GLOBAL ENERGY AND EMISSIONS SCENARIOS[i]

<u>Issue:</u> What central messages can be drawn from review of recent scenarios exploring global energy demand to the year 2100?

Within a range of plausible alternative futures to which energy policy in British Columbia may have to respond, continuing strong growth in global population and income is seen as driving substantial increase in demand for energy services. There is a wide range of possible values for rates of improvement in energy intensity and in carbon intensity. Intense focus on research and policy initiatives that can lead to more rapid reduction in primary energy requirements for energy services and per dollar of output, and on reduction also of carbon intensity, can be anticipated as central in any response to this outlook. There is little consensus as to the actual scale or evolving mix of energy sources that might be considered plausible in the evolution of the global energy system to the end of this century.

Background

This briefing synthesizes the range of projections for global energy demand and carbon emissions across numerous published scenarios for the remainder of this century. It also discusses the assumed changes in the underlying driving forces such as population levels, economic growth, energy intensities and carbon intensities. These are reviewed over three time frames – up to 2020, 2050 and 2100 – reflecting the near-term, mid-term and long-term projections.

These results are drawn primarily from an extensive study reported in a 2006 paper by Nakicenovic and his colleagues at the International Institute for Applied Systems Analysis (IIASA) along with some results on energy intensity and carbon intensity reported in the other papers listed at the end of this note. That report examined over 500 scenarios that explore the current thinking on the long-term outlook for global energy consumption, carbon emissions, and their driving forces. These scenarios include some that envisage active policy intervention and some that do not (the latter referred to here as non-intervention scenarios). They also span the range of scenarios used by Nicholas Stern in the much-discussed Stern Review released last Fall.

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The structure of the global energy system has undergone major transitions over the past two centuries. The energy triangle in Figure-1 offers a useful tool for visualizing these grand transitions.

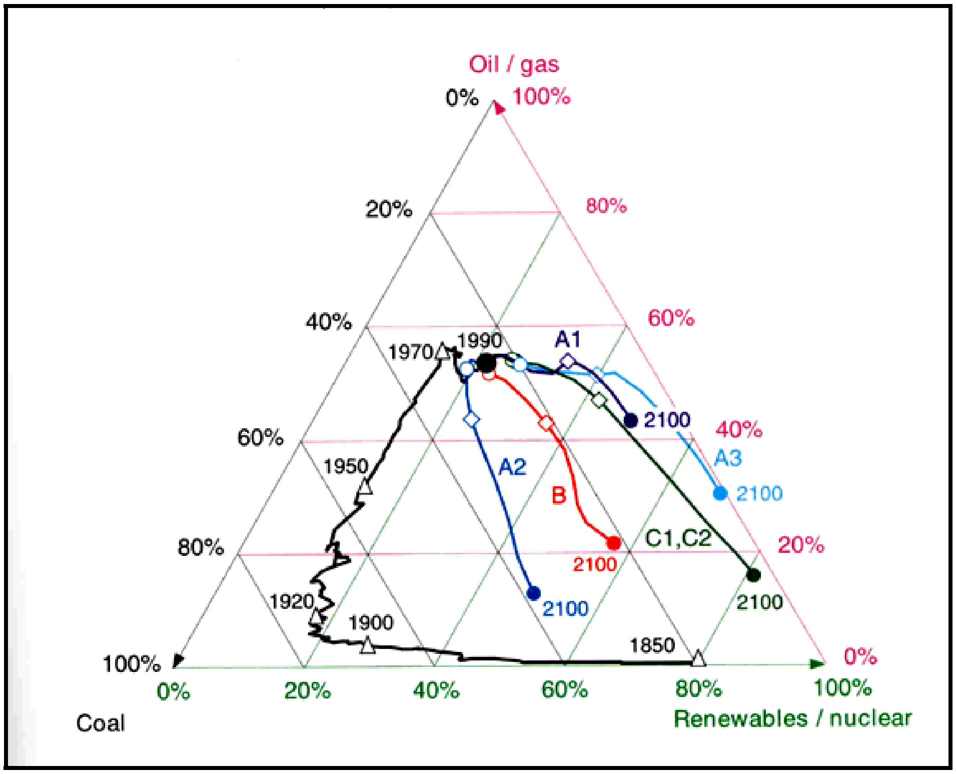

Figure 1: Evolution of Global Primary Energy Structure. (Nakicenovic et al., 1998). *The figure may be interpreted by focusing on the 3 vertices of the triangle, each representing a situation in which one of the 3 kinds of primary energy has a 100% share, with no contributions from the other two. nce the triangle does not have a time dimension, selected points in time are marked on the curves. For example, looking at the end point at 2100 for scenario A1, one sees a projection of roughly 42% oil/gas (reading across the horizontal pink lines to the pink scale), roughly 48% renewables/nuclear (reading down the green diagonals to the green scale), and roughly 10% coal (reading up the black diagonals to the black scale).*

In this diagram, the primary energy structure has evolved clockwise as coal replaced traditional renewable energy between 1850 and 1920, while oil and gas largely replaced coal between 1920 and 1990. Dramatic further change can be anticipated in the period up to the end of the present century. Very different possible pictures of the future role of coal as an energy source might be entertained, for example, depending on the expectations one might have for hydrocarbon supplies and the viability of new technologies for 'clean coal' through carbon management. The end-points at 2100 shown in Figure-1 highlight just five such different pathways for energy system change over the 21st century.

Two qualitative features of these pathways to date and into the future might be noted. The first is the long time scales involved, due to the very long lifetimes of the power plants, refineries, grids, distribution systems and other energy infrastructure and capital. This inertia means that policy decisions made in the next decade or two regarding the orientation of research and development and the turnover of capital will largely dictate our trajectory for the rest of the century. On the other hand, the dramatic structural change observed from 1850 to 2000 suggests that similar transformations are likely over the coming century, also plausibly within the adjustment capacity of the economy and society.

Discussion: Characteristics of Scenarios Reviewed

This section provides a summary of results for global primary energy consumption and associated carbon emissions to 2100, based on a range of projections of the two principal drivers or determinants, population and economic output, for the most recent scenarios published in the literature, since the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (TAR) in 2001. Linking these drivers to energy demand and associated emissions requires assumptions as to trends in energy intensity and carbon intensity; these are reviewed briefly below. The discussion in this section focuses mainly on longer term projections (up to 2100) however the tables below also provide near-term projections to 2020 and mid-term projections to 2050.

It is essential to emphasize that scenarios are not forecasts. One should not attempt to draw conclusions about likely future developments from a review of scenarios. The purpose of scenario exercises is to provoke reflection on feasible institutional or societal responses to alternative possible developments in an uncertain future.

What can be drawn from a review such as that sketched here is a sense of the range of alternative futures that have been considered sufficiently plausible as to warrant exploration. In that sense, the features of the paths described below can be considering as bracketing a likely range of plausible values and indeed identifying some scenarios that must be considered as suggesting implausibly extreme outlying values.

Global Primary Energy Consumption

Historically primary energy consumption has increased at a rate of more than 2% per year since 1900. However, recent scenarios (post-2001) assume growth rates between -0.29 to 1.77 per year, with a median value of 1.2% per year. This drop in overall growth rates, generating a major downward shift in projected levels of primary energy consumption in recent scenarios compared to earlier, reflects more optimistic assumptions as to improvements in energy intensity. As a result there has been a 35% reduction in the upper bound for the primary energy estimates for 2100 – from 3783 EJ in scenarios prior to 2001 compared to approximately 2500 EJ in post-2001 scenarios (see Table-1).

It should be noted that these estimates of primary energy consumption at the end of this century range from 250EJ to 2500EJ, a factor of 10. The lower tail of the distribution of estimates (near the low end at 250EJ) includes relatively few scenarios compared to a long tail at the higher end which consists of more than half the scenarios. As one would expect, those around 800 EJ and lower for 2100 represent mostly intervention scenarios, but the long tail from 1500-2500 EJ includes both intervention and non-intervention scenarios. The median for the entire distribution in 2100 is at 1275 EJ.

Table 1: Global Primary Energy projections for recently published scenarios (post-2001).

Year	**Range [EJ] ***	**Number of Scenarios**	**Distribution**	**Modes [EJ]**
2020	400-1000	178	Asymmetrical	90% between 475-575 EJ
2050	300-1500	159	Bi-modal with long tail at high end	550, 750 (long tail extends to 1500)
2100	250-2500	117	Bi-modal with long tail at high end	800, 1300 (long tail from 1500-2500)

* 1 Exajoule (EJ) is equivalent to 278 Billion Kilowatt Hours, or 160 million barrels of oil

What are the assumptions with respect to the central drivers and intensities—population growth, economic growth, energy intensity and carbon intensity—that give rise to these results? The following sub-sections offer brief summaries.

Global Population Projections

Population is an important driving force of future energy demand and carbon emissions. Most population projections used for the various emissions and mitigation scenarios are taken from one of three main research groups: United Nations, World Bank or IIASA (International Institute for Applied Systems Analysis). An interesting feature of the more recent scenarios is that the upper end of the population projection for 2100 (~ 15 Billion) is markedly lower compared to the highest projections (19 Billion) prior to the publication of the IPCC TAR in 2001. Although a wide range exists for the population distribution both in 2050 and in 2100, as shown in Table-2, the population projections used in the scenarios tend to cluster around certain values, creating multi-modal distributions. Nevertheless the median projection for 2100 (over 117 scenarios) suggests a more than 50% increase from today's population of 6.4 billion.

Despite the large range in global population projections in 2100, the ratio between highest and lowest projections is only about 3.5, compared to 10 for primary energy demand and 20 for global economic output, as discussed later.

Table 2: Global population projections for recently published scenarios (post-2001).

Year	**Range [Billions]**	**Number of Scenarios**	**Distribution**	**Modes [Billions]**	**Median [Billions]**
2020	6.5-9.5	137	Symmetrical	7.6	7.6
2050	6.5-11.5	128	Bi-modal	8-10 (most), ~11	9.2
2100	4-15.5	117	Tri-modal	7, 10-12, ~15 (70% < 11)	10

Global Economic Output

Assumptions about future economic developments are critical to future energy consumption and resulting carbon emissions. However, as far as the variation in projections is concerned, global economic output in 2100 ranges from 25-550 $Trillion (1990 $US, purchasing power parity estimates) displaying the largest factor range of 20, among all major driving forces (Table-3). As we move from 2020 to 2050 the median economic output doubles from 50 to 100 $Trillion, and more than doubles again to 235 $Trillion in 2100.

Table 3: Global economic output projections for recently published scenarios (post-2001).

Year	Range [Trillion 1990 $US]	Number of Scenarios	Distribution	Modes [Trillion 1990 $US]	Median [Trillion 1990 $US]
2020	25-75	209	Symmetrical	50	50
2050	25-165	191	Symmetrical	100	100
2100	25-550	178	Asymmetrical	75% between 200-350 $US	235

Energy intensity

Global Primary Energy intensity of GDP was approximately 16 kJ/US$1990 in 1990. Compared to scenarios prior to 2001 the more recent scenarios demonstrated a shift in assumptions toward more rapid energy intensity improvements. While the range of energy intensity improvements is generally assumed to be 0.7%-1.3% per year up to 2100, a number of notable outliers envisage more than 3% improvements annually, resulting in an assumed reduction of energy intensity of more than 25 fold over the course of this century, to less than 1 kJ/US$1990. By comparison, the hundred year average for energy intensity improvements over the past century has been approximately 1% per year.

Carbon Intensity of Primary Energy

An unintended consequence of energy consumption (especially fossil based) is CO_2 emissions along with a variety of other green house gases (GHGs). Given the increasing concern about such emissions, it is important to consider the treatment of carbon intensities, carbon emissions and carbon policies across the various global energy scenarios.

The overall tendency toward reductions in carbon intensity is a result of the continuous replacement of high carbon content fuels with those of low carbon content. While carbon intensities are expected to decline where policies favour low carbon fuels, scenarios with the most intensive use of fossil fuels lead to practically no reduction in carbon intensities. On the other hand, while the long-term decarbonization rate has been a rather slow 0.3% per year, some of the more recent intervention scenarios that assume decarbonisation rates of 2.5% are based on an assumption of a complete transition in the energy system away from carbon-intensive fossil fuels. For intervention scenarios post-2001 the average rate, however, is only 1.1%, though still much greater than the historical average of 0.3%. This rather slow historical rate of decarbonisation reflects the fact that our present energy system is still fossil intensive, in spite of the changes in the energy mix over the past two centuries (see Figure-1).

An interesting relationship has been demonstrated in the Special Report on Emissions Scenarios (SRES scenarios) prepared for the Third Assessment Report (2001) (TAR) of the Intergovernmental Panel on Climate Change (IPCC) between carbon intensity and energy intensity for various post-SRES stabilization scenarios. The authors of these stabilization scenarios assume that more opportunities will be found to reduce energy intensity in the near term, and more opportunity to shift to non-carbon primary sources after 2050. A regional disaggregation of these results shows that in the first half of the century developing regions make significant advances in energy end-use technologies, thereby improving their energy intensities and hence lowering carbon emissions. By contrast, in the second half of this century developing countries are expected to be able to reduce their carbon emissions more from switching to lower carbon-content fuels than by energy intensity improvements alone.

Global Carbon Emissions

Global CO2 emissions have increased over the past century at a rate of 1.7% annually. If this trend were to continue, global emissions would double within the next three to four decades. While the range around that estimate is quite large, the median emissions path to 2100, over hundreds of scenarios in the literature, indicates a doubling of atmospheric concentrations of CO2 to approximately 750 ppmv as compared to today's 380 ppmv.

Current global carbon emissions are just over 6 GtC. According to Table-4 there is likely to be a substantial increase in global carbon emissions within the next half century toward 10 GtC. However, most long range intervention scenarios expect a reversal of this trend around mid-century as the median emissions level very gradually trends downward thereafter, toward 9 GtC (still 50% above today's levels). It is interesting—and puzzling—to note that with the exception of the few extreme outliers to 80 GtC for some of the non-intervention scenarios, the intervention scenarios maintain the same three modes of 7, 21 and 25 GtC in 2100.

The expected reduction in the median emissions rate toward the end of this century is largely due to the assumed average decarbonisation rate of 0.6% (double the historical average of 0.3% over 150 years). Even so, for atmospheric concentrations to stabilize, net emissions will have to fall well below current levels and asymptotically cease altogether. It is worth noting that while most scenarios in the past focused on reductions of CO_2 only, a large number of newer intervention scenarios explore stabilization by means of reduction in some or all of the greenhouse gases covered under the Kyoto Protocol (namely, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride (SF_6), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs)) . This broader coverage results in relatively less CO2 mitigation envisaged in these scenarios due to their assumed multi-gas flexibility.

Table 4: Global carbon emission projections for recently published scenarios (post-2001).

Year	Range [GtC]	Number of Scenarios	Distribution	Modes [GtC]	Median [GtC]
2020	4-12.7	218	Symmetrical	9	~8.5
2050	6-25	199	Asymmetrical	Most (>97%) between 6-16 GtC	10
2100	0-80	179	Tri-modal	7, 21 and 25 GtC	9

Carbon Policy

Across the recent (post 2001) mitigation scenarios, there is a wide difference in the range of carbon taxes explored. In the scenarios to 2050 a majority of carbon mitigation takes place in the \$50 to \$200 per tonne of carbon (\$/tC) range (equivalent to 12cents to 46 cents per litre of gasoline), while for scenarios to 2100 a much wider range of 100\$/tC to 1400 \$/tC is observed (equivalent to 23 cents to \$3.24 per litre of gasoline). For a given carbon tax, results vary widely across regions.

The analysis also reveals that across a large number of mitigation scenarios (with carbon taxes at differing levels) the potential impact on GDP ranges from a loss of about 22% and a gain of about 5% in scenarios to 2100. (The apparently puzzling suggestion that introduction of a carbon tax could be associated with an increase in estimated GDP would not be inexplicable for an economist prepared to believe that correcting market mechanisms by removing the distortions in market signals resulting from the failure to price fuels at their social cost would introduce sufficient gains in efficiency to lead to increased GDP over the course of a century.) Although no regional trend appears in the analysis, generally larger GDP losses are more evident in developing regions than in developed regions.

Conclusions

A review of the long-term energy scenarios to 2100 highlights expectations of significant transitions in the global energy system. However, the assumed rates of change in the underlying drivers of the global energy system—as well as their direction—vary dramatically across the scenarios, pointing to a very wide range in projected values of global energy demand, running from 250-2500 EJ in 2100. Even rejecting a wide range of outlying projections, the range of estimates in the core bundle of scenarios remains very wide. The implication is that public policy will need to learn how to hedge, how to pursue ‘insurance policies’, and how to maintain a posture of maximum flexibility and adaptive capacity, building resilient systems in both public and private decision fora.

For atmospheric concentrations of greenhouse gases to stabilize, net emissions will have to fall well below current levels and asymptotically cease altogether. Even with assumed rates of decarbonization at 0.6% per year (twice the historical average) for the rest of this century, median projections of CO_2 emissions are expected to rise to 9 GtC by 2100 (50% above current levels). Of course, as features prominently in current debate, while we may reduce our carbon intensity per unit of primary energy, if overall primary energy consumption increases faster than carbon intensity improvements, then emissions and atmospheric concentrations of greenhouse gases will continue to rise. If a desirable future is one in which atmospheric concentrations of CO_2 (equivalents) stabilize or decline, then much more stringent policies (e.g., aggressive carbon policies) will be needed to guide a transition in that direction.

Given the shorter turnover rates for end-use applications (1-2 decades) compared to energy supply technologies and infrastructures (5 decades or more) changes in end-use applications can be implemented rather quickly and the effects are also more pervasive. The power to influence the direction of change in tomorrow's energy systems is with us today, but given the long lead times for energy infrastructure and supply technologies, the choices we make over the next decade or so will decide the nature and direction of our energy systems and their global impacts in the second half of this century. Initiating long-term changes therefore requires aggressive but adaptive actions sooner rather than later.

ANNEX

Global Energy Scenarios to 2030, 2050 and 2100:

Summary results from diverse scenarios

As observed at the beginning of this note, the discussion above is based on an examination of hundreds of scenarios released since 2001 carried out by Nakicenovic and his colleagues and reported in their 2006 paper cited in the references below. In that study they attempted to ensure consistency of treatment across those scenarios, and reported results for 2020, 2050 and 2100 based on the same collection for each date.

In this annex are presented summary results from a review of several bundles of scenarios from diverse sources. For the near and medium-term horizons, only a handful of scenarios are reviewed; these relate to 2030 and 2050. For the long term scenarios to 2100, a larger number of examples was available. It should be emphasized, therefore, that the results reported here are not based on consistent sets of assumptions either over time or across scenarios for a specific horizon. They provide merely an illustration of the range of conclusions drawn from scenarios reported over the last decade.

Global Energy Scenarios to 2030 - Near Term

Summary

1. **World population** is expected to grow at around 1% per year while **GDP per capita** is expected to grow around 3% per year.
2. Among five major scenario studies up to 2030 that were reviewed, all project **global energy demand** to increase between 1.6%/yr and 2%/yr from 444 EJ in 2003 to between 682-762 EJ in 2030. The fastest growth is seen in the industrial sector while the slowest growth is in the transport sector. In the absence of dramatic policy action, the demand for fossil fuels is expected to stay above 80% of overall primary energy supply up to and beyond 2030.
3. Global demand for oil in 2030 is expected to be between 115 and 120 mbbl/d
4. Demand for natural gas is expected to rise significantly, especially due to its use in power generation. Liquefied Natural Gas (LNG) becomes a significant energy carrier globally. The decline in Canadian conventional natural gas production increases the interest in unconventional natural gas resources such as tight-sands, shale and coal-bed methane.
5. Coal consumption will double in 2030 compared to today's levels, mainly due to the demand in non-OECD countries.
6. Renewable energy (non-hydro and non-biomass) grows above 6%/yr but will account for only 2% of primary energy in 2030. Electricity from renewable energy will grow from its share of 2% today to 4% in 2030.
7. Per capita transportation energy use is expected to slow to 0.7%/yr from 0.9%/yr globally, but India and China see substantial increases.
8. Demand for electricity in OECD countries is expected to grow around 1.5%/yr while in non-OECD countries it is expected to grow above 4%/yr. More than 50% of the

production is expected to come from advanced gas and coal-powered turbines. The share of nuclear power in electricity production is expected to decline.

9. The cumulative investment in the energy sector is estimated to be $US 17 Trillion up to 2030. Of this, more than 70% will be related to power generation, transmission and distribution; 40% is to provide energy and fuels to OECD countries.
10. Energy intensity improvements are expected to be between 1.5% to 1.9% between 2003 and 2030.
11. There are large regional differences in carbon intensities worldwide. India and China are expected to increase their carbon intensities, while all industrialized countries except North America show a drop in their carbon intensities.
12. Even with alternative policies that curb energy consumption by 10% over the typical reference case, global energy consumption will grow by 40% and CO_2 emissions by 30% over 2003 levels.

Global Energy Scenarios to 2050 – Medium Term

Summary

1. Assuming population projections between 9.1 and 9.5 billion, economic growth rates of approximately 2%/yr, and energy intensity improvements of 0.7%/yr to 2%/yr, the **total global energy demand in 2050** is expected to be in the range of 684-787 EJ. This is a 60%-85% increase over 2003 levels. Even in 2050 fossil fuels are expected to represent 66%-75% of the global primary energy mix.
2. The share of electricity from renewable energy sources (hydro and biomass included) is expected to double to 35% by 2050. The share of biomass is expected to increase from under 2% today to over 6% in 2050. However, there are conflicting views about the role of bio-fuels in decarbonising the transport sector, mainly due to concerns about competing uses for land and water as well as uncertainties about technologies able to support production at competitive prices.
3. Future energy plants may be conceived to be poly-generation plants or energyplexes, which produce an array of synthetic-fuels and chemicals by the gasification of fossil fuels. Although present economics, market conditions and public perception may not favour gas-to-liquid (GTL) or coal-to-liquid (CTL) syn-fuel production, given appropriate technological improvements in carbon capture and storage (CCS) and markets, these may figure more prominently in our energy systems by 2050.
4. Among various CO_2 mitigation options, energy efficiency emerges as about twice as effective as carbon capture and storage (CCS) and CCS is about twice as effective as fuel switching. Although energy efficiency is considered to be the cheapest, fastest and most environmentally friendly method to curb energy demand, it is important to consider the impact of the *rebound effect* of increased consumption in reducing the overall impact of improved energy efficiency.
5. Given that there are no ‘silver bullet’ technologies in the medium term a portfolio of technologies must be pursued to reduce future costs and risks. However, technologies do exist today to make a difference over the next 10-50 years.
6. In addition to the quantity and price of energy, energy quality – which includes convenience, flexibility, efficiency and environmental cleanliness – will become increasingly important for future energy systems. Although end-use patterns are likely

to converge toward higher quality fuels such as electricity, natural gas or hydrogen, primary energy supply trends are likely to diverge globally.

7. Environmental concerns, financing and technological needs are considered to be more likely sources of future limits to global energy systems than the unequal distribution of fossil resources, regional shortages and resulting price increases.
8. Given the shorter turnover rates for end-use applications (1-2 decades) compared to energy supply technologies and infrastructures (5 decades or more) changes in end-use applications can be implemented rather quickly and the effects are also more pervasive. Given the long-lead times for energy infrastructure and supply technologies, 'betting on the wrong horse may have serious, possibly irreversible consequences'. RD&D and investment decisions made now and in the immediate future will determine which options become available or foreclosed in the long-term. Therefore, initiating long-term changes requires actions sooner rather than later.

Global Energy Scenarios to 2100 – Long Term

Summary

1. All major driving forces of primary energy demand have been revised downward in global energy scenarios published since 2001, compared to those published by 2001.
2. Projections of global population in 2100 range from 4-15 billion with a median of around 10 billion. The vast majority of this population is expected to be urbanized.
3. The projected GDP range in 2100 is between US$ 25 Trillion and US$ 550 Trillion. This range as well as the upper-bound projection has been revised down substantially in the post-2001 scenarios.
4. The median projections for energy intensity (EI) improvements are between 0.7%-1.3%/year up to 2100. Factors other than GDP growth seem to affect EI improvements in the latter half of this century, when EI improvements are also expected to be less than prior to 2050.
5. The factor range or ratio between highest and lowest projections (uncertainty range) is greatest in 2100 for global economic output at 20, lowest for population range at 3.5 and 10 for primary energy demand. (It should be emphasized that these broad ranges reflect the large number of disparate long-range scenarios reviewed, not the uncertainty within each. They also illustrate well the challenge of policy-making in the absence of any confident expectations about the evolution of critical features into the future.)
6. The demand for primary energy in 2100 is projected to be between 243 EJ and 2447 EJ across 178 scenarios.
7. Long-term energy scenarios to 2100 point to a possible transition in the global energy system as we move toward more non-fossil energy sources, although to varying degrees and directions.
8. Even with the assumed median 0.6% rate of decarbonisation (above the historical average of 0.3%), the median CO2 emissions projections are expected to rise to 9 GtC (50% over today's emissions) in 2100. Even with the median emission projections, atmospheric CO_2 levels are expected to rise to 750 ppmv.
9. In OECD countries carbon emissions can potentially be reduced through a combination of advanced energy technologies as well as fuel switching with comparable effectiveness.

10. The effect of various levels of carbon tax on GDP ranges from losses of about 22% to gains of about 5 in 2100. Although no regional trend appears, generally larger GDP losses are more prevalent in developing regions than in developed regions.
11. Sector-specific carbon policies increase the cost of emissions reductions and reduce electrification of the energy system significantly.
12. The power to influence tomorrow's energy systems is with us today but the choices we make over the next decade or so will decide the nature and direction of our energy systems and their global impacts in the second half of this century.

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