Amer	0.347	0.387	0.431	0.436	0.442	0.448	0.45	0.45	0.445	0.441	0.433	0.427	0.416	0.408	0.4	0.397	0.395	0.395	0.395	0.394	0.39
Middle Eas	0.292	0.285	0.311	0.324	0.343	0.364	0.384	0.402	0.415	0.428	0.435	0.441	0.439	0.438	0.433	0.432	0.428	0.427	0.424	0.422	0.419
Southeast /	0.42	0.445	0.463	0.467	0.465	0.459	0.452	0.444	0.437	0.426	0.418	0.408	0.404	0.398	0.394	0.385	0.379	0.371	0.365	0.359	0.355
USA	0.447	0.494	0.508	0.504	0.497	0.489	0.48	0.471	0.462	0.457	0.45	0.447	0.44	0.436	0.431	0.428	0.425	0.422	0.418	0.417	0.416
Western Eu	0.434	0.463	0.471	0.471	0.468	0.464	0.458	0.453	0.445	0.441	0.434	0.429	0.418	0.409	0.396	0.387	0.375	0.365	0.355	0.351	0.354

Labor Productivity Growth Rate
INPUT_TABLE
Variable ID
30

			1990-2005	2005-2010																	
	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu
region	1975	1990	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095
Africa	0	-0.00415	0.00911	0.01201	0.01423	0.01433	0.01433	0.01331	0.01438	0.01446	0.01834	0.02176	0.02818	0.0319	0.03598	0.03762	0.03916	0.03904	0.03827	0.03651	0.03433
Australia_I	0	0.00621	0.02286	0.00922	0.01863	0.01869	0.01846	0.01764	0.01708	0.01598	0.01563	0.01502	0.01525	0.01494	0.01511	0.01492	0.01516	0.01519	0.01528	0.0151	0.01482
Canada	0	0.00659	0.01934	-0.00466	0.01884	0.01768	0.01735	0.01762	0.01798	0.01858	0.01885	0.01912	0.01901	0.019	0.01877	0.01863	0.01835	0.01817	0.01804	0.01806	0.01821
China	0	0.05924	0.08354	0.08401	0.06837	0.05883	0.05438	0.05163	0.05	0.04815	0.04669	0.04483	0.04311	0.04096	0.03887	0.03659	0.03442	0.03217	0.02995	0.02769	0.02541
Eastern Eu	0	0.01015	0.02302	0.02833	0.04088	0.03887	0.03529	0.03512	0.03297	0.03521	0.03329	0.03396	0.03111	0.03174	0.03062	0.03117	0.03002	0.02957	0.02869	0.02826	0.02768
Former Sov	0	0.00075	-0.00726	0.03192	0.04088	0.03887	0.03529	0.03512	0.03297	0.03521	0.03329	0.03396	0.03111	0.03174	0.03062	0.03117	0.03002	0.02957	0.02869	0.02826	0.02768
India	0	0.0258	0.03944	0.0465	0.05048	0.04989	0.04901	0.04807	0.04714	0.04625	0.04538	0.04452	0.04365	0.04276	0.04187	0.04096	0.04004	0.03912	0.03819	0.03728	0.03638
Japan	0	0.03169	0.00968	-0.0005	0.01779	0.0186	0.01909	0.01877	0.01858	0.01757	0.01725	0.01646	0.01649	0.01583	0.01565	0.01507	0.01501	0.01479	0.01474	0.01456	0.01444
Korea	0	0.05457	0.03082	0.03339	0.02651	0.02628	0.02574	0.02514	0.02451	0.02402	0.02351	0.02314	0.02276	0.02251	0.02225	0.02206	0.02184	0.02163	0.02138	0.02113	0.02084

Latin Amer	0	-0.00304	0.00952	0.016	0.01425	0.01729	0.01828	0.01943	0.01997	0.02211	0.02331	0.0256	0.02668	0.02886	0.03006	0.03141	0.03162	0.03156	0.03087	0.02993	0.02857
Middle Eas	0	-0.02257	0.01068	0.01095	0.01064	0.0103	0.01015	0.01105	0.0118	0.01393	0.01505	0.01694	0.01749	0.01908	0.01978	0.02094	0.02113	0.02139	0.02123	0.0211	0.02074
Southeast /	0	0.03977	0.0281	0.01518	0.04722	0.04806	0.04534	0.04416	0.04182	0.04228	0.04063	0.04058	0.03881	0.03884	0.03794	0.03774	0.03664	0.03577	0.03462	0.03358	0.03243
USA	0	0.01674	0.01712	-0.00194	0.01882	0.01802	0.01728	0.01702	0.01667	0.01694	0.01677	0.017	0.01671	0.01696	0.01692	0.01719	0.01711	0.01716	0.01708	0.01708	0.01703
Western Eu	0	0.01709	0.01478	-0.00153	0.01596	0.01721	0.01746	0.01684	0.0167	0.01612	0.0168	0.01732	0.01897	0.01981	0.02092	0.02117	0.02139	0.02074	0.01952	0.01736	0.01434

Price elasticity of GDP
INPUT_TABLE
Variable ID
40

	e_GDP_elas
region	1975
Africa	0
Australia_N	0
Canada	0
China	0
Eastern Eu	0
Former Sov	0
India	0
Japan	0
Korea	0
Latin Amer	0
Middle Eas	0
Southeast /	0
USA	0
Western Eu	0

Base GDP
INPUT_TABLE
Variable ID
50

	baseGDP
region	1975
Africa	250238
Australia_N	174747
Canada	278868
China	118793
Eastern Eu	232364
Former Sov	410608
India	106889
Japan	1830703
Korea	71339
Latin Amer	814694
Middle Eas	298287
Southeast /	222332
USA	3473912
Western Eu	3802404

MODIFIED SOCIO-ECON FILE FOR "HIGH POPULATION SCENARIO"

Population
INPUT_TABLE
Variable ID

10																					
	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop
region	1975	1990	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095
Africa	418765	638729	921073	1033043	1162940	1303919	1452274	1604027	1760929	1924730	2094651	2267483	2440517	2606926	2767958	2924152	3074359	3216382	3349234	3473039	3588334
Australia_NZ	16743	20512	24542	25853	27358	28967	30616	32166	33628	35083	36616	38248	39988	41618	43209	44821	46490	48206	49912	51557	53135
Canada	23148	27707	32313	33896	35786	37864	39997	41982	43804	45593	47479	49521	51745	53851	55864	57859	59893	61988	64087	66123	68068
China	984012	1240759	1436760	1485468	1547998	1611180	1663766	1701131	1730081	1757868	1784749	1806201	1823555	1836118	1850121	1868091	1888280	1910839	1935871	1964846	1998099
Eastern Europe	112197	122167	119082	118409	118600	119047	119161	118593	117769	117159	116953	116955	116983	116705	116456	116582	117203	118372	119960	121872	124072
Former Soviet Unior	254445	288827	284833	283391	285962	289410	291894	292867	293882	296109	299505	303147	306780	309615	312733	316789	321884	327641	333771	340229	347060
India	617432	862162	1130618	1214464	1306485	1400175	1490916	1572055	1646717	1721445	1795324	1865353	1932896	1992321	2046114	2095683	2141075	2181932	2218788	2252779	2284622
Japan	111619	123191	127449	126995	126721	125939	124619	122725	120499	118152	115979	114161	113153	111924	110727	109753	109242	109375	110038	111073	112381
Korea	34721	42983	47566	48501	49592	50576	51360	51744	51714	51312	50662	49915	49223	48489	47769	47133	46679	46472	46530	46830	47281
Latin America	320439	438842	552663	584716	620507	657380	693788	727012	757820	786839	814581	840502	865466	888543	910113	930780	951018	971042	990936	1010804	1031147
Middle East	79426	135816	193881	214951	237539	261765	286332	309842	333148	356660	380326	403364	425486	445919	465016	483189	500838	518066	534796	551052	566630
Southeast Asia	464088	656919	863178	932169	1010594	1092630	1175518	1254892	1331651	1407913	1484576	1559839	1633191	1700875	1764571	1825897	1885952	1944513	2000842	2054662	2106248
USA	222047	258393	306653	321639	339190	357665	376099	393217	409429	425561	442385	460319	479433	497996	516230	534512	552966	571326	589066	605720	621137
Western Europe	402236	433444	471664	485193	499729	514131	527885	539919	550864	561782	573500	586078	599782	612160	624233	637270	652021	668437	685761	703158	720233

Labor Force Participation Rate
INPUT_TABLE
Variable ID

20																					
	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce
region	1975	1990	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095
Africa	0.425	0.44	0.419	0.434	0.446	0.457	0.466	0.475	0.48	0.491	0.497	0.505	0.502	0.5	0.491	0.486	0.475	0.464	0.452	0.446	0.446
Australia_NZ	0.446	0.499	0.51	0.508	0.5	0.491	0.48	0.472	0.464	0.462	0.46	0.46	0.458	0.458	0.455	0.454	0.449	0.445	0.44	0.437	0.44
Canada	0.453	0.542	0.527	0.533	0.53	0.524	0.514	0.503	0.491	0.482	0.472	0.466	0.456	0.449	0.44	0.434	0.427	0.42	0.413	0.408	0.406
China	0.522	0.574	0.609	0.609	0.614	0.62	0.62	0.615	0.603	0.586	0.564	0.541	0.515	0.493	0.474	0.463	0.457	0.456	0.457	0.457	0.448
Eastern Europe	0.506	0.489	0.515	0.514	0.505	0.493	0.477	0.464	0.45	0.445	0.439	0.44	0.434	0.434	0.43	0.432	0.431	0.43	0.427	0.427	0.43
Former Soviet Unior	0.502	0.498	0.515	0.509	0.502	0.493	0.485	0.477	0.47	0.462	0.456	0.45	0.447	0.443	0.44	0.436	0.433	0.43	0.429	0.428	0.43
India	0.432	0.43	0.447	0.458	0.468	0.476	0.483	0.488	0.491	0.492	0.49	0.486	0.482	0.475	0.467	0.457	0.447	0.437	0.428	0.422	0.418
Japan	0.502	0.518	0.525	0.515	0.503	0.489	0.476	0.464	0.453	0.446	0.44	0.437	0.434	0.433	0.433	0.434	0.434	0.435	0.435	0.435	0.435
Korea	0.383	0.458	0.606	0.575	0.547	0.522	0.5	0.481	0.465	0.455	0.446	0.44	0.432	0.427	0.42	0.416	0.41	0.405	0.398	0.394	0.393
Latin America	0.347	0.387	0.431	0.436	0.442	0.448	0.45	0.45	0.445	0.441	0.433	0.427	0.416	0.408	0.4	0.397	0.395	0.395	0.395	0.394	0.39
Middle East	0.292	0.285	0.311	0.324	0.343	0.364	0.384	0.402	0.415	0.428	0.435	0.441	0.439	0.438	0.433	0.432	0.428	0.427	0.424	0.422	0.419
Southeast Asia	0.42	0.445	0.463	0.467	0.465	0.459	0.452	0.444	0.437	0.426	0.418	0.408	0.404	0.398	0.394	0.385	0.379	0.371	0.365	0.359	0.355
USA	0.447	0.494	0.508	0.504	0.497	0.489	0.48	0.471	0.462	0.457	0.45	0.447	0.44	0.436	0.431	0.428	0.425	0.422	0.418	0.417	0.416
Western Europe	0.434	0.463	0.471	0.471	0.468	0.464	0.458	0.453	0.445	0.441	0.434	0.429	0.418	0.409	0.396	0.387	0.375	0.365	0.355	0.351	0.354

Labor Productivity Growth Rate
INPUT_TABLE
Variable ID

30			1990-2005	2005-2010																	
	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborproductivity
region	1975	1990	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095
Africa	0	-0.00415	0.00911	0.01201	0.01223	0.01233	0.01233	0.01131	0.01238	0.01246	0.01634	0.01976	0.02618	0.0299	0.03398	0.03562	0.03716	0.03704	0.03627	0.03451	0.03233
Australia_NZ	0	0.00621	0.02286	0.00922	0.01663	0.01669	0.01646	0.01564	0.01508	0.01398	0.01363	0.01302	0.01325	0.01294	0.01311	0.01292	0.01316	0.01319	0.01328	0.0131	0.01282
Canada	0	0.00659	0.01934	-0.00466	0.01684	0.01568	0.01535	0.01562	0.01598	0.01658	0.01685	0.01712	0.01701	0.017	0.01677	0.01663	0.01635	0.01617	0.01604	0.01606	0.01621
China	0	0.05924	0.08354	0.08401	0.06637	0.05683	0.05238	0.04963	0.048	0.04615	0.04469	0.04283	0.04111	0.03896	0.03687	0.03459	0.03242	0.03017	0.02795	0.02569	0.02341
Eastern Europe	0	0.01015	0.02302	0.02833	0.03888	0.03687	0.03329	0.03312	0.03097	0.03321	0.03129	0.03196	0.02911	0.02974	0.02862	0.02917	0.02802	0.02757	0.02669	0.02626	0.02568
Former Soviet Unior	0	0.00075	-0.00726	0.03192	0.03888	0.03687	0.03329	0.03312	0.03097	0.03321	0.03129	0.03196	0.02911	0.02974	0.02862	0.02917	0.02802	0.02757	0.02669	0.02626	0.02568
India	0	0.0258	0.03944	0.0465	0.04848	0.04789	0.04701	0.04607	0.04514	0.04425	0.04338	0.04252	0.04165	0.04076	0.03987	0.03896	0.03804	0.03712	0.03619	0.03528	0.03438
Japan	0	0.03169	0.00968	-0.0005	0.01579	0.0166	0.01709	0.01677	0.01658	0.01557	0.01525	0.01446	0.01449	0.01383	0.01365	0.01307	0.01301	0.01279	0.01274	0.01256	0.01244
Korea	0	0.05457	0.03082	0.03339	0.02451	0.02428	0.02374	0.02314	0.02251	0.02202	0.02151	0.02114	0.02076	0.02051	0.02025	0.02006	0.01984	0.01963	0.01938	0.01913	0.01884
Latin America	0	-0.00304	0.00952	0.016	0.01225	0.01529	0.01628	0.01743	0.01797	0.02011	0.02131	0.0236	0.02468	0.02686	0.02806	0.02941	0.02962	0.02956	0.02887	0.02793	0.02657
Middle East	0	-0.02257	0.01068	0.01095	0.00864	0.0083	0.00815	0.00905	0.0098	0.01193	0.01305	0.01494	0.01549	0.01708	0.01778	0.01894	0.01913	0.01939	0.01923	0.0191	0.01874
Southeast Asia	0	0.03977	0.0281	0.01518	0.04522	0.04606	0.04334	0.04216	0.03982	0.04028	0.03863	0.03858	0.03681	0.03684	0.03594	0.03574	0.03464	0.03377	0.03262	0.03158	0.03043
USA	0	0.01674	0.01712	-0.00194	0.01682	0.01602	0.01528	0.01502	0.01467	0.01494	0.01477	0.015	0.01471	0.01496	0.01492	0.01519	0.01511	0.01516	0.01508	0.01508	0.01503
Western Europe	0	0.01709	0.01478	-0.00153	0.01396	0.01521	0.01546	0.01484	0.0147	0.01412	0.0148	0.01532	0.01697	0.01781	0.01892	0.01917	0.01939	0.01874	0.01752	0.01536	0.01234

Price elasticity of GDP

INPUT_TABLE
Variable ID

	40
	e_GDP_elas
region	1975
Africa	0
Australia_NZ	0
Canada	0
China	0
Eastern Europe	0
Former Soviet Unior	0
India	0
Japan	0
Korea	0
Latin America	0
Middle East	0
Southeast Asia	0
USA	0
Western Europe	0

Base GDP
INPUT_TABLE
Variable ID

	50
	baseGDP
region	1975
Africa	250238
Australia_NZ	174747
Canada	278868
China	118793
Eastern Europe	232364
Former Soviet Unior	410608
India	106889
Japan	1830703
Korea	71339
Latin America	814694
Middle East	298287
Southeast Asia	222332
USA	3473912
Western Europe	3802404

MODIFIED SOCIO-ECON FILE FOR "LOW CONVERGENCE SCENARIO"

Population
INPUT_TABLE
Variable ID
10

	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop	totalPop
region	1975	1990	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095
Africa	412028	630697	919484	1032840	1134742	1225761	1319913	1404323	1493557	1559406	1630097	1683839	1755813	1809448	1864499	1893855	1922680	1937867	1948830	1944503	1928285
Australia_NZ	16909	20532	24548	25835	27057	28226	29387	30430	31400	32164	32819	33278	33647	33809	33832	33652	33363	32961	32509	32029	31592
Canada	23139	27698	32318	33896	35040	35934	36799	37386	37910	38126	38344	38425	38630	38755	38938	39070	39283	39521	39813	40094	40343
China	980561	1223291	1426771	1469426	1511917	1544737	1564310	1574451	1574778	1564877	1548112	1523878	1500563	1473884	1449614	1422749	1399717	1376916	1355263	1328750	1293598
Eastern Europe	112678	122883	119100	118410	117147	115835	114477	112907	110998	109156	106905	104655	101539	98436	94866	91661	88225	85111	82267	80347	79646
Former Soviet Unio	254228	289091	284342	283390	283487	284059	284080	284395	283991	284128	283238	282204	279466	276550	272704	269095	264977	261167	257763	255727	255638
India	606142	849515	1094583	1214464	1291722	1352178	1412225	1456108	1494751	1521585	1544450	1561583	1569149	1569662	1559181	1544504	1519125	1487947	1449540	1411441	1377394
Japan	111469	123478	127773	126995	126369	125521	124121	122841	121335	120020	118428	116732	114698	112501	110071	107461	104726	101995	99478	97414	96155
Korea	35278	42869	48138	48501	48866	48896	48574	48264	47965	47528	47119	46495	46156	45559	45025	44054	43149	42102	41194	40297	39629
Latin America	319222	436676	549919	584391	619954	654891	686786	717081	743913	770226	793205	815184	833139	850658	866087	881779	895362	907541	916824	923083	924592
Middle East	76657	131495	188106	210542	232198	253011	273172	292929	312247	330563	347974	363789	378471	390958	401515	409339	415117	418699	420752	421589	422203
Southeast Asia	474445	666169	875769	955566	1033074	1108389	1180396	1247683	1308968	1364412	1412063	1452295	1482438	1504280	1516383	1520705	1515847	1503409	1483694	1458934	1430679
USA	215079	250181	299730	321704	336265	349627	365110	379007	393314	407363	421860	437135	450656	464450	476574	489725	501034	512070	521816	532323	544015
Western Europe	402474	434467	473526	485073	490863	493372	496156	495666	495146	489924	485052	477411	471984	464058	456467	446389	437248	428119	420708	414689	411450

Labor Force Participation Rate
INPUT_TABLE
Variable ID
20

	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce	laborforce
region	1975	1990	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095
Africa	0.425	0.44	0.419	0.434	0.446	0.457	0.466	0.475	0.48	0.491	0.497	0.505	0.502	0.5	0.491	0.486	0.475	0.464	0.452	0.446	0.446
Australia_NZ	0.446	0.499	0.51	0.508	0.5	0.491	0.48	0.472	0.464	0.462	0.46	0.46	0.458	0.458	0.455	0.454	0.449	0.445	0.44	0.437	0.44
Canada	0.453	0.542	0.527	0.533	0.53	0.524	0.514	0.503	0.491	0.482	0.472	0.466	0.456	0.449	0.44	0.434	0.427	0.42	0.413	0.408	0.406
China	0.522	0.574	0.609	0.609	0.614	0.62	0.62	0.615	0.603	0.586	0.564	0.541	0.515	0.493	0.474	0.463	0.457	0.456	0.457	0.457	0.448
Eastern Europe	0.506	0.489	0.515	0.514	0.505	0.493	0.477	0.464	0.45	0.445	0.439	0.44	0.434	0.434	0.43	0.432	0.431	0.43	0.427	0.427	0.43
Former Soviet Unio	0.502	0.498	0.515	0.509	0.502	0.493	0.485	0.477	0.47	0.462	0.456	0.45	0.447	0.443	0.44	0.436	0.433	0.43	0.429	0.428	0.43
India	0.432	0.43	0.447	0.458	0.468	0.476	0.483	0.488	0.491	0.492	0.49	0.486	0.482	0.475	0.467	0.457	0.447	0.437	0.428	0.422	0.418
Japan	0.502	0.518	0.525	0.515	0.503	0.489	0.476	0.464	0.453	0.446	0.44	0.437	0.434	0.433	0.433	0.434	0.434	0.435	0.435	0.435	0.435
Korea	0.383	0.458	0.606	0.575	0.547	0.522	0.5	0.481	0.465	0.455	0.446	0.44	0.432	0.427	0.42	0.416	0.41	0.405	0.398	0.394	0.393
Latin America	0.347	0.387	0.431	0.436	0.442	0.448	0.45	0.45	0.445	0.441	0.433	0.427	0.416	0.408	0.4	0.397	0.395	0.395	0.395	0.394	0.39
Middle East	0.292	0.285	0.311	0.324	0.343	0.364	0.384	0.402	0.415	0.428	0.435	0.441	0.439	0.438	0.433	0.432	0.428	0.427	0.424	0.422	0.419
Southeast Asia	0.42	0.445	0.463	0.467	0.465	0.459	0.452	0.444	0.437	0.426	0.418	0.408	0.404	0.398	0.394	0.385	0.379	0.371	0.365	0.359	0.355
USA	0.447	0.494	0.508	0.504	0.497	0.489	0.48	0.471	0.462	0.457	0.45	0.447	0.44	0.436	0.431	0.428	0.425	0.422	0.418	0.417	0.416
Western Europe	0.434	0.463	0.471	0.471	0.468	0.464	0.458	0.453	0.445	0.441	0.434	0.429	0.418	0.409	0.396	0.387	0.375	0.365	0.355	0.351	0.354

Labor Productivity Growth Rate
INPUT_TABLE
Variable ID
30

			1990-2005	2005-2010																	
	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu	laborprodu
region	1975	1990	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095
Africa	0	-0.00415	0.00911	0.01201	0.01223	0.01233	0.01233	0.01131	0.01238	0.01246	0.0148	0.01532	0.01697	0.01781	0.01892	0.01917	0.01939	0.01874	0.01752	0.01536	0.01503
Australia_NZ	0	0.00621	0.02286	0.00922	0.01663	0.01669	0.01646	0.01564	0.01508	0.01398	0.01363	0.01302	0.01325	0.01294	0.01311	0.01292	0.01316	0.01319	0.01328	0.0131	0.01282
Canada	0	0.00659	0.01934	-0.00466	0.01684	0.01568	0.01535	0.01562	0.01598	0.01658	0.01685	0.01712	0.01701	0.017	0.01677	0.01663	0.01635	0.01617	0.01604	0.01606	0.01621
China	0	0.05924	0.08354	0.08401	0.064	0.052	0.048	0.046	0.045	0.043	0.042	0.04	0.038	0.032	0.03	0.03	0.028	0.02	0.02	0.02	0.02
Eastern Europe	0	0.01015	0.02302	0.02833	0.032	0.02428	0.02374	0.02314	0.02251	0.02202	0.02151	0.02114	0.02076	0.02051	0.02025	0.02006	0.01984	0.01963	0.01938	0.01913	0.01884
Former Soviet Unio	0	0.00075	-0.00726	0.03192	0.035	0.02428	0.02374	0.02314	0.02251	0.02202	0.02151	0.02114	0.02076	0.02051	0.02025	0.02006	0.01984	0.01963	0.01938	0.01913	0.01884
India	0	0.0258	0.03944	0.0465	0.04848	0.04789	0.04701	0.04607	0.04514	0.04425	0.04338	0.04252	0.038	0.032	0.03	0.03	0.028	0.02	0.02	0.02	0.02
Japan	0	0.03169	0.00968	-0.0005	0.01579	0.0166	0.01709	0.01677	0.01658	0.01557	0.01525	0.01446	0.01449	0.01383	0.01365	0.01307	0.01301	0.01279	0.01274	0.01256	0.01244
Korea	0	0.05457	0.03082	0.03339	0.02451	0.02428	0.02374	0.02314	0.02251	0.02202	0.02151	0.02114	0.02076	0.02051	0.02025	0.02006	0.01984	0.01963	0.01938	0.01913	0.01884
Latin America	0	-0.00304	0.00952	0.016	0.01225	0.01529	0.01546	0.01484	0.0147	0.01412	0.0148	0.01532	0.01697	0.01781	0.01892	0.01917	0.01939	0.01874	0.01752	0.01536	0.01503
Middle East	0	-0.02257	0.01068	0.01095	0.00864	0.0083	0.00815	0.00905	0.0098	0.01193	0.01305	0.01494	0.01549	0.01708	0.01778	0.01894	0.01913	0.01939	0.01752	0.01536	0.01234

Southeast Asia	0	0.03977	0.0281	0.01518	0.03	0.02428	0.02374	0.02314	0.02251	0.02202	0.02151	0.02114	0.02076	0.02051	0.02025	0.02006	0.01984	0.01963	0.01938	0.01913	0.01884
USA	0	0.01674	0.01712	-0.00194	0.01682	0.01602	0.01528	0.01502	0.01467	0.01494	0.01477	0.015	0.01471	0.01496	0.01492	0.01519	0.01511	0.01516	0.01508	0.01508	0.01503
Western Europe	0	0.01709	0.01478	-0.00153	0.01396	0.01521	0.01546	0.01484	0.0147	0.01412	0.0148	0.01532	0.01697	0.01781	0.01892	0.01917	0.01939	0.01874	0.01752	0.01536	0.01234

Price elasticity of GDP
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40

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Canada	0
China	0
Eastern Europe	0
Former Soviet Unio	0
India	0
Japan	0
Korea	0
Latin America	0
Middle East	0
Southeast Asia	0
USA	0
Western Europe	0

Base GDP
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Variable ID
50

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Africa	250238
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Canada	278868
China	118793
Eastern Europe	232364
Former Soviet Unio	410608
India	106889
Japan	1830703
Korea	71339
Latin America	814694
Middle East	298287
Southeast Asia	222332
USA	3473912
Western Europe	3802404

Appendix C -- GCAM Results Data from new GCAM scenarios

GCAM Results: Regional CO2 Emissions (Million Tons Carbon)

China	2015	2020	2025	2030	2035	2040	2045	2050	2060	2070	2075	2080	2085	2090	2095
PolicyElecNucDelay	2644	2354	2396	2470	2532	2291	1930	1566	591	342	175	38	-66	-126	-173
PolicyElecNucTransDelay	2644	2353	2394	2467	2527	2283	1916	1550	601	350	181	44	-61	-123	-171
PolicyElecNucTransReLiqudDela	2644	2353	2396	2473	2543	2316	1984	1695	748	436	253	97	-26	-117	-207
Reference	2594	3073	3508	3905	4262	4533	4759	4944	5194	5280	5277	5239	5191	5091	4839
NewReference_Policy	2594	2299	2278	2258	2209	1803	1379	1004	730	464	327	184	70	-25	-94

USA	2015	2020	2025	2030	2035	2040	2045	2050	2060	2070	2075	2080	2085	2090	2095
PolicyElecNucDelay	1736	1555	1382	1227	1079	779	561	326	387	325	263	201	147	85	0
PolicyElecNucTransDelay	1736	1554	1380	1224	1074	774	556	321	386	324	262	200	146	82	-9
PolicyElecNucTransReLiqudDela	1736	1553	1374	1206	1038	698	395	-28	124	106	71	39	20	-3	-34
Reference	1736	1768	1807	1833	1861	1885	1904	1943	1990	2022	2036	2047	2070	2095	2123
NewReference_Policy	1736	1565	1463	1370	1291	1069	863	660	516	355	273	180	108	46	-43

GCAM Results: Global CO2 Emissions (Million Tons Carbon)

Scenario	2015	2020	2025	2030	2035	2040	2045	2050	2060	2070	2080	2085	2090	2095
Policy	9,932	8,982	8,878	8,774	8,670	7,611	6,553	5,494	4,775	3,836	2,675	2,250	1,825	1,400
Low_Conv	9,827	10,775	11,691	12,564	13,453	14,212	14,933	15,674	16,593	17,128	17,339	17,346	17,286	17,105
Reference	9,896	10,994	12,067	13,120	14,200	15,176	16,129	17,152	18,778	20,153	21,258	21,664	21,978	22,145
High_GDP	9,955	11,128	12,286	13,435	14,628	15,718	16,795	17,957	19,839	21,466	22,782	23,266	23,669	24,148
High_Population	9,939	11,212	12,485	13,754	15,085	16,411	17,806	19,389	22,284	25,248	28,377	29,969	32,152	33,643

GCAM Results: Regional CO2 Emissions (Million Tons Carbon)

High Income Countries

	2015	2020	2025	2030	2035	2040	2045	2050	2060	2070	2080	2085	2090	2095
PolicyElecNucDelay	3915	3472	3148	2836	2513	1840	1352	890	1072	965	765	672	571	483
PolicyElecNucTransDelay	3914	3471	3144	2830	2504	1830	1343	881	1071	963	763	668	567	479
PolicyElecNucTransReLiq	3914	3468	3133	2793	2423	1661	1026	269	651	672	518	475	436	460
Reference	3910	4006	4095	4164	4245	4317	4376	4479	4592	4637	4648	4654	4665	4703
NewReference_Policy	3910	3479	3289	3116	2950	2484	2050	1627	1338	1034	751	634	533	434

Low & Middle Income Countries

	2015	2020	2025	2030	2035	2040	2045	2050	2060	2070	2080	2085	2090	2095
PolicyElecNucDelay	6017	5510	5730	5938	6157	5771	5201	4604	3703	2871	1910	1578	1254	917
PolicyElecNucTransDelay	6015	5511	5733	5944	6166	5782	5210	4613	3704	2872	1912	1582	1258	921
PolicyElecNucTransReLiq	6015	5514	5745	5981	6247	5949	5527	5225	4124	3164	2157	1775	1389	940
Reference	5986	6988	7972	8955	9955	10859	11753	12673	14186	15516	16610	17010	17313	17441
NewReference_Policy	5986	5503	5589	5657	5720	5127	4503	3867	3437	2802	1924	1616	1291	966

GCAM Results: Global Primary Energy (EJ)

Scenario	2010	2015	2020	2025	2030	2035	2040	2045	2050	2060	2070	2080	2090	2095
Low_Conv_Policy	537	588	595	640	687	735	772	809	844	899	928	941	940	938
Low_Conv	537	588	639	693	746	797	844	889	936	1001	1049	1082	1096	1097
NewReference_Policy	537	592	602	655	712	770	819	864	912	998	1066	1125	1166	1188
PolicyElecNucDelay	537	593	600	647	695	742	767	794	828	973	1062	1130	1181	1208
PolicyElecNucTransDelay	537	593	600	647	695	742	767	793	828	974	1063	1130	1182	1212
PolicyElecNucTransReLiqudDelay	537	593	600	646	692	737	758	781	814	971	1060	1130	1183	1220
High_GDP_Policy	537	595	607	665	727	790	844	894	948	1045	1126	1195	1247	1285
Reference	537	592	650	713	775	837	897	956	1019	1127	1228	1319	1386	1412
High_GDP	537	595	657	724	792	860	926	992	1063	1187	1304	1410	1489	1530
High_Pop_Policy	537	594	611	674	742	812	876	939	1010	1148	1285	1439	1621	1704
High_Population	537	594	662	736	811	887	966	1051	1146	1327	1525	1741	1983	2089

GCAM GDP RESULTS (Million1990US$)

Scenario	Region	2005	2015	2025	2035	2045	2055	2065	2075	2085	2095
High_GDP	Africa	592628	886875	1242670	1661890	2209770	3076440	4461240	6486590	9142000	1.26E+07
High_GDP	Australia_NZ	446803	554358	694812	852442	1033250	1225660	1421230	1605720	1783530	2010680
High_GDP	Canada	666479	779396	944334	1108630	1297530	1525410	1788850	2103530	2467270	2941640
High_GDP	China	1592970	3545740	6424540	1.03E+07	1.51E+07	2.05E+07	2.70E+07	3.56E+07	46854100	5.70E+07
High_GDP	Eastern Europe	409212	554520	736627	941739	1239140	1602590	2016620	2540930	3128090	4018490
High_GDP	Former Soviet Union	427135	593455	826893	1119600	1517150	2021120	2639030	3410950	4380860	5738250
High_GDP	India	522833	1037190	1896310	3248510	5242670	8065880	1.18E+07	1.63E+07	21763900	2.90E+07
High_GDP	Japan	4049050	4179920	4682660	5241810	5905600	6643080	7435500	8232380	9075120	1.01E+07
High_GDP	Korea	538839	663177	778977	914167	1089390	1296900	1534690	1783890	2045200	2391210
High_GDP	Latin America	1919720	2578920	3469360	4516710	5865940	7661970	1.02E+07	1.43E+07	19849700	2.64E+07
High_GDP	Middle East	649161	983950	1434730	1985570	2678250	3486900	4422890	5565920	6900660	8416880
High_GDP	Southeast Asia	1230630	1979910	3470930	5668770	8780370	1.31E+07	1.91E+07	2.65E+07	35284600	4.58E+07
High_GDP	USA	9104140	1.09E+07	1.36E+07	1.66E+07	2.05E+07	2.53E+07	3.11E+07	3.82E+07	46328300	5.69E+07
High_GDP	Western Europe	7801260	8631060	1.01E+07	1.16E+07	1.31E+07	1.46E+07	1.64E+07	1.84E+07	20440400	2.33E+07
High_GDP	Global	29950860	37831571	50311043	65822838	85538960	1.1E+08	1.41E+08	1.81E+08	2.29E+08	2.87E+08
High_Population	Africa	584102	885508	1306040	1835030	2607430	3850690	5849650	8986030	13352000	1.96E+07
High_Population	Australia_NZ	451122	560547	709809	877751	1086740	1346370	1644970	1988120	2385600	2.89E+06
High_Population	Canada	666116	787901	996177	1219050	1499210	1869560	2302560	2821370	3425800	4.20E+06
High_Population	China	1598500	3583890	6618940	1.08E+07	1.62E+07	2.28E+07	3.09E+07	4.23E+07	57767800	7.45E+07
High_Population	Eastern Europe	410904	558409	748103	956173	1272380	1699710	2235150	2989070	3961300	5.33E+06
High_Population	Former Soviet Union	427508	592401	824714	1103040	1498080	2032010	2718500	3650350	4901250	6.60E+06
High_Population	India	530170	1020090	1909950	3349640	5595920	8949920	1.36E+07	1.99E+07	28325500	4.01E+07
High_Population	Japan	4033350	4144970	4558720	4949430	5391620	5990410	6703600	7545920	8648710	1.00E+07
High_Population	Korea	540977	677191	812735	953736	1111460	1286990	1485720	1726770	2026930	2.45E+06
High_Population	Latin America	1921970	2546160	3389800	4363730	5602440	7259240	9623910	1.33E+07	18459800	2.48E+07
High_Population	Middle East	645765	961916	1408910	1945850	2636180	3461460	4435180	5701470	7302350	9.22E+06
High_Population	Southeast Asia	1240000	1961220	3433810	5620080	8824810	1.36E+07	2.05E+07	2.97E+07	42109700	5.85E+07
High_Population	USA	9022130	1.05E+07	1.31E+07	1.60E+07	1.95E+07	2.39E+07	2.92E+07	3.59E+07	43705800	5.33E+07
High_Population	Western Europe	7775180	8705960	1.05E+07	1.23E+07	1.44E+07	1.70E+07	2.02E+07	2.41E+07	28768200	3.46E+07
High_Population	Global	29847794	37496163	50342908	66218910	87233570	1.15E+08	1.51E+08	2.01E+08	2.65E+08	3.46E+08
Low_Conv	Africa	592628	878165	1206410	1581860	2046760	2613570	3256340	3932070	4539050	5.15E+06
Low_Conv	Australia_NZ	446803	548937	674627	811550	964484	1121750	1275340	1412750	1538550	1.70E+06
Low_Conv	Canada	666479	771776	916883	1055440	1211240	1396260	1605540	1851220	2129050	2.49E+06
Low_Conv	China	1592970	3473810	5911660	9031750	1.26E+07	1.63E+07	1.97E+07	2.44E+07	28828800	3.29E+07

Low_Conv	Eastern Europe	409212	531267	621682	712644	830458	959450	1086670	1234180	1383100	1.63E+06
Low_Conv	Former Soviet Union	427135	576881	708065	859620	1031650	1227710	1442850	1680980	1965340	2.36E+06
Low_Conv	India	522833	1027350	1842840	3097150	4903620	7272220	9500670	1.18E+07	13133100	1.49E+07
Low_Conv	Japan	4049050	4139010	4546610	4990470	5512880	6080380	6672850	7243710	7829250	8.57E+06
Low_Conv	Korea	538839	656741	756512	870628	1017410	1187740	1378260	1570990	1766150	2.02E+06
Low_Conv	Latin America	1919720	2553590	3354810	4160950	4983480	5902360	7077350	8745400	10717600	1.24E+07
Low_Conv	Middle East	649161	974253	1392710	1889650	2499060	3190200	3967850	4896340	5902900	6.72E+06
Low_Conv	Southeast Asia	1230630	1822390	2566050	3447650	4412180	5508400	6723450	7877170	9007550	1.02E+07
Low_Conv	USA	9104140	1.08E+07	1.32E+07	1.58E+07	1.92E+07	2.32E+07	2.79E+07	3.36E+07	39970500	4.82E+07
Low_Conv	Western Europe	7801260	8546440	9843660	1.11E+07	1.22E+07	1.34E+07	1.47E+07	1.62E+07	17638600	1.97E+07
Low_Conv	Global	29950860	37257510	47517619	59390862	73358822	89404940	1.06E+08	1.26E+08	1.46E+08	1.69E+08
Reference	Africa	592628	878165	1206410	1581860	2062330	2815650	4004760	5711680	7896200	1.07E+07
Reference	Australia_NZ	446803	548937	674627	811550	964484	1121750	1275340	1412750	1538550	1.70E+06
Reference	Canada	666479	771776	916883	1055440	1211240	1396260	1605540	1851220	2129050	2.49E+06
Reference	China	1592970	3512670	6245180	9848140	1.41E+07	1.89E+07	2.43E+07	3.15E+07	4.06E+07	4.84E+07
Reference	Eastern Europe	409212	549213	715629	897352	1158100	1469020	1813000	2240430	2705010	3.41E+06
Reference	Former Soviet Union	427135	587775	803321	1066830	1417930	1852670	2372560	3007550	3788340	4.87E+06
Reference	India	522833	1027350	1842840	3097150	4903620	7400990	1.06E+07	1.44E+07	1.88E+07	2.46E+07
Reference	Japan	4049050	4139010	4546610	4990470	5512880	6080380	6672850	7243710	7829250	8.57E+06
Reference	Korea	538839	656741	756512	870628	1017410	1187740	1378260	1570990	1766150	2.02E+06
Reference	Latin America	1919720	2553590	3368380	4299980	5476220	7014730	9193280	1.26E+07	1.71E+07	2.23E+07
Reference	Middle East	649161	974253	1392710	1889650	2499060	3190200	3967850	4896340	5952670	7.12E+06
Reference	Southeast Asia	1230630	1961080	3372790	5403760	8210530	1.21E+07	1.72E+07	2.34E+07	3.05E+07	3.89E+07
Reference	USA	9104140	1.08E+07	1.32E+07	1.58E+07	1.92E+07	2.32E+07	2.79E+07	3.36E+07	4.00E+07	4.82E+07
Reference	Western Europe	7801260	8546440	9843660	1.11E+07	1.22E+07	1.34E+07	1.47E+07	1.62E+07	1.76E+07	1.97E+07
Reference	Global	29950860	37463900	48860652	62694310	79907004	1.01E+08	1.27E+08	1.59E+08	1.98E+08	2.43E+08

GCAM Population Results (thousands)

Scenario	Region	2005	2015	2025	2035	2045	2055	2065	2075	2085	2095
Reference	Africa	919484	1134740	1319910	1493560	1630100	1755810	1864500	1922680	1948830	1928290
Reference	China	1426770	1511920	1564310	1574780	1548110	1500560	1449610	1399720	1355260	1293600
Reference	Former Soviet Union	284342	283487	284080	283991	283238	279466	272704	264977	257763	255638
Reference	India	1094580	1291720	1412230	1494750	1544450	1569150	1559180	1519130	1449540	1377390
Reference	Latin America	549919	619954	686786	743913	793205	833139	866087	895362	916824	924592
Reference	Middle East	188106	232198	273172	312247	347974	378471	401515	415117	420752	422203
Reference	Southeast Asia	875769	1033070	1180400	1308970	1412060	1482440	1516380	1515850	1483690	1430680
Reference	MLI	5338970	6107089	6720888	7212211	7559137	7799036	7929976	7932836	7832659	7632393
Reference	Australia_NZ	24548	27057	29387	31400	32819	33647	33832	33363	32509	31592
Reference	Canada	32318	35040	36799	37910	38344	38630	38938	39283	39813	40343
Reference	Eastern Europe	119100	117147	114477	110998	106905	101539	94866	88225	82267	79646
Reference	Japan	127773	126369	124121	121335	118428	114698	110071	104726	99478	96155
Reference	Korea	48138	48866	48574	47965	47119	46156	45025	43149	41194	39629
Reference	USA	299730	336265	365110	393314	421860	450656	476574	501034	521816	544015
Reference	Western Europe	473526	490863	496156	495146	485052	471984	456467	437248	420708	411450
Reference	HI	1125133	1181607	1214624	1238068	1250527	1257310	1255773	1247028	1237785	1242830
Reference	Global	6464103	7288696	7935512	8450279	8809664	9056346	9185749	9179864	9070444	8875223
High_Population	Africa	921073	1162940	1452270	1760930	2094650	2440520	2767960	3074360	3349230	3588330
High_Population	China	1436760	1548000	1663770	1730080	1784750	1823560	1850120	1888280	1935870	1998100
High_Population	Former Soviet Union	284833	285962	291894	293882	299505	306780	312733	321884	333771	347060
High_Population	India	1130620	1306490	1490920	1646720	1795320	1932900	2046110	2141080	2218790	2284620
High_Population	Latin America	552663	620507	693788	757820	814581	865466	910113	951018	990936	1031150
High_Population	Middle East	193881	237539	286332	333148	380326	425486	465016	500838	534796	566630
High_Population	Southeast Asia	863178	1010590	1175520	1331650	1484580	1633190	1764570	1885950	2000840	2106250
High_Population	MLI	5383008	6172028	7054494	7854230	8653712	9427902	10116622	10763410	11364233	11922140
High_Population	Australia_NZ	24542	27358	30616	33628	36616	39988	43209	46490	49912	53135
High_Population	Canada	32313	35786	39997	43804	47479	51745	55864	59893	64087	68068
High_Population	Eastern Europe	119082	118600	119161	117769	116953	116983	116456	117203	119960	124072
High_Population	Japan	127449	126721	124619	120499	115979	113153	110727	109242	110038	112381
High_Population	Korea	47566	49592	51360	51714	50662	49223	47769	46679	46530	47281
High_Population	USA	306653	339190	376099	409429	442385	479433	516230	552966	589066	621137
High_Population	Western Europe	471664	499729	527885	550864	573500	599782	624233	652021	685761	720233
High_Population	HI	1129269	1196976	1269737	1327707	1383574	1450307	1514488	1584494	1665354	1746307
High_Population	Global	6512277	7369004	8324231	9181937	10037286	10878209	11631110	12347904	13029587	13668447

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