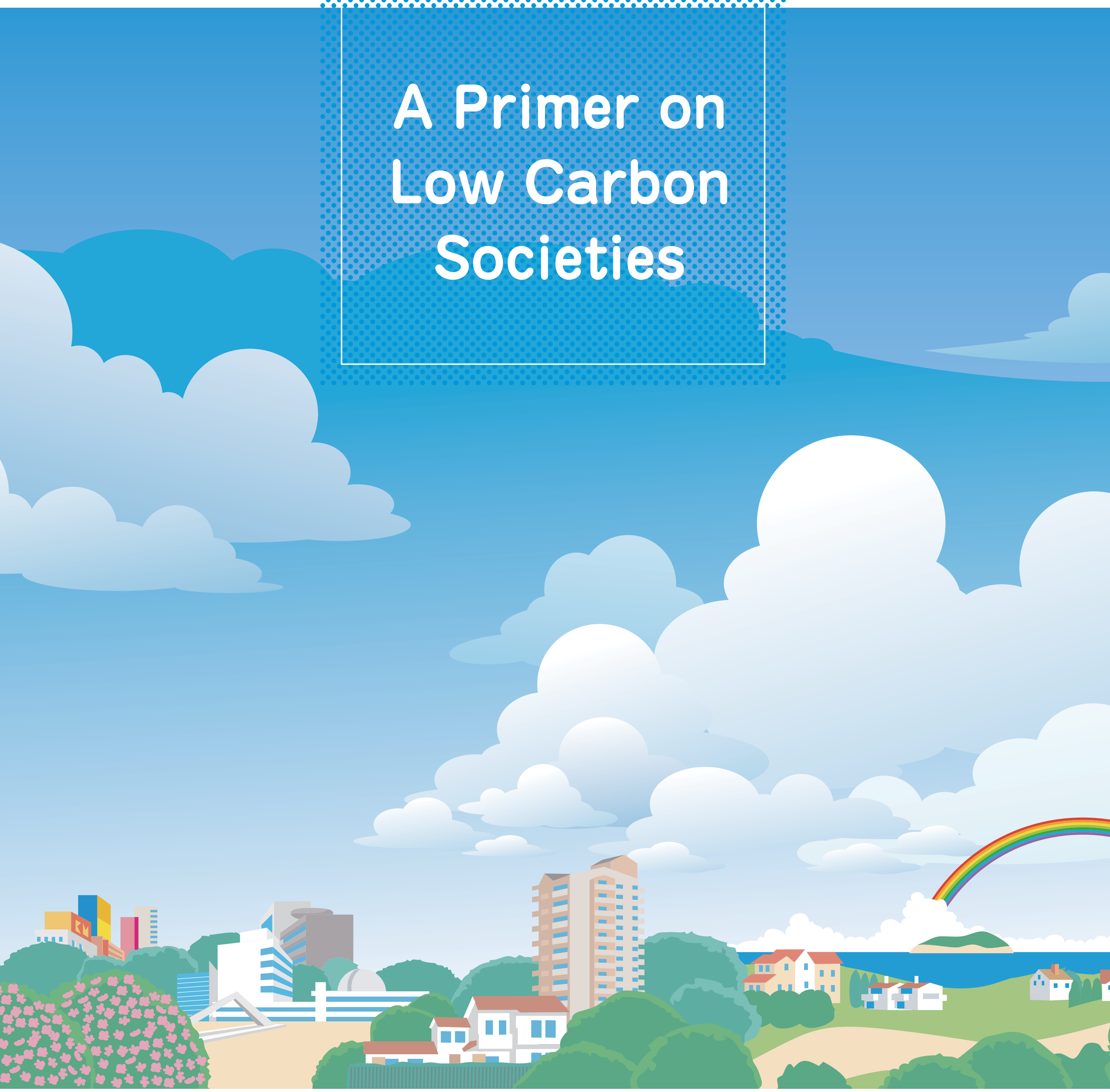
A Primer on Low Carbon Societies



International Research Network for Low Carbon Societies [LCS-RNet]

Foreword

The Intergovernmental Panel on Climate Change asserted in the Fifth Assessment Report, "Human influence on the climate system is clear," and that in order to reduce climate change risks substantially, the world must move toward zero emissions. A path forward was hammered out at the 21st session of the Conference of the Parties (COP21) to the United Nations Framework Convention on Climate Change (UNFCCC), held in Paris in 2015. Under that agreement, all countries, including developing countries, will cooperate to reduce greenhouse gas emissions from human activities essentially to zero during the latter half of the 21st century, moving toward the target of limiting the average global temperature increase to no more than 2°C.

A large number of countries, including developing countries, have already submitted to the UNFCCC their Intended Nationally Determined Contributions (INDCs), which are their new post-2020 greenhouse gas emission reduction targets. However, implementing only the measures outlined in these INDCs at present is expected to lead to a temperature rise of more than 3°C by the year 2100. Consequently, further greenhouse gas emissions reductions will be necessary to attain the 2°C target.

In order to build a low-carbon society with substantially reduced greenhouse gas emissions in real terms, countermeasures in both developed and developing countries will play an important role. That said, transitioning to a low-carbon society will not be easy. To bring about such a society, it will be critical for social actors including central and provincial-level local governments, the private sector, NGOs and NPOs, citizens, and the international community to set their gaze squarely on the type of society to be sought from a long-term perspective and make efforts cooperatively, thoroughly mindful of the role each of them plays.

This primer was written for students, businessmen and women, policymakers and others who will work to bring about a low-carbon society in the future. It lays out what a low-carbon society is and what should be done to realize just such a society. We hope that this primer will help to promote concrete actions that bring about a low-carbon society.

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01 The Science of Climate Change

During most of the past ten thousand years or more the Earth's mean surface temperature has been maintained at an average of about 14°C, a level suitable for human and many other life forms. Human civilization has flourished and developed in this climate. Levels of greenhouse gases (GHGs)[1] present in the atmosphere have remained by and large stable all these years as the rate of their emission from the Earth's land and ocean surfaces has been balanced by the rate of their absorption by natural sinks. That is, the emission of GHGs from the Earth's natural systems into the atmosphere has been balanced by their absorption or removal from the atmosphere by conversion to different chemical compounds. This has helped to maintain the Earth's surface temperature at a stable level. Without GHGs, the average temperature of the Earth's surface would be about 33°C colder than the present level.

However, the past few hundred years since the advent of industrialization have witnessed the rapid growth of modern industries, technologies and human population, as well as drastic changes in production and consumption activities and lifestyles in human societies. This has resulted in a much greater rate of emission of GHGs from human activities, especially carbon dioxide from burning fossil fuels (coal, oil, natural gas) in industries and methane and nitrous oxide from farmland, than what can be absorbed by Earth's surfaces and natural sinks. Therefore the concentration of GHGs in the Earth's atmosphere has begun to rise and accumulate steadily. Rising global mean surface temperature is strongly correlated with this rising GHG concentration.

It has been observed that the globally averaged land and ocean surface temperature of the Earth between the average of the 1850-1900 period and that of the2003-2012 period rose by about 0.78°C (IPCC WG I, 2013). Palaeoclimatic studies that use changes in climatically sensitive indicators to infer past changes in global climate on time scales ranging from decades to millions of years indicate that the warmth of the last half century is unusual in at least the previous 1300 years. The last time the polar regions were significantly warmer than present for an extended period (about 125,000 years ago), reductions in polar ice volume led to 4 to 6 m of sea level rise (IPCC WG I, 2007).

IPCC WG I (2013) states that the warming of the climate system is unequivocal, and many of the changes observed since the 1950s have been unprecedented over decades to millennia. The atmosphere and ocean have warmed, amounts of snow and ice have diminished, sea levels have risen, and concentrations of GHGs have increased (Figures 1, 2, 3). The next sections provide a summary of scientific evidence of climate change, its correlation with GHG emissions, its observed and projected impacts, and anthropogenic (i.e. human related) causes of GHG emissions.

1.1 Scientific evidence of climate change and its effects

Scientific observations indicate that each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. Considering multiple independent datasets, the globally averaged surface temperature data show a warming of 0.85°C (with a 0.65-1.06°C range estimate) over the period 1880-2012 (Figure 1). Based on the single longest dataset available, the total increase between the

1 Greenhouse gases (GHGs) are the gases that absorb and emit infrared radiation in the wavelength range emitted by the Earth. The most abundant GHGs in Earth's atmosphere are water vapor (H_2O), carbon dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), Ozone (O_3), and Chlorofluorocarbons (CFCs).

average of the 1985-1990 period and that of the 2003-2012 period is 0.78°C (with a 0.72-0.85°C range estimate). With medium confidence it can be said that in the Northern Hemisphere, 1983-2012 was likely the warmest 30-year period of the past 1400 years. As Figure 2 shows, almost the entire globe has experienced surface warming during 1901-2012, the longest period during which calculation of regional trends is sufficiently complete (IPCC WG I, 2013).

The global temperature datasets released in January 2016 from three independent records maintained by NASA, the US National Oceanic and Atmospheric Administration (NOAA) and the UK Met Office document unprecedented high temperatures in 2015, pushing the global average to at least 1°C above pre-industrial levels. Thus 2015 was the hottest year on record. Although El Niño boosted temperatures late in the year, US government scientists say that the steady increase in atmospheric concentrations of greenhouse gases continues to drive overall warming (Tollefson, 2016a).

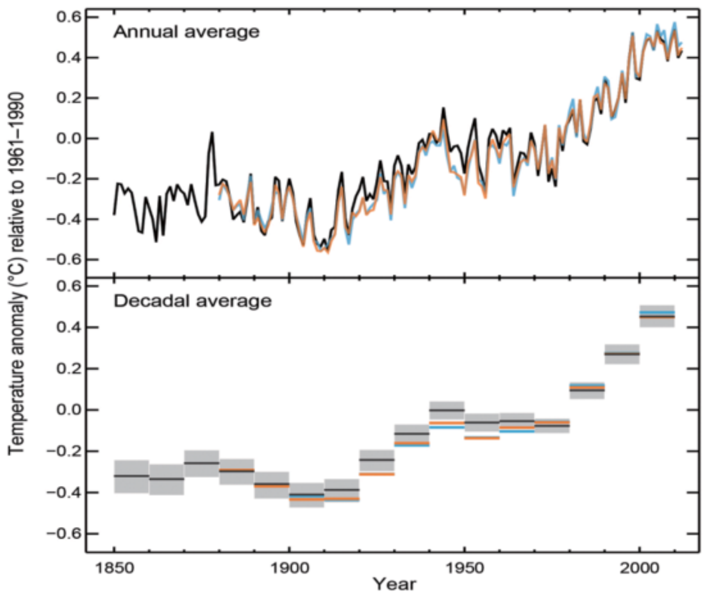


Figure 1. **Observed globally averaged combined land and ocean surface temperature anomaly from 1850 to 2012, relative to the mean of the 1961-1990 period** (Source: Figure SPM.1(a) of IPCC WG I, 2013)

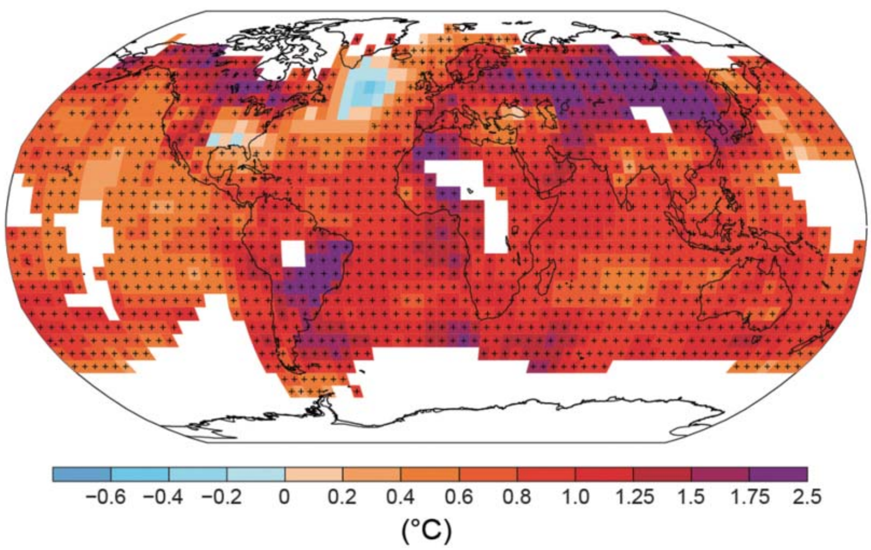


Figure 2. **Observed change in surface temperature from 1901 to 2012 (grid boxes where the trend is significant at the 10% level are indicated by a + sign)**
(Source: Figure SPM.1(b) of IPCC WG I, 2013)

Changes in many extreme weather and climate events have been observed since about 1950 (Box 1). It is very likely[2] that the number of cold days and nights has decreased and the number of warm days and nights has increased on a global scale. It is likely that the frequency of heat waves has increased in large parts of Europe, Asia and Australia (IPCC WG I, 2013).

Box 1. Global assessment of extreme weather and climate changes since 1950 or 1970, and likelihood of human contribution to those changes

Events with likely-very likely chance of occurrence and human contribution	Events with medium-low confidence of occurrence and human contribution
• Warmer and/or fewer cold days and nights over most land areas • Warmer and/or hot days and nights over most land areas • Greater frequency and/or duration of warm spells/heat waves over most land areas • Increased incidence and/or magnitude of extreme high sea level	• Increase in frequency, intensity and/or amount of precipitation of heavy precipitation events • Increases in intensity and/or duration of drought • Increases in intense tropical cyclone activity

Source: Adapted from Table SPM.1 of IPCC WG I, 2013

IPCC WG I (2013) reports with high confidence that over the last two decades, the Greenland and Antarctic ice sheets have been losing mass, glaciers have continued to shrink almost worldwide, and Arctic sea ice and Northern Hemisphere spring snow cover have continued to decrease in extent (Figure 3).

There has been substantial Arctic warming since the mid-20th century. Witze (2016) reports that in the end of 2015-beginning of 2016 winter season Arctic sea-ice cover seemed to reach one of its smallest winter maxima ever. As of 28 February 2016, Arctic ice covered 14.525 million square kilometres, or 938,000 square kilometres less than the 1981-2010 average.

The average rate of ice loss from the Greenland ice sheet has very likely substantially increased from an average of 34[3] Gt/yr over the period 1992 to 2001 to 215 Gt/yr over the period 2002 to 2011. The average rate of ice loss from the Antarctic ice sheet has likely increased from an average of 30 Gt/yr over the period 1992 to 2001 to 147 Gt/yr over the period 2002 to 2011. The average rate of ice loss from glaciers around the world, excluding glaciers on the periphery of the ice sheets, was very likely 226 Gt/yr over the period 1971 to 2009, and very likely 275 Gt/yr over the period 1993 to 2009. The annual mean Arctic sea ice extent decreased over the period 1979 to 2012 with a rate that was very likely in the range 3.5% to 4.1% per decade, with the average decrease in decadal mean extent being most rapid in summer. There is very high confidence that the extent of Northern Hemisphere snow cover has decreased since the mid-20th century (IPCC WG I, 2013).

Loss of ice-sheet mass is a major contributor to current sea-level rise, and is expected to continue as global warming proceeds. For instance, the Greenland ice sheet contributed substantially to sea-level rise throughout the twentieth century, providing at least 25 ± 9.4 millimetres of the total global mean rise (Csatho, 2015). The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia. Over the period 1901 to 2010, global mean sea level rose by an average of 19 cm (Figure 3) (IPCC WG I, 2013).

2 IPCC WG I (2013) reports changes in climate indicators and impacts in terms of 'very likely', 'likely', 'medium confidence' or 'low confidence'. These terms indicate degrees of statistical confidence based on analysis of large datasets.

3 Here we report only average point estimates of quantified indicators. IPCC WG I (2013) reports both average point and interval (or range) estimates.

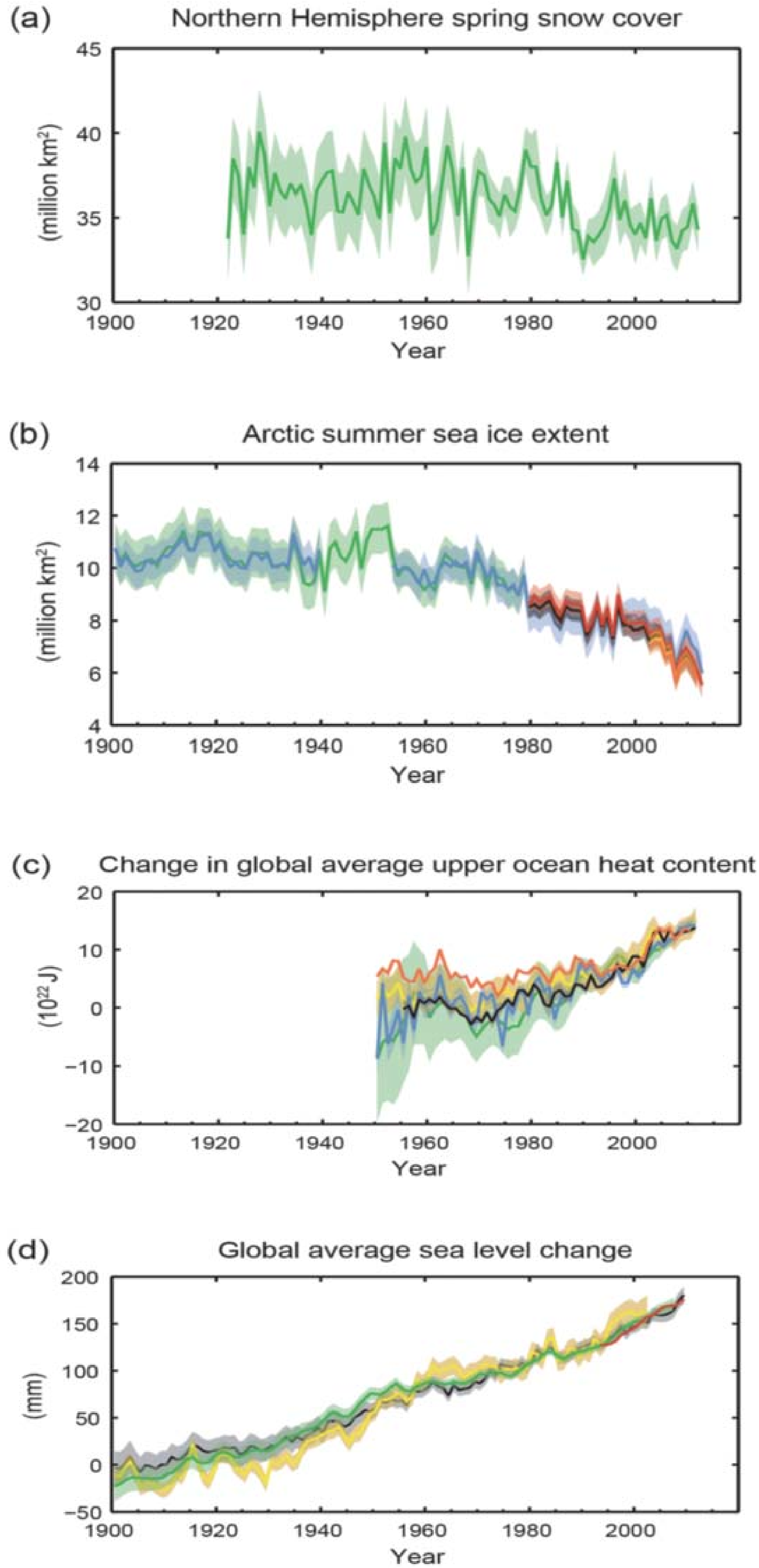


Figure 3. **Observed indicators of changing global climate** (Source: Figure SPM.3 of IPCC WG I, 2013)

1.2 Correlation between GHG emissions rise and climate change

The atmospheric concentrations of major GHGs – carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)– have increased to levels unprecedented in at least the last 800,000 years. In 2011 the concentrations of CO_2, CH_4, and N_2O were 391 ppm[4], 1803 ppb[5], and 324 ppb, exceeding pre-industrial levels by about 40%, 150%, and 20%, respectively (IPCC WG I, 2013). The increase in atmospheric concentrations of all these gases has been due to human activity. For instance, the increase in CO_2 concentrations since pre-industrial times has been primarily from fossil fuel emissions and secondarily from net land use change emissions.

From 1750 to 2011, CO_2 emissions from fossil fuel combustion and cement production have released 375 GtC[6] to the atmosphere, while deforestation and other land use changes are estimated to have released 180 GtC. This has resulted in cumulative anthropogenic emissions of 555 GtC. Of these cumulative anthropogenic CO_2 emissions, about 240 GtC have accumulated in the atmosphere, 155 GtC have been absorbed by the ocean and 160 GtC have accumulated in natural terrestrial ecosystems (i.e., the cumulative residual land sink). As shown in Figure 4, the pH of ocean surface water has decreased by about 0.1 since the beginning of the industrial era,

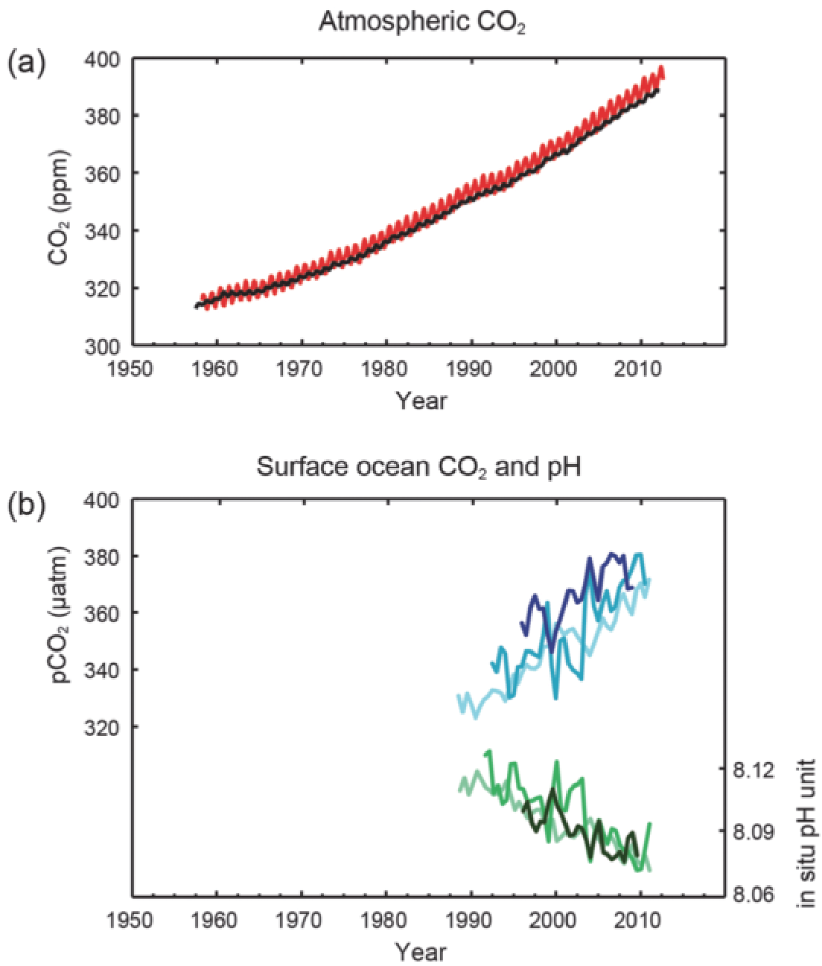


Figure 4. Indicators of changing global carbon cycle: (a) atmospheric concentrations of CO_2 at particular locations; (b) partial pressure of dissolved CO_2 at the ocean surface and in situ pH

(Source: Figure SPM.4 of IPCC WG I, 2013)

4 Parts per million (i.e. number of gas molecules per million molecules of dry air)
5 Parts per billion (i.e. number of gas molecules per billion molecules of dry air)
6 Amount of carbon dioxide gas emission or concentration is measured in units such as tC (ton carbon), ktC (kiloton carbon), MtC (million ton carbon), GtC (gigaton carbon), tCO_2, (ton CO_2), $ktCO_2$ (kiloton CO_2), $MtCO_2$ (million ton CO_2), and $GtCO_2$ (gigaton CO_2). A given amount of CO_2 gas measured in tC is the mass of carbon atoms contained in it, whereas, measured in tCO_2, it is the mass of CO_2 molecules contained in it. 1 tC = 3.67 tCO_2.

indicating increasing acidification of the ocean (IPCC WG I, 2013). This is on account of the fact that the world ocean has absorbed about one-third of the carbon released by humans. Observations of the ocean interior confirm that increases in CO_2 emissions from fossil-fuel burning are accompanied by an increase in carbon content in the upper ocean (Ilyina, 2016).

A measure to quantify the change in energy fluxes caused by changes in natural and anthropogenic substances is radiative forcing[7]. Positive radiative forcing leads to surface warming and negative radiative forcing leads to surface cooling. The total anthropogenic radiative forcing for 2011 relative to 1750 is 2.29 W/m², and it has increased more rapidly since 1970 than during prior decades. The radiative forcing due to natural causes, i.e. changes in solar irradiance, for 2011 relative to 1750 is estimated at 0.05 W/m². Therefore total radiative forcing is positive and it has led to an uptake of energy by the climate system. The largest contribution to total radiative forcing is caused by the increase in the atmospheric concentration of CO_2 since 1750. Other significant contributors are emissions of CH_4, Halo-carbons, and N_2O (IPCC WG I, 2013).

Observed data during 1870-2010 show a strong positive correlation between rising cumulative GHG emissions and rising global mean surface temperature (see Figure 5)[8].

1.3 Likely future impacts

The Intergovernmental Panel on Climate Change (IPCC) adopted Representative Concentration Pathways (RCPs) as representative of the wide range of possible changes in the future anthropogenic GHGs for its fifth Assessment Report (AR5). The RCPs comprise four distinct GHG concentration trajectories that describe four possible climate futures depending on the quantity of GHGs emitted in the years to come. These pathways are used for climate modeling and research to analyze future scenarios of GHG emissions and options to mitigate them. The four RCPs – RCP2.6, RCP4.5, RCP6.0, RCP8.5 – are named after a possible ranges of radiative forcing values (+2.6, +4.5, +6.0, +8.5 W/m², respectively) in 2100 relative to 1750.

For RCP6.0 and RCP8.5, radiative forcing does not peak by year 2100; for RCP2.6 it peaks and declines; and for RCP4.5 it stabilizes by 2100. Each RCP provides spatially resolved data sets of land use change and sector-based emissions of air pollutants, and it specifies annual greenhouse gas concentrations and anthropogenic emissions up to 2100. RCP8.5 is the scenario with very high GHG emissions; RCP4.5 and RCP6.0 are stabilization scenarios; and RCP2.6 is the mitigation scenario leading to a very low forcing level. Total GHG concentrations in 2100 reach 475 ppm, 630 ppm, 800 ppm and 1313 ppm in RCP2.6, RCP4.5, RCP6.0 and RCP8.5, respectively, in CO_2-equivalent terms. CO_2 concentrations alone reach 421 ppm, 538 ppm, 670 ppm and 936 ppm, respectively, in the four scenarios (IPCC WG I, 2013).

Figure 5 shows the rise in global mean surface temperature as a function of total global CO_2 emissions, historically during 1870-2010, and projected into the future corresponding to the RCP scenarios. Evidently, cumulative emissions of CO_2 largely determine global mean surface warming by the late 21st century. The obvious consequences of this near-linear relationship are (i) that every ton of CO_2 contributes about the same amount of global warming no matter when it is emitted, (ii) that any target for the stabilization of global mean temperature rise implies a finite CO_2 budget that can be emitted, and (iii) that global net emissions at some

7 Radiative forcing (RF) is the measurement of the capacity of a gas or other forcing agents to affect the energy balance, thereby contributing to climate change. It is defined as the difference of insolation (sunlight) absorbed by Earth and energy radiated back to space. As mentioned, a positive forcing (more incoming energy) warms Earth's surface, while negative forcing (more outgoing energy) cools it. Causes of RF include changes in insolation and concentrations of GHGs and aerosols.

8 It could be inferred from Figure 5 that since 555 GtC GHGs were emitted until 2011 and 2°C rise in global mean temperature is the agreed target as discussed in Chapter 2, the world cannot emit more than 235 GtC emissions after 2011 if it is to avoid dangerous impacts. This point is discussed in Section 2.1 of Chapter 2.

point need to be zero (Seneviratne *et al.*, 2016). Continued and unabated GHG emissions in the future will cause further warming and changes in all components of the climate system.

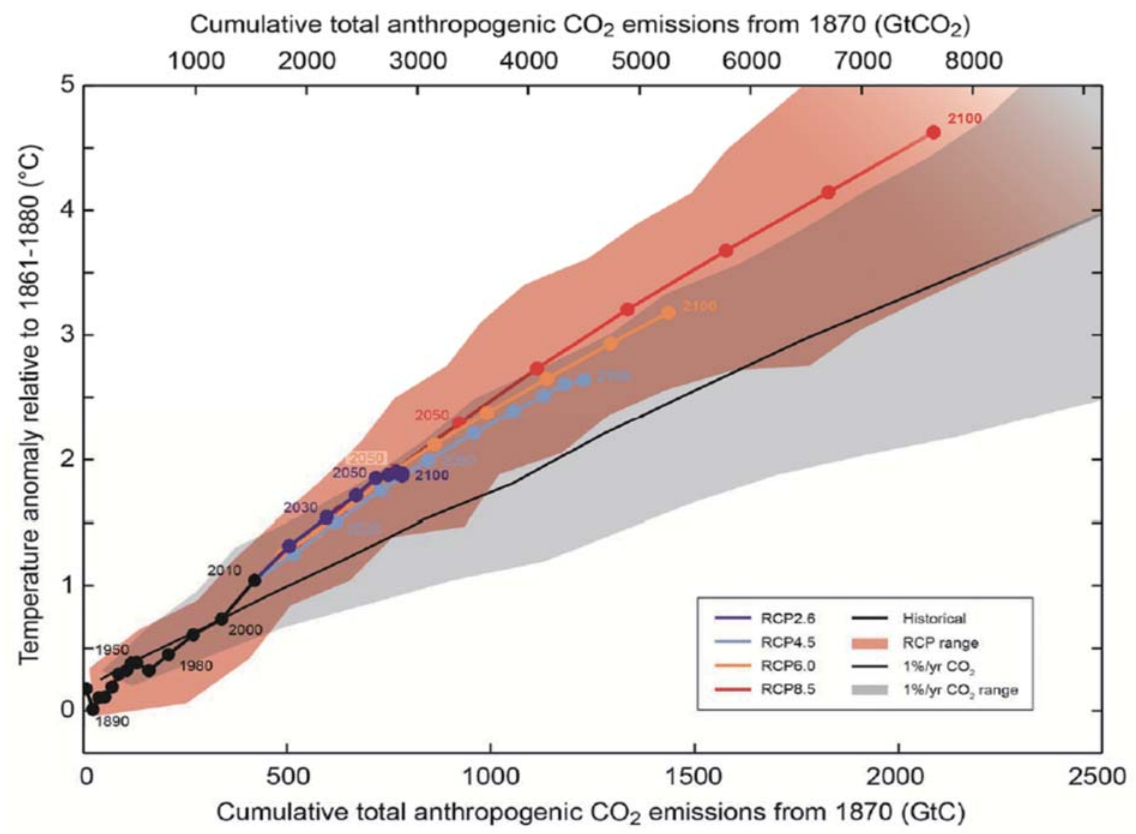


Figure 5. Global mean surface temperature rise as a function of cumulative total global CO_2 emissions in the past (1870-2010) and its projection in the future (until 2100) corresponding to RCP scenarios

(Source: Figure SPM.10 of IPCC WG I, 2013)

Global surface temperature change for the end of the 21st century is likely to exceed 1.5°C relative to 1850-1900 for all RCP scenarios except RCP2.6. It is likely to exceed 2°C for RCP6.0 and RCP8.5, and more likely than not to exceed 2°C for RCP4.5. Warming will continue beyond 2100 under all RCP scenarios except RCP2.6 (IPCC WG I, 2013). Seneviratne *et al*. (2016) analyzed regional level impacts through climate model simulations and found that rise in annual temperature extremes at regional levels is expected to be much more steep than rise in global mean surface temperature. For example, a 2°C warming in hot extremes (i.e. annual warmest daytime temperature) may take place in the Mediterranean, in contrast to a change of 1.4°C in global mean surface temperature.

Figure 6 indicates the projected changes in global mean surface temperature, Northern Hemisphere sea ice content, and global mean ocean surface pH, and Figure 7 shows global mean sea level rise in the four RCP scenarios. The global ocean will continue to warm during the 21st century and heat will penetrate from the surface to the deep ocean and affect ocean circulation. It is very likely that the Arctic sea ice cover will continue to shrink and that Northern Hemisphere spring snow cover will decrease during the 21st century as global mean surface temperature rises. Global glacier volume will further decrease. Global mean sea level will continue to rise during the 21st century. Under all RCP scenarios, the rate of sea level rise will very likely exceed that observed during 1971 to 2010 due to increased ocean warming (i.e. thermal expansion) and increased loss of mass from glaciers and ice sheets. Climate change will affect carbon cycle processes in a way that will exacerbate the increase of CO_2 in the atmosphere. Further uptake of carbon by the ocean will increase ocean acidification (IPCC WG I, 2013).

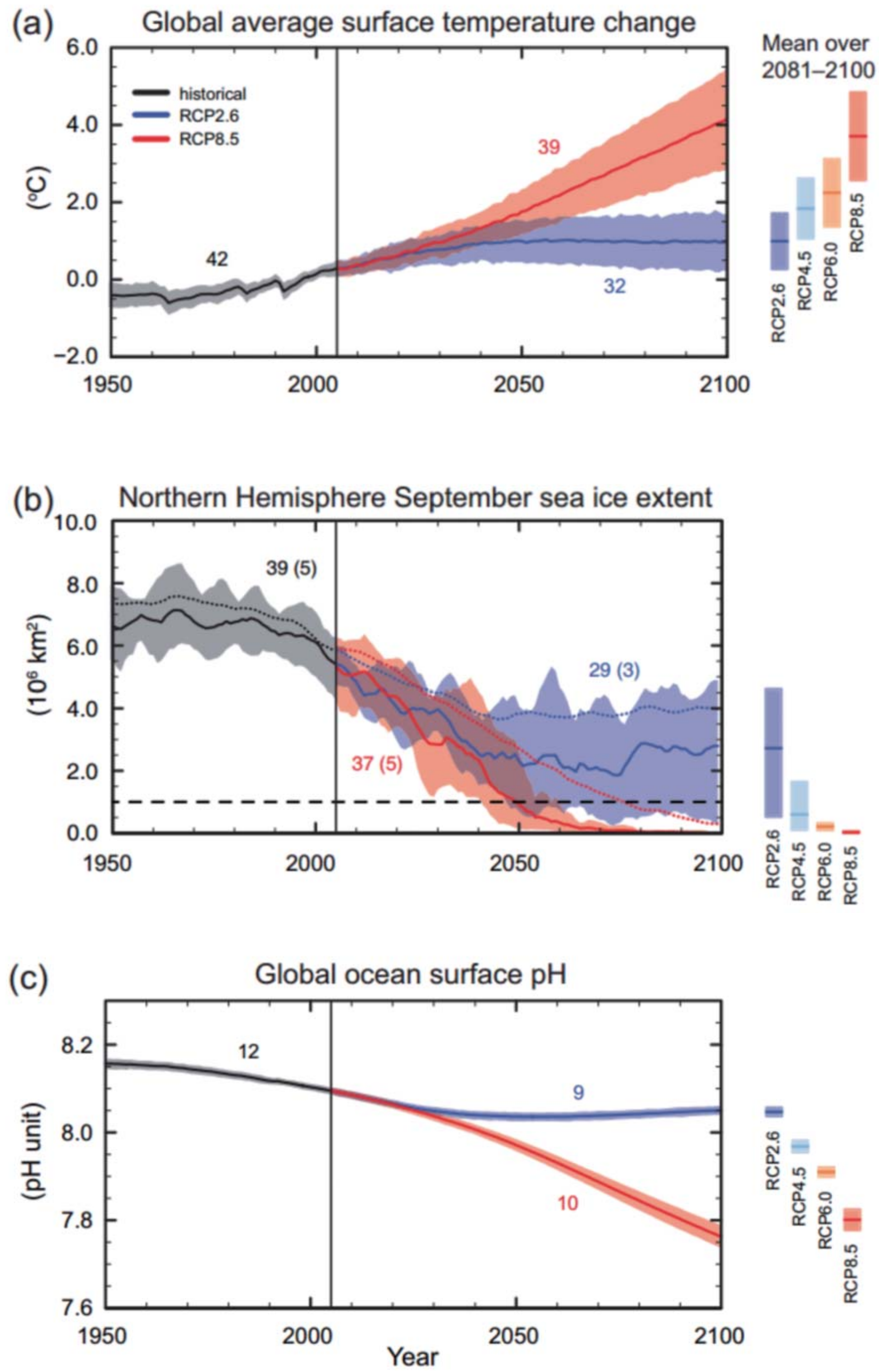


Figure 6. Projections of global mean surface temperature change relative to 1986-2005, Northern Hemisphere September sea ice content, and global mean ocean surface pH (Source: Figure SPM.7 of IPCC WG I, 2013)

Many modeling and simulation studies have reported that climate change is likely to eventually impact health and food security. The 2015 Lancet Commission on Health and Climate Change concluded that the direct effects of climate change include increased heat stress, floods, drought and increased frequency of intense storms, while indirect effects threaten human health through adverse changes in air pollution, the spread of disease vectors, food insecurity and under-nutrition, displacement, and worsened mental health. Future projections of climate change represent an unacceptably high and potentially catastrophic risk to human health, and a real possibility of reversing the health gains achieved from economic development by human societies (Watts *et al.*, 2015).

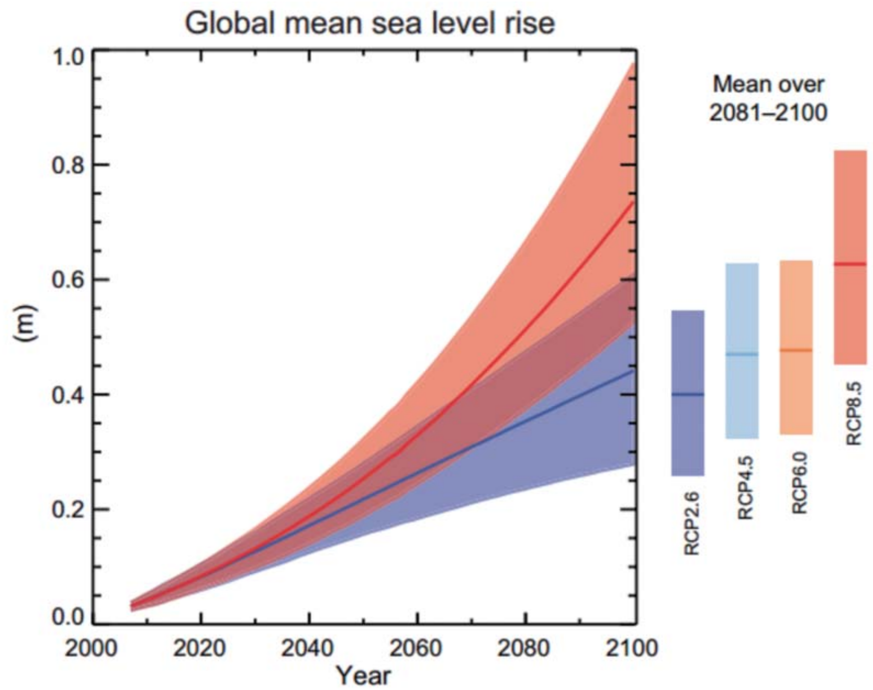


Figure 7. **Projections of global mean sea level rise over the 21st century relative to 1986-2005**
(Source: Figure SPM.9 of IPCC WG I, 2013)

1.4 GHG emissions and their anthropogenic causes

Since a rise in global average surface temperature and changes in other climate indicators are strongly correlated with a rise in radiative forcings and GHG concentrations in the atmosphere, which in turn is due to a rise in anthropogenic GHG emissions, let us briefly look at the characteristics of these emissions and their sources.

Total anthropogenic GHG emissions continued to increase during 1970-2010 with larger absolute decadal increases toward the end of this period. Total annual emissions reached 49 $GtCO_2eq$[9]/yr in 2010 (IPCC WG III, 2014). Table 1 lists major GHGs, their global warming potential, and major sources. Figure 8 shows their trajectory during 1970-2010. CO_2 emissions from fossil fuel combustion and industrial processes contributed about 78% of the total GHG emission increase from 1970 to 2010. Annually, since 1970, about 75% of anthropogenic GHG emissions have been in the form of CO_2, and the rest in the form of non-CO_2 gases.

9 CO_2eq or carbon dioxide equivalent, is a quantity that describes, for a given amount of a GHG or a mixture of multiple GHGs, the amount of CO_2 that would have the same global warming potential (GWP), when measured over a specific time scale (generally 100 years). See Table 1 for GWP numbers for various GHGs.

Table 1. Major GHGs, their global warming potential, major emission sources, and CO_2eq share in GHG emissions

GHG	Global Warming Potential (GWP)[10] 100-Year	Atmospheric lifetime (years)	Major emission source	CO_2eq share in total GHG emission in 2010 (%)
Carbon Dioxide (CO_2)	1	A	Fossil fuel combustion; deforestation	76
Methane (CH_4)	28	12	Paddy; livestock	16
Nitrous Oxide (N_2O)	265	121	Fuel combustion; fertilizer	6.2
Chlorofluorocarbons (CFCs)	1000-10,000s	1-700	Refrigerant gas; propellant gas; metal cleaning	small
Hydrofluorocarbons (HFCs)	100-10,000s	1-300	Refrigerant gas; propellant gas; metal cleaning	small
Perfluorinated carbon (PFC)	100-10,000s	1,000s	Semiconductor process	small
Sulphur Hexafluoride (SF_6)	23,500	3,200	Electric insulator	small

A: No single lifetime can be given for CO_2 (see Box 6.1, 6.11, 8.7 of IPCC WG I, 2013)
Sources: IPCC WG I (2013), IPCC WG III (2014)

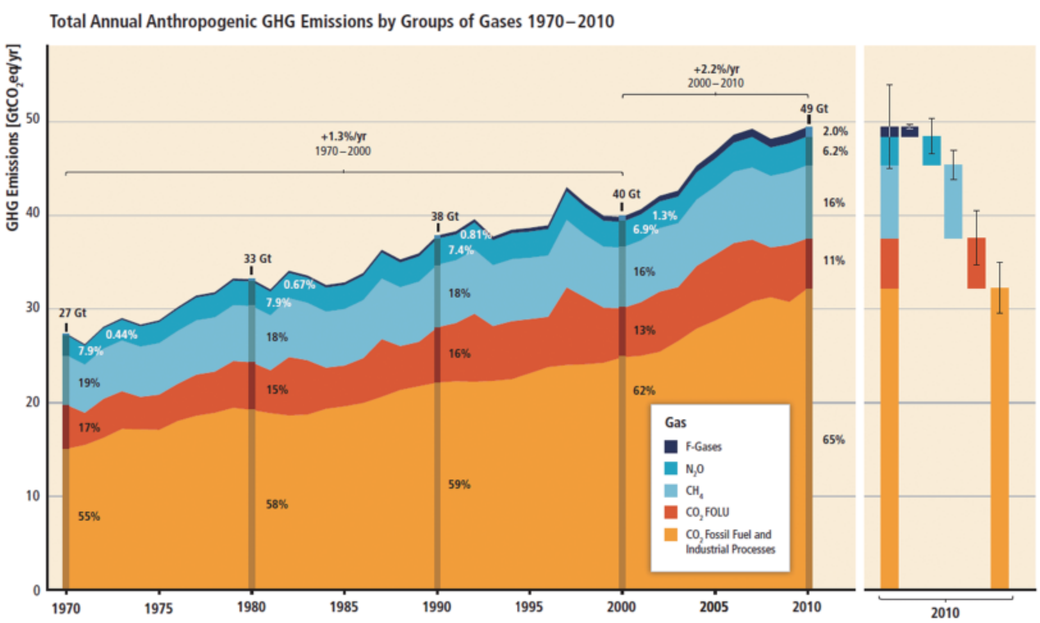


Figure 8. Anthropogenic GHG emissions ($GtCO_2eq/yr$) by gases, 1970-2010
(Source: Figure SPM.1 of IPCC WG III, 2014)

10 Global Warming Potential (GWP) is a relative measure of the quantity of heat a greenhouse gas traps in the atmosphere. It is measured by the amount of heat trapped by a certain mass of the gas divided by the amount of heat trapped by an equal mass of CO_2. GWP of a gas varies over different time horizons. Numbers mentioned in Table 1 correspond to a time horizon of about 100 years.

About half of the cumulative anthropogenic CO_2 emissions between 1750 and 2010 occurred in the last 40 years. Annual anthropogenic GHG emissions have increased by 10 $GtCO_2eq$ between 2000 and 2010, with this increase directly coming from the energy supply (47%), industry (30%), transport (11%) and buildings (3%) sectors. Accounting for indirect emissions (i.e. emissions embedded in electricity and heat production) raises the contributions of buildings and industry sectors (IPCC WG III, 2014).

Figure 9 shows anthropogenic GHG emissions in 2010, broken down by sector. Of the 49 $GtCO_2eq$ of emissions in 2010, 35% of GHG emissions were released in the energy supply sector, 24% in agriculture, forestry and other land use (AFOLU), 21% in industry, 14% in transport and 6.4% in buildings. When emissions from electricity and heat production are attributed to the end-use sectors, the industry and buildings sectors' share of global GHG emissions increases to 31% and 19%, respectively (IPCC WG III, 2014).

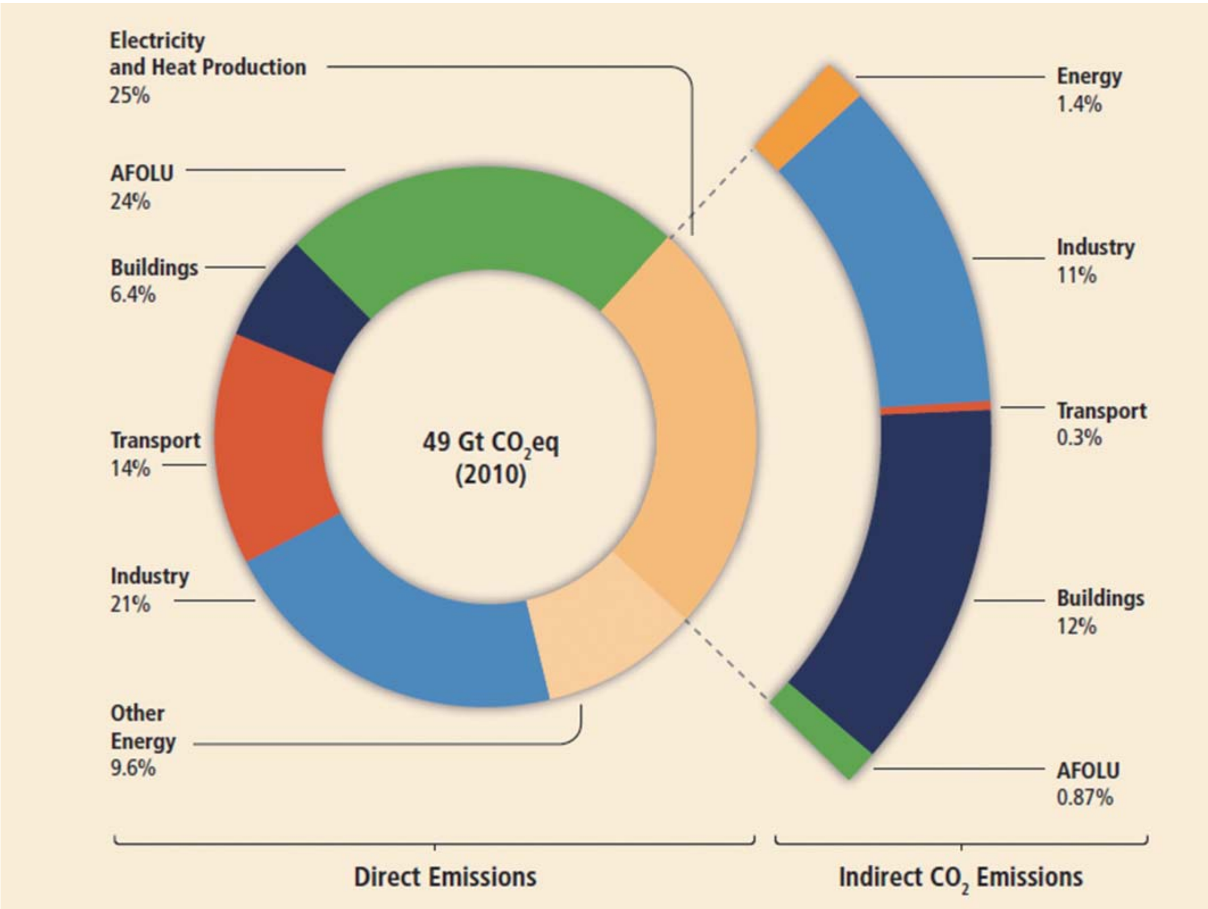


Figure 9. Anthropogenic GHG emissions ($GtCO_2eq/yr$) in 2010, by economic sectors
(Source: Figure SPM.2 of IPCC WG III, 2014)

02 | The Need to Transition to a Low Carbon Society

As we saw in Chapter 1, scientists have established with high confidence that it is human-induced activities, especially those resulting in anthropogenic GHG emissions, and not other factors, that are causing unprecedented global mean surface temperature rise and associated effects since the mid-20th century.

IPCC WG I (2013) reports that it is extremely likely that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in greenhouse gas concentrations and other anthropogenic forcings together. Over every continental region except Antarctica, anthropogenic forcings have likely made a substantial contribution to surface temperature increases since the mid-20th century. The best estimate of the human-induced contribution to warming is similar to the observed warming over this period.

It is also very likely that human influence has contributed to observed global scale changes in the frequency and intensity of daily temperature extremes since the mid-20th century, and likely that human influence has more than doubled the probability of the occurrence of heat waves in some locations (see Box 1 in Chapter 1). Anthropogenic influences have very likely contributed to Arctic sea ice loss since 1979, to the retreat of glaciers since the 1960s, to the increased surface mass loss of the Greenland ice sheet since 1993, to the reductions in Northern Hemisphere spring snow cover since 1970, and to the global mean sea level rise since the 1970s due to thermal expansion and glacier mass loss. On the other hand, there is high confidence that changes in total solar irradiance have not contributed to the increase in global mean surface temperature over the period 1986 to 2008, based on direct satellite measurements of total solar irradiance (IPCC WG I, 2013).

Scientists also agree that continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system, and that limiting climate change will require substantial and sustained reductions of greenhouse gas emissions similar to the levels assumed in RCP2.6 scenario.

Therefore at the Cancun Climate Change Conference in 2010 the Parties to the United Nations Framework Convention on Climate Change (UNFCCC)[11] agreed to commit to a maximum temperature rise of 2°C above pre-industrial levels (UNFCCC, 2010). This threshold was deemed to be a level that will meet the objective in Article 2 of the Convention, of "achieving stabilization of GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." The Convention further states that "such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner" (IPCC WG III, 2014). Thus, scientists agree that adverse changes in climate and their impacts on human and other life systems would dangerously deepen if the Earth's mean surface temperature were to increase by 2°C or more as compared to pre-industrial levels.

The Paris Agreement on Climate Change in 2015 went a significant step further and prescribed holding the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change (see Figures 10 and 12).

11 The UNFCCC is an international treaty to address climate change. It is discussed in Section 4.1 of Chapter 4.

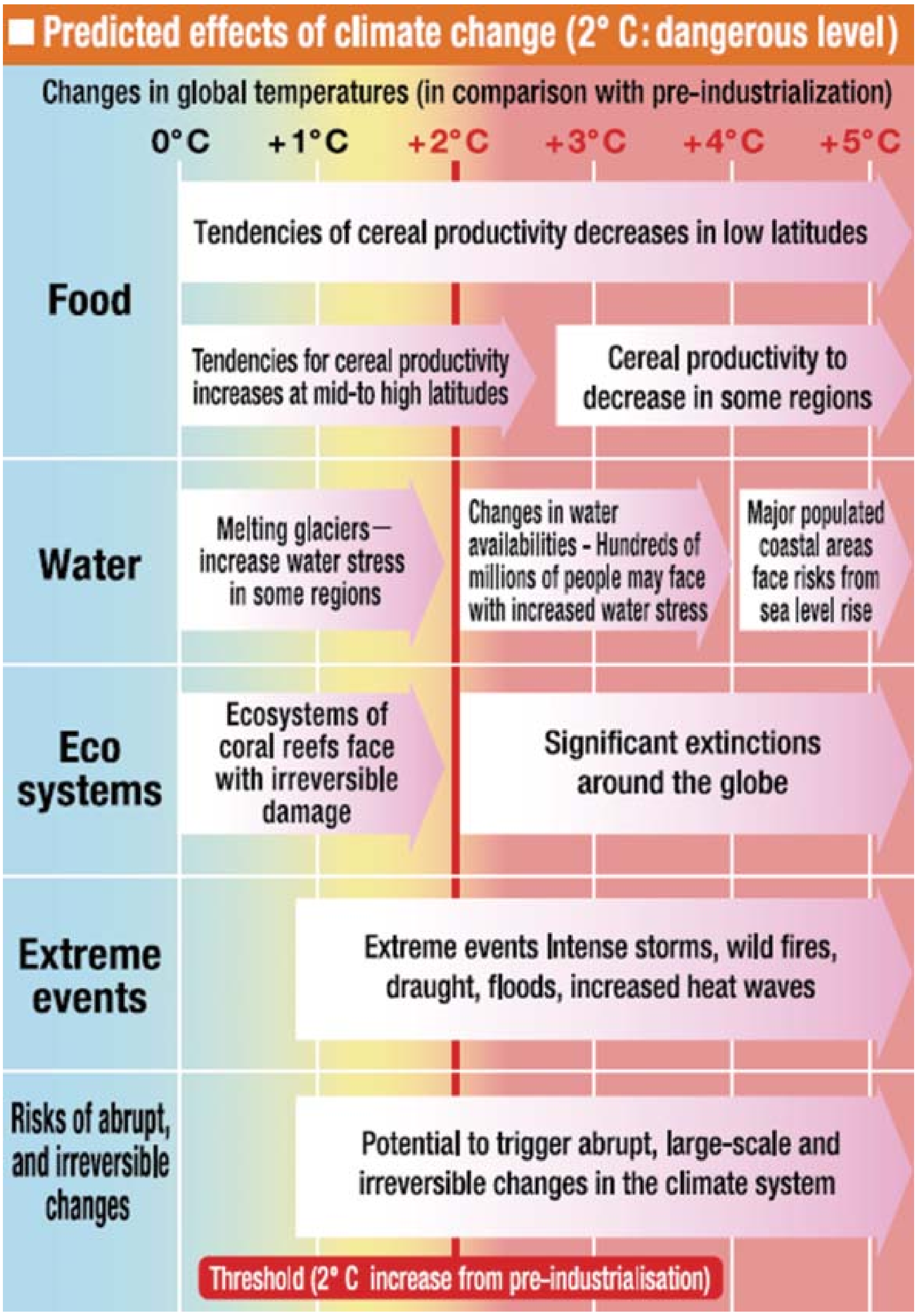


Figure 10. Potential effects of climate change (Source: Figure 1 of LCS-RNet, 2010)

2.1 Why is a transition to a Low Carbon Society essential?

Since, as discussed in Chapter 1, rising global mean temperature and increasing rate of climate change are strongly correlated with increasing levels of GHGs in the Earth's atmosphere, stabilizing the climate requires reducing emissions to a level that can be absorbed by nature. A drastic reduction in GHG emissions, especially carbon emissions, is necessary in order to achieve the internationally agreed goal of limiting anthropogenic warming to less than 2°C. Meeting this target will require global net emissions of GHGs to approach zero in the second half of this century (DDPP, 2015). If we consider the Paris Agreement to be a step towards limiting the temperature increase to 1.5°C, it seems there is no alternative to an early reduction of emissions to the near-zero level. On the other hand, if no mitigation efforts are taken, then the global mean surface temperature could rise by 3.7 to 4.8°C over this century.

Figures 11 and 12 depict the range of GHG emissions trajectories in the RCP scenarios and their effects on the rise in the global mean surface temperature and associated risks. RCP 2.6 is the only scenario that offers a decent chance of the global mean temperature rise being within 2°C and associated risks being barely moderate.

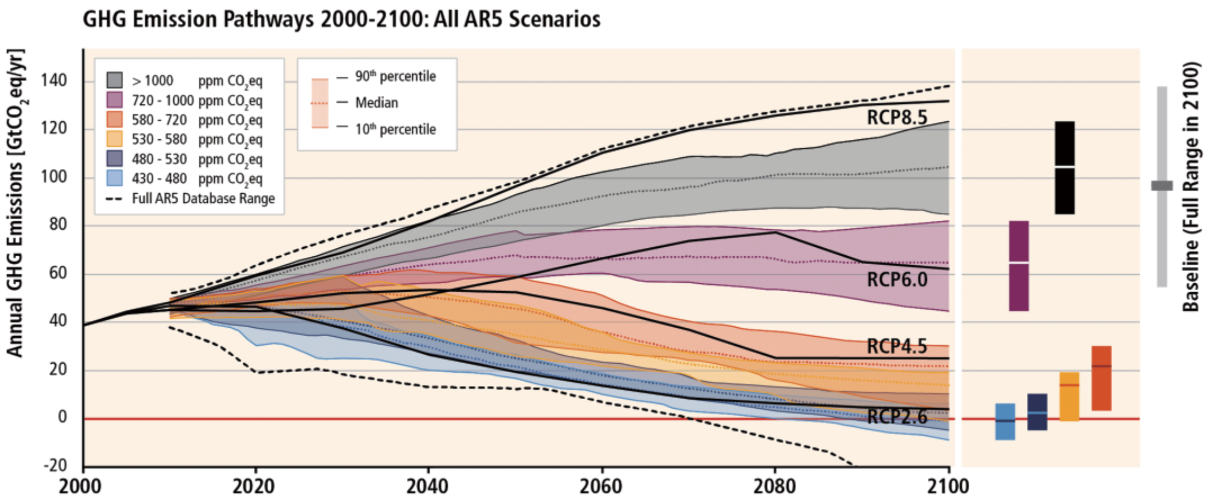


Figure 11. Range of GHG emission pathways and RCP scenarios
(Source: Figure SPM.4 of IPCC WG III, 2014)

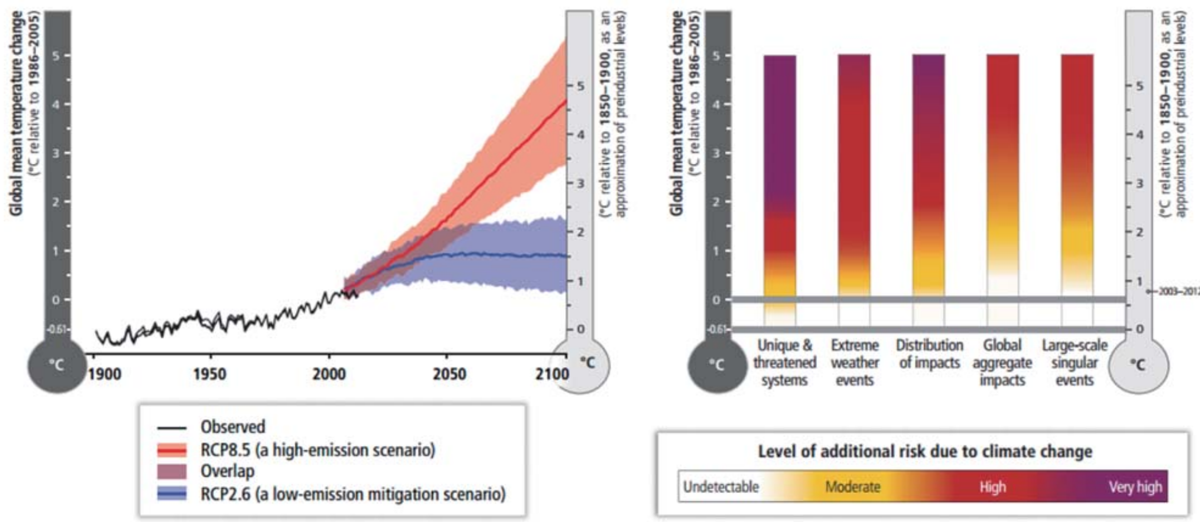


Figure 12. Increasing risks with temperature rise under RCP scenarios
(Source: Assessment Box SPM.1 Figure 1 of IPCC WG II, 2014)

Limiting the warming caused by anthropogenic CO_2 emissions alone with a probability of more than 66% to less than 2°C since the period 1861–1880 will require cumulative CO_2 emissions from all anthropogenic sources since that period to stay between 0 and about 1000 GtC (3670 $GtCO_2$). The upper amount is reduced to about 790 GtC (2900 $GtCO_2$) when accounting for non-CO_2 forcings as in RCP2.6 (IPCC WG1, 2013). Since 555 GtC GHGs have already been emitted until now, the world can afford to emit no more than 235 GtC additional GHGs if it is to prevent dangerous impacts. This could also be inferred from Figure 5 in Chapter 1.

The IPCC has concluded that holding warming to 2°C will probably require emissions to be cut by 40 to 70% by 2050 compared with 2010 levels. Achieving the 1.5°C target would require substantially larger emissions cuts – of the order of 70 to 95% by 2050 (Tollefson and Weiss, 2015).

Thus the 2010 Cancun agreements, and almost all international meetings and agreements since then, including the 2015 Paris conference, have underscored the importance of a paradigm shift toward building a Low Carbon Society (LCS) that offers substantial opportunities and ensures continued high growth and sustainable development (Kainuma and Pandey, 2015). It must be noted that while 'Low Carbon Society' has become a popular term, some groups of researchers and policy makers use other terms, for example 'deep decarbonization', that convey similar intent.

That is, a transition to an LCS is necessary for the survival of humankind. IPCC WG III (2014) reports that annual global GHG emissions have increased by about 10 $GtCO_2eq$ between 2000 and 2010. Before this ten-year period, an increase of 10 $GtCO_2eq$ occurred over a 25-year period, i.e. between 1975 and 2000, implying a rapid increase in the average rate of annual GHG emissions over the past few decades. Furthermore, about half of cumulative anthropogenic CO_2 emissions over the past 260 years have occurred in the last 40 years (IPCC WG III, 2014), implying the increase has accelerated in recent decades compared to earlier ones. Therefore if we do not take any action and continue emitting GHGs at the current rate, we face the risk of moving beyond a point of no return after about 2040 or even before that. Hence a majority of scientists agree that the transition to LCS must begin immediately, during the next 10 to 20 years, in order to prevent some of the adverse impacts from becoming irreversible and to reach an LCS somewhere between 2050 and 2100. It is critical for the present generation to take corrective actions so that future generations can survive and live in a sustainable manner.

2.2 Characteristics of an LCS

As name suggests, an LCS is a low-carbon or near-zero-carbon society. However, this simple sounding term refers to a profound concept. An LCS aims to minimize carbon emissions in all sectors while shifting to a simpler and higher quality life and coexistence with nature (Ho and Matsuoka, 2012). According to Skea and Nishioka (2008), an LCS takes actions that are compatible with the principles of sustainable development, ensuring that the development needs of all groups within the society are met and an equitable contribution is made toward the global effort to stabilize the atmospheric concentration of CO_2 and other GHGs at a level that will avoid dangerous climate change, through deep cuts in global emissions. Another definition of an LCS is a society that adopts patterns of consumption and behaviour that are consistent with low levels of GHG emissions (LCS-RNet, 2010). Realizing an LCS entails radical changes in technologies, energy systems, production and consumption patterns, social value systems, and lifestyles (Kainuma *et al.*, 2013). Let us look at some of these aspects in the following sub-sections.

2.2.1 LCS and energy

Energy supply and use, especially the dependence on fossil fuel burning and inefficient end-use, in various economic and other activities has been a major source of carbon emissions. Therefore major changes in energy systems are needed to mitigate the problem. The present energy systems characterized by low efficiencies and high carbon intensities are inherent to the design of high carbon societies. Almost all global and national studies of LCS or drastic reduction of GHG emissions conclude that both improvement in energy efficiency and change in energy mix toward renewable energy and other low-carbon energy sources, among other measures, are integral to achieving low carbon targets. Reilly (2013) insists that in the longer term, with the goal of atmospheric stabilization, virtually no fossils fuels can be used unless the CO_2 is somehow removed from the fuels, smokestacks, or air. In addition a majority of studies also emphasize the importance of demand-side measures. Kainuma *et al.* (2013) assert that decreasing final energy demand in the demand-side sectors and decarbonization in the energy supply sectors will play an important role in achieving the 2°C climate target.

The relationship of LCS with energy can be understood by exploring the Kaya identity (Equation 1).

$$Emission = \left(\frac{Emission}{PrimaryEnergyConsumption}\right) \times \left(\frac{PrimaryEnergyConsumption}{GDP}\right) \times \left(\frac{GDP}{Population}\right) \times Population \quad (1)$$

This identity shows the main factors which determine the total emissions in a country, region, or the world. The first term measures the average emission intensity (or, carbon intensity in case of CO_2 emissions) of primary energy. Mitigating this factor implies a reduction in the carbon intensity of primary energy. This could be achieved by either changing the primary energy mix toward greater shares of cleaner energy sources or reducing the emission from fossil fuels by appropriate technological treatment. The second term measures the average primary energy intensity of a unit of economic activity. Mitigation of this factor could be achieved by multiple means – reducing end-use energy input in a unit of economic activity by changing the activity's pattern or behavior, improving energy efficiency of the end-use technology or process which serves that activity, changing the end-use technology or process so as to substitute a more efficient energy carrier for an existing one, or substituting non-energy material for energy in the end-use technology or activity. This factor could also be mitigated by improving the efficiency of conversion from primary energy carrier to secondary energy carrier.

The third and fourth terms relate to the economic value and population. These two factors together influence the level of economic activities or the demand for all services or activities which use energy. While reducing this demand is certainly one of the options to mitigate emissions, it has limited prospects in the contemporary world in which there are widespread economic disparities across regions, countries, states, prefectures, cities and villages, and where vast populations, especially in the developing world, do not have access to basic livelihood inputs such as employment, adequate housing, clean water, food, healthcare, education and electricity. Therefore it is the first and second terms of equation (1) – both closely related to energy supply and use – which offer the maximum intervention potential to achieve LCS.

Figure 13 depicts the decomposition of the change in total annual CO_2 emissions from fossil fuel combustion by decade and four driving factors: population, income (GDP) per capita, energy intensity of GDP, and carbon intensity of energy. Globally, economic and population growth continue to be the most important drivers of increases in CO_2 emissions from fossil fuel combustion. Between 2000 and 2010, both drivers outpaced emission reductions from improvements in energy intensity (IPCC WG III, 2014). However, as mentioned before, bringing about change through policies and other human interventions in these two drivers has limited prospects. LCS must be achieved primarily through intervening in the domains of the carbon intensity of energy and energy intensity of GDP. Therefore, severe reductions would be required in the latter two factors. This magnitude of reduction would likely entail changes in not only technology systems but also socio-economic structures and behaviors.

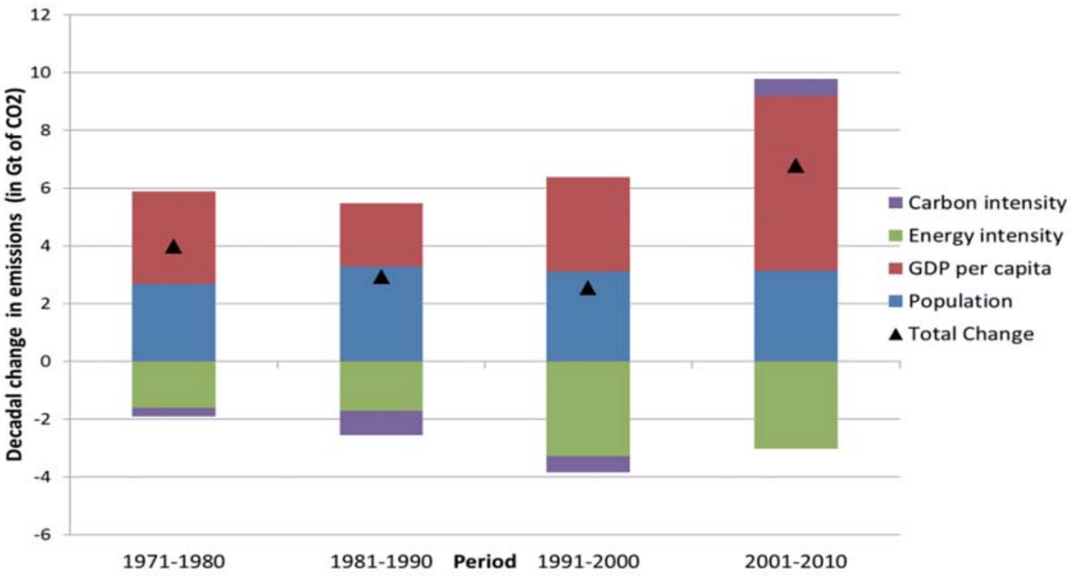


Figure 13. Decomposition of decadal absolute changes in global energy related CO_2 emissions
(Source: Figure SPM.3 of IPCC WG III, 2014)

2.2.2 LCS and sustainable development

In September 2015, countries adopted the historic United Nations' 2030 Agenda for Sustainable Development: goals and targets to end poverty, protect the planet from degradation, ensure prosperity and foster peaceful, just and inclusive societies (UN, 2015). By including GHG emissions reduction and renewable energy in its objectives, the 2030 Agenda for Sustainable Development embraced climate change mitigation goals. Likewise, forums and agreements on climate change are increasingly stressing integration with sustainable development goals.

The Cancun Agreement of 2010 and Paris Agreement of 2015, while emphasizing transition toward LCS, underscore the importance of sustainable development. IPCC WG III (2014) states that limiting the effects of climate change is necessary to achieve sustainable development and equity, including poverty eradication. At the same time, some mitigation efforts could undermine actions on sustainable development, poverty eradication and equity. Consequently, a comprehensive assessment of climate policies involves going beyond a focus on mitigation and adaptation policies alone and to examine development pathways more broadly, along with their determinants.

Sustainable development was defined by the Report of the World Commission on Environment and Development (Brundtland Commission, 1987) as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." In other words, sustainable development requires the balancing of social, economic and environmental objectives of a society. As the use of natural resources including energy is inherent in the growth and sustenance of economic activity, and that, in turn, impacts the environment and biosphere including the climate change, the ideas and goals of LCS and sustainable development are strongly correlated.

The report of the Asia-Pacific Integrated Modeling Team (2007) makes a strong case for aligning development and climate actions as an endogenous process of shaping the development path along a sustainable trajectory.

It views the domestic sustainable development goals of nations such as improving local pollution, land conservation and resource use as the driving force for transitioning to an LCS. Hashimoto and Moriguchi (2013) highlight the importance of reducing the use of carbon intensive materials by means of demand management, weight saving, substitution, lifetime extension and recycling in order to achieve GHG emission reduction. Such measures fall in the category of sustainable use and management of resources.

While the correlation between LCS and sustainable development is well recognized, there are two perspectives on this relationship. The conventional view emphasizes co-benefits of climate change mitigation and adaptation actions for sustainable development goals such as improving local air quality or land conservation. This approach intends to ensure that climate actions are not adversarial to local or national development goals. The alternate perspective views climate change from the lens of sustainable development. It acknowledges that driving forces of emissions as well as adaptive and mitigative capacities are shaped by development paths. It views the aligning of development and climate actions as an endogenous process of shaping the development path along the sustainable trajectory (Asia-Pacific Integrated Modeling Team, 2007). This latter perspective has gained increasing support among a number of researchers and policymakers, especially from the developing countries.

It must be evident that transitioning to a sustainable development path necessitates a change in lifestyles as well. Besides helping to achieve an LCS, such a path could be justified by other benefits. A GEA (2012) report demonstrates that the twin goals of energy and sustainability generate substantial benefits across multiple social and economic objectives besides cutting GHG emissions. It also makes an important point that such an approach is practical, as the measures which lead to local and national benefits of health, environment and economy may be easier to adopt than those measures which are global and long-term in nature.

2.3 Feasibility of achieving LCS

The IPCC report shows that a path to halving current GHG emissions by 2050 is reasonable in order to attain the goal of not exceeding a 2°C temperature rise. The RCP2.6 scenario indicates that in order to avoid a 2°C rise, the target of achieving a 50% GHG emission reduction from now is both feasible and reasonable. This implies average per capita GHG emissions of about 2 tCO_2 per year in 2050.

Several research studies such as DDPP (2015), Low-Carbon Asia Research Project (2013), Kainuma *et al.* (2013), Fujimori, Masui, and Matsuoka (2013), GEA (2012), ETP (2012) and others have demonstrated through thorough analyses that it is possible to achieve such drastic reductions in GHG emissions in almost all regions of the world while accommodating expected economic and population growth.

As an example, the Low Carbon Asia Research Network (LoCARNet) and Asia-Pacific Integrated Modeling (AIM) team carried out an analysis of an LCS scenario for Asia and reported its feasibility through a set of ten actions. A Declaration made at a meeting of Asian researchers and policy makers in Malaysia made some interesting points about the implementation feasibility and success of achieving LCS in Asia (see Box 2).

As another example, a collaborative study of research teams from 16 countries that represent 74% of current global CO_2 emissions from energy was carried out by DDPP (2015). It showed that while assuming expected population growth of 17% on average and aggregate GDP growth of 250% among the 16 countries during the 2010-2050 period, in the most ambitious scenario the total energy-related CO_2 emissions could be reduced to 48 to 57% below 2010 levels, consistent with meeting the 2°C target (Figure 14). This implies a reduction in average emissions per unit of GDP by 87% relative to 2010, or to a level of 2.1 tCO_2/capita in 2050, across those countries (Figure 15).

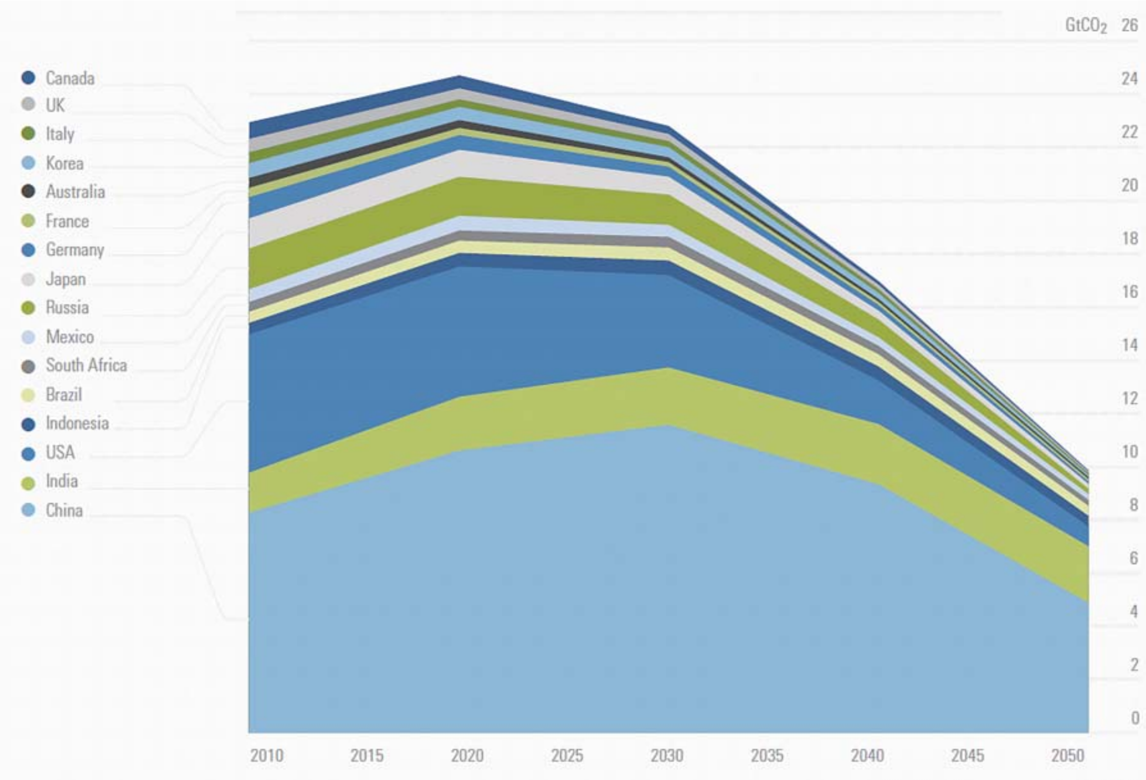


Figure 14. Emissions trajectories for energy CO_2, 2010-2050, showing most ambitious but feasible reduction scenarios for sixteen countries (Source: Figure 1 of DDPP, 2015)

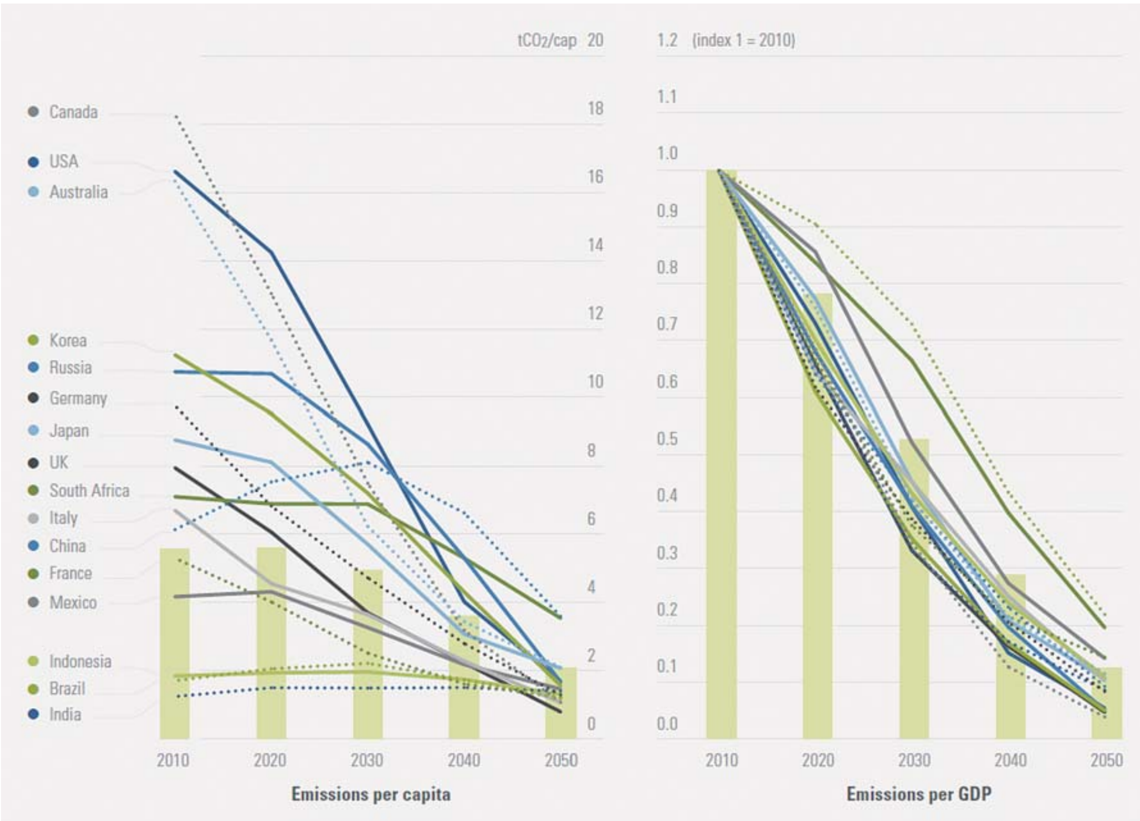


Figure 15. (L) Energy-related CO_2 emissions per capita; (R) Energy-related CO_2 emissions per unit of GDP for sixteen countries, 2010-2050, indexed to 2010 (Source: Figure 2 of DDPP, 2015)

High carbon lock-in from long-life energy technologies is a particularly relevant concern for future investment by developing countries, as they are projected to account for over 90% of the increase in primary energy demand by 2035 (IEA, 2011). The relative lack of existing energy capital in many developing countries bolsters potential opportunities to develop new energy systems, and hence reduce the effective carbon lock-in from broader energy infrastructures, or the very long life capital stock embodied in buildings and urban patterns (Guivarch and Hallegatte, 2011; Jaccard and Rivers, 2007). Hence leapfrogging to new and low-carbon capital investments is a distinctly feasible possibility for the vast majority of developing and emerging economies.

Box 2. Necessity and Feasibility of LCS in Asia

GHG emissions from Asia accounted for about 38% of global emissions in 2005 and are projected to double if no effort is made toward achieving Low Carbon Societies. At the same time, there is the potential to reduce GHG emissions by 69% compared to the reference case in Asia. The figure below depicts the feasibility of a 69% reduction in GHG emissions in Asia by undertaking ten actions. These actions are described in Section 3.2 of Chapter 3.

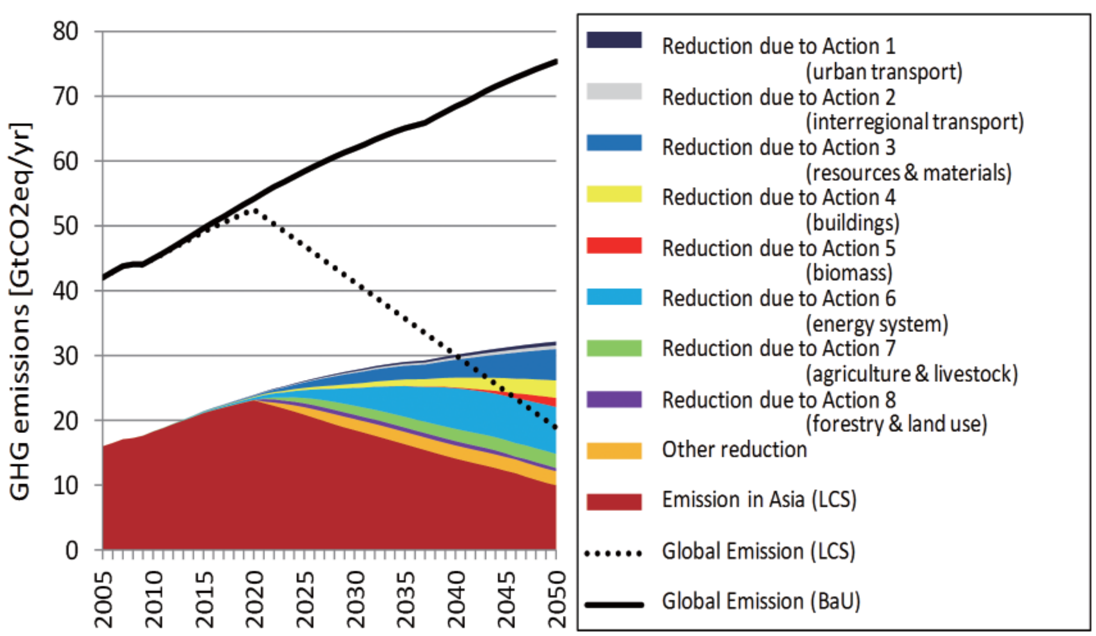


Figure. Contribution of ten actions toward Asia LCS

The LoCARNet Iskandar Malaysia Declaration, released in 2015 in Malaysia by the Low Carbon Asia Research Network, stated that transformation of Asian economies into sustainable low carbon economies by embracing green growth needs to be accelerated, and it could be achieved by leveraging Asian wisdom that espouses frugality, collective action, a sufficiency economy and mutual benefits for all, through inclusive and enabling policies that empower people to take positive climate stabilization actions, by designing policies that are not only based on good scientific evidence but are also feasible in terms of implementation. The Declaration called for an emphasis on new opportunities and possibilities for economic growth in Asia arising out of climate change mitigation and adaptation actions. It stated that with the support of smart partnerships in the form of North-South and South-South cooperation to enhance capacity building, mutual learning, technology transfer, technical assistance and financial aid, Asia could transition toward a resilient LCS that is compatible with an increase in average surface temperatures limited to 1.5° to 2°C compared to the pre-industrial level.

Source: Low-Carbon Asia Research Project, 2013

03 Energy and Socio-economic Systems to Realize an LCS

Transitioning to an LCS will entail a profound transformation of energy systems through deep declines in carbon intensity in all sectors (DDPP, 2015). In this chapter we shall review the major components of energy and socio-economic systems that are likely to form essential parts of an LCS, as reported by various energy and climate modeling and research teams.

The main components of realizing an LCS are: 1) decarbonization in power generation, 2) substitution of electricity for direct use of fossil fuels in buildings and industry, and in part for transportation fuels, 3) reduction of energy demands through energy efficient technologies and other substitutions, such as sustainable resource use.

Kainuma and Pandey (2015) reviewed several LCS scenarios analyzed by various energy emissions modeling expert teams. These scenarios vary along both the temporal and spatial dimensions, i.e. the time horizon or target year selected for drastic carbon mitigation, and the spatial or geographical politico-economic entity analyzed. The time horizon varies from short-term (up to about 2025) to medium-term (up to 2050) to long-term (up to 2100). Spatial coverage ranges from city level to country level to the entire world. The global- and regional-scale scenarios reviewed were: Kainuma *et al.* (2013); GEA (2012); WEO (2012); ETP (2012); and Fujimori, Masui, and Matsuoka (2013). The country-level scenarios were: for Japan, Asia-Pacific Integrated Modeling Team (2007); for China, Jiang *et al.* (2013); for India, Shukla *et al.* (2011) and Shukla, Dhar, Mahapatra (2008); for Brazil, La Rovere *et al.* (2013); for Thailand, Limmeechokchai (2010); and for Nepal, Shrestha and Shakya (2012). Local-scale province and city-level scenarios were: for Kyoto, Japan, Gomi, Ochi, and Matsuoka (2011) and Gomi, Shimada, and Matsuoka (2010); for Bhopal, India, Gomi, Deshpande, and Kapshe (2013); for Iskandar, Malaysia, Ho and Matsuoka (2012); and for Gyeonggi Province, Republic of Korea, Lee *et al.* (2012).

A summary of results of these LCS scenarios is provided in Table 2. There are several common features among the scenarios, whereas certain other features vary across scenarios. The variations are either the result of region- or country-specific characteristics (for example, the domestic energy resource base and present level of technological advancement) or the result of certain scenario-specific assumptions made by the modeling team.

In the global- and country-level LCS scenarios, the common features are the rapid increase of renewable energy technologies and conversion efficiency on the energy supply side and the diffusion of energy efficiency measures in the energy demand sectors. Variations among these scenarios are seen largely with respect to the availability of nuclear and carbon capture and storage (CCS)[12] technologies, and the extent of a sustainable supply of biomass and biofuels, which hinge on differing assumptions about the future availability and acceptability of these options. The scenarios also differ in terms of the relative contributions of demand side vis-à-vis supply side interventions to total GHG reduction. These results are influenced by assumptions about the range of low-carbon technologies available in the energy supply sectors and the impact of behavioral changes in demand sectors.

The local region- and city-level LCS scenarios also project renewable energy options, including decentralized ones in residences and other end-use sectors. However, more importantly, they emphasize several efficiency

12 Carbon capture and storage (CCS) (or carbon capture and sequestration) refers to the technology or process of capturing waste CO_2 from fossil fuel power plants or other CO_2-emitting industries and facilities, transporting it to storage sites, and depositing it safely (typically in underground geological formations) such that it will not enter the atmosphere.

improvement measures and behavioral changes in end-use sectors of residential, commercial, transportation and industry. Certain measures like redesigning cities, the exact mode-mix for urban public transportation, and reforestation and biomass supply depend on the characteristics of the specific urban and rural regions.

Table 2. **Summary of the results of LCS scenarios: Common and varying characteristics of energy and socio-economic systems**

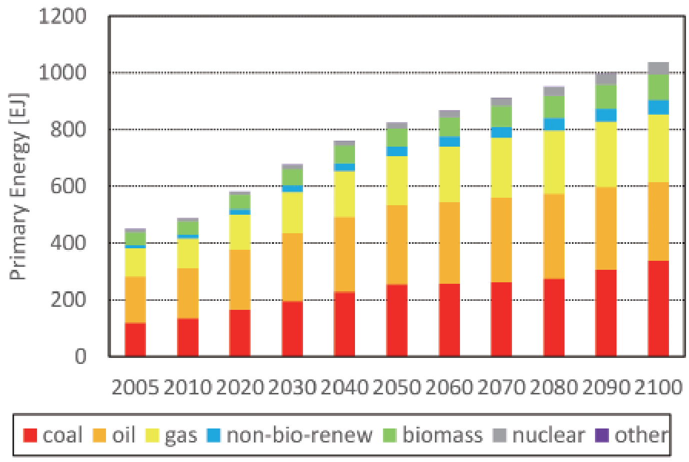
Scenario type	Measure type	Energy supply side	Energy demand side
Global and country scenarios	Common features	• Renewable energies – solar, wind, biomass • Conversion efficiency improvement	• Energy efficient technologies and other measures in end-use sectors • Demand reduction eases burden on supply side and saves cost
	Features varying across regions and scenarios	• Extent of nuclear power • Extent of CCS deployment • Extent of biomass and biofuels	• Relative contribution of demand side measures to total carbon reduction • Behavioral changes and their extent
Local and city level scenarios	Common features	• Renewable energies – both centralized and de-centralized options	• Energy efficient technologies in residential, commercial industry and transport sectors • Urban public transport systems • Behavioral changes toward eco-friendly lifestyle
	Features varying across regions and scenarios	• Mix of renewable energy sources • Extent of biomass and biofuels	• Urban design/compact city • Mode-mix for urban transportation • Reforestation • Extent of behavioral changes

(Source: Kainuma and Pandey, 2015)

Figure 16 depicts an example of results from a LCS scenario analysis, carried out by NIES and MHIR (2015), which shows the contributions of energy supply and demand side measures to drastic GHG mitigation. It compares global primary energy supply in an 'LCS-type' mitigation scenario with that in a reference (i.e. no mitigation) scenario. The mitigation scenario corresponds to meeting the Copenhagen pledges[13] for 2020 made at the Copenhagen Accord, meeting INDC[14] commitments by various countries in 2030, followed by mitigation policies to achieve the target of keeping the global mean temperature rise by 2100 to less than 2°C above pre-industrial levels. In the mitigation scenario, global GHG emissions peak out by 2030 and then decline steadily to zero toward the last decades of this century. This is achieved by a combination of demand-side and supply-side measures. Global primary energy supply in 2100 in the mitigation scenario is about 60% of its level in the reference scenario, largely due to energy savings on the demand-side. In addition, the energy mix on the supply side changes radically from fossil fuels to non-fossil energy, with renewable energy comprising about 75% of total supply in 2100. Let us now look at some of the measures listed in Table 2 in detail.

13 The "Copenhagen pledges" made at the Copenhagen Accord refer to non-binding GHG emissions targets for 2020 set by developed countries at the UNFCCC Conference of Parties at Copenhagen in 2009. See Section 4.1 of Chapter 4.

14 Intended Nationally Determined Contributions (INDCs) are post-2020 climate actions that countries put forward in the lead-up to the UNFCCC Conference of Parties at Paris in 2015, which countries have committed to take to reduce GHG emissions by 2025 or 2030. See Section 4.1 of Chapter 4.



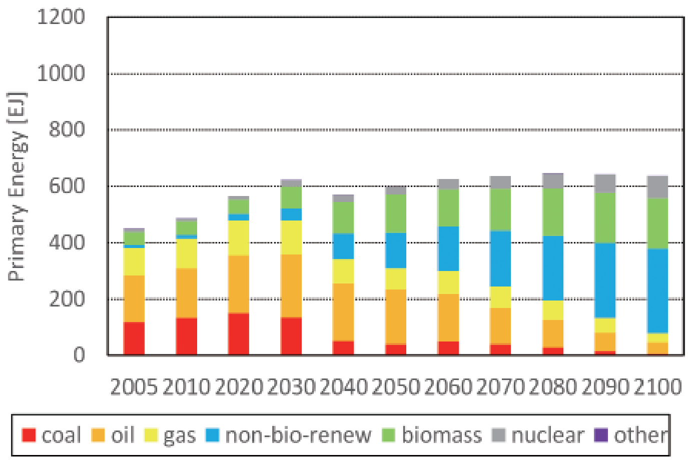


Figure 16. **Trends of global primary energy supply under reference scenario and an 'LCS-type' mitigation scenario to achieve the 2°C target**

(Source: NIES and MHIR, 2015)

3.1 Energy supply side measures

Decarbonization of the energy supply is the most important contributor to GHG reduction in almost all LCS scenarios. The energy supply side interventions rely primarily on renewable energies like solar, wind, biomass and hydro to the extent that these sources almost completely replace fossil fuels in 2050, if the target of a global GHG reduction of 50% in 2025 as compared to the 1990 level is to be met (Kainuma *et al.*, 2013). When CCS and nuclear options are not easily available or acceptable, the energy demand side options of end-use efficiency improvements and behavioral changes also contribute significantly to meeting the reduction target, which will be discussed in Section 3.2.

The Global Energy Assessment Council, composed of experts from different countries, explored various scenarios up to 2100 with multiple goals of (i) global CO_2 emissions from the energy sector peaking around 2020 and declining thereafter to 30 to 70% below 2000 levels by 2050, and reaching almost zero or net negative emissions in the second half of the century, (ii) achieving universal access to electricity and cleaner cooking fuels by 2030, (iii) meeting WHO air quality guidelines by the majority of the population by 2030, and (iv) enhancing energy security by limiting dependence on imported energy and by increasing the diversity and resilience of energy systems (GEA, 2012). Results showed that together with significant end-use efficiency measures energy supply sectors would be able to meet the goals through the radical diffusion of renewable energy options. In one of its scenarios renewable energy reaches 75% of primary energy by 2050 and 90% by the end of the century, with CCS providing an optional bridge for the medium-term transition toward renewables.

World Energy Outlook 2012 (WEO, 2012) of the International Energy Agency (IEA) set out the 450 Scenario, which examines the actions necessary up to 2035 to achieve the 2°C target. The scenario mandates peaking of global CO_2 emissions before 2020. Renewables would account for 21% of emissions reductions, with solar energy growing most rapidly among them, and biomass (for power generation) and biofuels growing four-fold with rising international trade. WEO's 450 Scenario states that if CCS technology is not deployed widely then no more than one-third of proven fossil fuel reserves can be consumed before 2050. This underscores the overwhelmingly important role that renewable energy sources and technologies will play in future low carbon societies.

IEA's Energy Technology Perspectives' ETP 2012 2°C Scenario, 2DS, explores the options up to 2050 needed to realize both the 2°C target and a sustainable future (ETP, 2012). It finds that while significant additional investments in clean energy and energy efficiency are required until 2050, they would be outweighed by fuel savings. In addition, there will be co-benefits of enhanced energy security, reduced fossil-fuel import bills, and improvements in local air pollution. Energy security will be achieved not only through reduced energy intensity but also through the geographical and technological diversification of energy sources resulting from increases in renewable energies. The share of renewable energy in total world electricity generation will have to increase from 19% in 2011 to 57% by 2050, corresponding to a six-fold increase in absolute terms. The use of coal in 2050 will be 45% lower than in 2009, oil use will fall by more than 50%, and natural gas use will increase by 10% as it provides flexibility to complement variable renewable energies in power generation. ETP's 2DS also emphasizes the role of CCS, especially to limit the burden of additional investments in the power sector.

Global and Asia scenarios with a 50% global GHG reduction target in 2050 (compared to the 1990 level) were analyzed by Fujimori, Masui, and Matsuoka (2013) with and without advanced technology options like CCS. In the advanced technology scenario, biomass with the CCS option will increase substantially in both the world and Asia, whereas in the conventional scenario (without advanced technologies), total energy supply will have to be reduced (which is discussed in Section 3.2) and the shares of non-fossil energies such as solar, wind and nuclear energy will rise.

In addition to global and regional LCS scenarios, country-level LCS scenarios have been analyzed by several researchers. For instance, the Asia-Pacific Integrated Modeling Team (2007) analyzed two LCS scenarios for Japan up to 2050 – one with high technical progress and high growth (A), and the other with a low growth, decentralized and community-centric development model (B). The LCS target was a 60 to 80% GHG reduction in 2050 compared to the 1990 level. The results showed many trend-breaking options in the two scenarios, but with different mixes. Both scenarios indicated the importance of renewable energy options such as solar PV, wind and biomass, but with crucial distinctions. One was that interventions on the energy demand side determine the extent of the changes and effort required on the energy supply side. A second was that in Scenario B the decentralized energy supply options could further reduce the burden on the energy supply side by a significant extent. Demand side options will be discussed more in Section 3.2.

In the LCS scenarios for 16 countries analyzed by DDPP (2015), electricity becomes nearly carbon free by 2050, with average emissions per kWh reduced by a factor of 15 below the 2010 value. This was accomplished by replacing fossil-fuel based electricity generation with varying mixes of renewable energy such as wind, solar, geothermal, and hydropower, and in some cases, nuclear power and fossil fuel generation with CCS. In addition, liquid and gas fuel supplies were decarbonized using biomass fuels and synthetic fuels such as hydrogen produced from decarbonized electricity.

Most of the LCS scenarios discussed so far essentially recommend rapid diffusion of renewable energy options together with demand side efficiency improvement, and sometimes balanced with technologies such as natural gas, CCS and nuclear in order to mitigate cost impact. Therefore, from the energy supply side perspective, these recommendations amount to changing the fuel mix drastically toward a low-carbon one, but they do not say much about the fundamental structure of energy production and use. One particular scenario – Scenario B set forth by the Asia-Pacific Integrated Modeling Team (2007) mentioned in the previous paragraph – explores decentralized supply and use of energy in Japan, and thereby looks at a shift in the structure.

Another study titled "Ten Actions toward Low Carbon Asia" carried out by Low-Carbon Asia Research Project (2013) reports ten sets of actions to achieve LCS in Asia and recommends actions at a concrete level. It also goes beyond changing the fuel mix and end-use efficiency, emphasizing a shift toward sustainable local production and local use based on local resources. Even though it does not quantify the extent of change required in societies' production-consumption structure, it points to the limitations of existing centralized energy supply and use structures and the need to explore alternate paradigms by questioning those limitations.

Of these ten sets of actions to achieve LCS in Asia (Figure 17), two sets – 'Low Carbon Energy System using Local Resources' and 'Local Production and Local Consumption of Biomass' – cover energy supply transition to a good extent. The set of actions under the low carbon energy system using local resources could contribute up to 37% of the total GHG reduction needed for a Low Carbon Asia, the greatest amount achieved by any single set of actions. Its contribution is likely to be even greater in countries like Japan, China and India. It includes actions such as promoting sustainable local energy systems with renewable energy options of solar and wind; creating smart energy supply systems that will enhance efficiency of supply; and integrating renewable energy and fossil energy systems so as to ensure energy security. The set of actions under local production and consumption of biomass could contribute up to 4.7% of the total GHG reduction toward a Low Carbon Asia. This includes sustainable co-production of biomass for energy and food, with local biomass resources converted to useful energy and supplied and utilized locally.

It must be noted that the options of local production and use of energy cannot be discussed comprehensively without adequate understanding of demand side interventions. This is because their design and implementation integrate local and decentralized energy supply options and demand side options. Moreover, as several LCS scenario results indicate, end-use side interventions not only contribute directly to GHG reductions but also reduce the cost, and thereby enhance the viability, of energy supply side interventions. Therefore, let us now look at the demand side characteristics of low carbon energy and socio-economic systems.

3.2 Energy demand side measures

In the two LCS scenarios analyzed for Japan by the Asia-Pacific Integrated Modeling Team (2007), the Scenario A simulation indicated similar levels of GHG reduction on the energy supply and demand sides, with energy efficient and new technology options on the supply side including CCS, nuclear power and renewable energies, and similarly efficient and new technologies on the energy demand side. The Scenario B simulation indicated a much greater GHG reduction on the energy demand side, with lower levels of demands of energy and materials, increased use of electricity and diffusion of decentralized renewable energy options like solar PV and biomass. The energy supply side, now needing to meet a lower energy demand, could do so primarily with renewable energies like solar, biomass and wind.

These findings offer two important lessons for LCS design and transition. Firstly, radical changes in the energy supply mix toward renewable energies would become sufficient and viable interventions on the supply side if energy demand is cut considerably through demand side interventions. Sufficiency of energy supply based on renewable energies is ensured by the reduction in demand that needs to be met. Its viability is supported by the major cost savings that reduced energy demands in various end-use sectors yield. Secondly, in order to achieve considerable cuts, demand side interventions need to include multiple options such as enhanced efficiencies in energy conversion in end-use devices and other production processes, leading to lower requirements of energy and materials; greater electrification of end-use devices and processes; and greater reliance on decentralized renewable energy systems that use local resources of solar, wind and biomass. The last option, even though it is an energy supply option, could be considered a demand-side intervention if it is initiated by local households, communities, commercial units and industries.

Most of the LCS scenario studies cited in Section 3.1, even though they do not analyze demand side options in detail, do point to their relevance as well as feasibility at aggregate levels. For example, Kainuma *et al*. (2013) find that while investments under the LCS scenario without CCS and nuclear are higher due to the need to build larger capacities of renewable energy technologies quickly, the cost savings achieved through energy efficiency gains are also higher. ETP's 2DS scenario (ETP, 2012) also reports that, while significant additional investments in clean energy and energy efficiency are required until 2050, the costs will be outweighed by fuel savings.

ETP's 2DS scenario (ETP, 2012),which analyzes the 2°C target and a sustainable future, demonstrates its feasibility if the rate of annual energy efficiency improvement doubles from the last four decades' average, to 2.4% during 2011 to 2050. In the conventional scenario of Fujimori, Masui, and Matsuoka (2013) that does not consider advanced technologies like CCS, total energy supply is reduced as a result of improvements in energy intensity at over 4% per year, which are largely achieved through extensive end-use efficiency measures.

One of the scenarios analyzed by GEA (2012), called "GEA-Efficiency" pathways, emphasizes very high rates of efficiency improvements in the demand sectors, leading to only a 42% increase in primary energy demand in 2050 from the 2005 level. Energy supply sectors are able to meet this reduced demand primarily through renewable energy, which will reach 75% of primary energy by 2050 and 90% by the end of the century. Comparison with another scenario, GEA-Supply, shows that with a modest energy efficiency improvement rate (than what is assumed in GEA-Efficiency) primary energy demand during 2005-2025 will increase by more than twice and energy supply sectors can meet such high demand levels only by relying on both renewables and fossil CCS, as well as more rapid up-scaling of capacity. Another of GEA's scenarios, called "GEA-Mix" pathways, emphasizes regional and local diversity of energy supply and technology portfolios, reflecting local choices and resource endowments, and reveals the importance of greater multiplicity of fuels in demand sectors, especially biofuels and electricity in the transport sector.

WEO's 450 Scenario reports that four-fifths of the CO_2 emissions allowable by 2035 are already locked-in by existing power plants, factories and buildings. It argues that rapid and early deployment of energy efficient end-use technologies which are economically viable would postpone complete lock-in to 2022 by reducing the growth in primary energy demand. Such energy efficiency measures can contribute to more than half of the required emissions reduction up to 2035 (WEO, 2012).

In the LCS scenarios analyzed for 16 countries as part of the DDPP (2015) study, energy efficiency improvements reduce the energy intensity of GDP by an average of 65% during 2010-2050 through measures such as improving vehicle fuel economy, better building design and construction materials, more efficient appliances, industrial processes and machinery, and conservation measures such as urban design to encourage walking and bicycling. In addition, much of the direct combustion of fossil fuels in end-use equipment such as automobiles, hot water heaters, and industrial boilers is replaced by decarbonized electricity, which more than doubles the share of electricity in final energy consumption in 2050, to over 40%.

The import of demand side measures is highlighted even more by sub-national and local- level LCS studies. Such studies have been carried out with a view to exploring mitigation options that are closer to ground- level realities along with concrete actions that local stakeholders can undertake. Evidently, most of these scenarios have shorter horizons than national and global scenarios and, by virtue of being closer to the reality on the ground, they consider demand side options in greater detail. The next paragraphs will overview some of these studies.

Gomi, Ochi, and Matsuoka (2011) and Gomi, Shimada, and Matsuoka (2010) analyzed LCS scenarios for the city of Kyoto in Japan, with a GHG reduction of 40 to 45% in 2030 compared to the 1990 level. On the supply side, they recommended the comprehensive use of renewable energy, somewhat similar to what is reported in the national-level studies. However, a greater range of options emerged on the demand side in this local scale analysis – urban redesign including a walkable city, eco-friendly buildings and forest development; behavioral change toward low-carbon lifestyles; and specific measures for the de-carbonization of industries.

An LCS scenario for the city of Bhopal in central India was explored by Gomi, Deshpande, and Kapshe (2013). The target set was a CO_2 reduction of 41% in 2035 compared to BaU[15]. While some of the options selected on the energy supply side, similar to those mentioned in Section 3.1, were expected, a new measure not commonly analyzed at more aggregate levels was also selected, namely the reduction of electricity distribution losses through better monitoring, control and billing mechanisms. This latter measure can qualify as a demand side measure as it improves efficiency in the management of power distribution to (and use by) consumers. Other major demand side measures recommended for Bhopal were efficiency improvement-led reduction of energy demand in residential and commercial appliances, buildings and transportation sectors, and changes in the structure of the transport sector, with integrated management and the use of urban public transportation systems that utilize multiple modes such as bus and rail.

Ho and Matsuoka (2012) explored the LCS scenario for the Iskandar region of Malaysia, with twin targets of a GHG reduction of 40% and a GHG intensity reduction of 56% in 2025 compared to BaU. Expectedly, while about a quarter of the reduction resulted from renewable energy supply options like solar PV and biomass, the majority of the reduction was reported by demand side options. These included energy efficient industry and buildings, compact city policy leading to behavioral change, and urban planning with an integrated transportation system and modal shifts.

Lee *et al*. (2012) analyzed an LCS scenario for Gyeonggi Province in Republic of Korea with a target of a 30% reduction of GHG emissions in 2020 compared to BaU. They recommended a few energy supply measures and many more demand side measures such as growth in forestry and vegetation, changes in lifestyle toward energy saving behavior, adoption of energy efficient devices, and use of urban public transportation.

Similar to sub-national level studies, the majority of the sets of actions recommended in the report of 'Ten Actions toward Low Carbon Asia' by the Low-Carbon Asia Research Project (2013) are on the demand side (Figure 17). Six actions that are fully demand side actions are reported to contribute to about 47% of the total GHG reduction required for LCS in Asia. Two other actions, the ones discussed in Section 3.1, also include demand side components. Taking all these into account, it can be said with confidence that demand side actions can contribute to a majority of the GHG reductions needed to achieve LCS in Asia. Let us look at these sets of actions.

The set of actions titled 'Hierarchically connected compact cities' includes compact city designs with well-connected hierarchical urban centers; a hierarchical urban public transport system; low-carbon vehicles (using electricity, biofuels and natural gas); and efficient road-traffic management systems. These could contribute to 2.2% of GHG reductions in Asia.

'Mainstreaming rail and water in inter-regional transport' is likely to contribute to 3.9% of GHG reduction in Asia. These include forming industrial corridors with low-carbon transport systems; establishing inter-modal

15 BaU refers to the "Business-as-Usual" scenario. It is often constructed as a reference scenario against which mitigation scenarios are compared.

transport systems linking rail and water; and reducing the use of aircrafts and fossil-fuel vehicles.

The actions under 'Smart ways to use materials' could contribute to a significant 17% of GHG reductions in Asia. They include incorporating new and efficient production process technologies that reduce the use of materials; extending the life-span of products; and developing systems to reuse material resources. The resultant GHG reduction is due to reduced energy use required to produce less quantity of materials.

'Buildings and energy-saving spaces utilizing sunlight and wind', another major contributor, could account for 13% of GHG reductions in Asia. This includes improving the energy efficiency of buildings; the application of high-efficiency equipment in buildings, especially for heating and cooling; and providing visibility and incentive to energy saving efforts.

In the set of actions titled 'Local production and local consumption of biomass' that is expected to contribute to 4.7% of GHG reductions in Asia, improvements to the living environment with intensive biomass utilization are largely a demand side action.

A 'Low carbon energy system using local resources' also includes both supply and demand side actions that could together contribute to 37% of GHG reductions in Asia. Demand side actions include smart energy management systems on the end-use side and decentralized small scale renewable energy systems based on locally available resources.

'Low emission agricultural technologies' are likely to contribute to 10% of GHG reductions in Asia. They include actions by farmers such as efficient water management in rice paddies; efficient fertilizer application and residue management; and recovery and use of methane gas from livestock manure (another example of a decentralized renewable energy system).

The set of actions under 'Sustainable forestry management' is expected to contribute to only 1.6% of GHG reductions in Asia. They include forest protection and plantation; sustainable peatland management, and monitoring and management of forest fires.

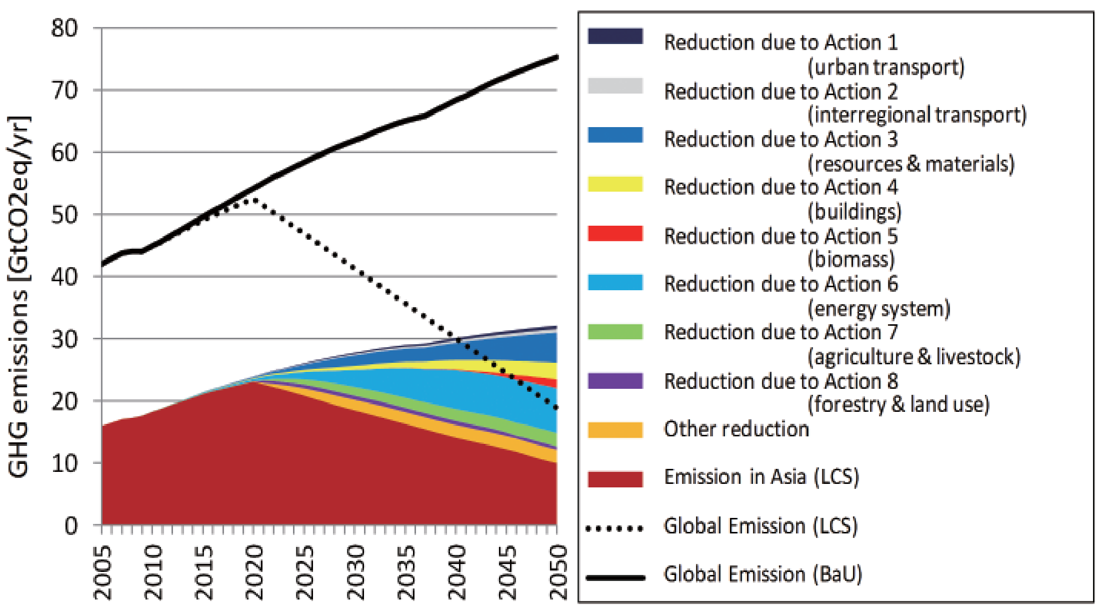


Figure 17. Contributions of ten actions toward low carbon Asia analyzed by Low-Carbon Asia Research Project and its comparison with a global LCS trajectory

(Source: Low-Carbon Asia Research Project, 2013)

04 Policies for LCS

Transition toward an LCS is essentially a process of improving infrastructure over time by replacing inefficient and carbon-intensive technologies with efficient and low-carbon technologies that provide the same services (DDPP, 2015). In addition, the process must induce changes in demand side practices as well. The policies for LCS are therefore the ones being undertaken or proposed at various levels – international, national, local – to set this process in motion.

4.1 The institution and process of the UNFCCC and international and national commitments

IPCC WG III (2014) emphasizes the criticality of international cooperation to effectively mitigate GHG emissions and to further the development, diffusion and transfer of knowledge and environmentally sound technologies. Climate change has the characteristics of a collective action problem at a global scale because most GHGs accumulate over time and mix globally, and emissions by any agent – an individual, community, company, or country – affect other agents. International cooperation is also necessary to resolve concerns of equity and fairness that arise because all countries' past and future contributions to GHGs in the atmosphere are different from each other, and because they face varying challenges and circumstances, each having a different capacity to address mitigation and adaptation (see Figure 18).

Cooperation, not only internationally but also between sectors and agencies within a country, is also essential because "climate policy intersects with other societal goals creating the possibility of co-benefits or adverse side-effects." These include goals related to human health, food security, biodiversity, local environmental quality, energy access, livelihoods, and equitable sustainable development (IPCC WG III, 2014). Climate policies and policies related to these societal goals would most likely influence each other.

The United Nations Framework Convention on Climate Change (UNFCCC) is the main international convention focused on addressing climate change, with nearly universal participation. It was negotiated at the Earth Summit in 1992 and entered into force on 21 March 1994. Its objective is to "stabilize GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." The Parties to the Convention have been meeting annually since 1995 in Conferences of the Parties (COPs) to assess progress in dealing with climate change and to discuss and agree on actions.

One of the important tasks under the UNFCCC has been establishing accounting processes for national GHG inventories and their mitigation. Updated inventories are regularly submitted by many countries.

Some of the important milestones of UNFCCC COPs have been: (i) the Kyoto Protocol, signed in 1997, which established legally binding obligations for developed countries to reduce their GHG emissions in the period 2008-2012; (ii) the 2009 Copenhagen Accord, considered disappointing by many, which endorsed the continuation of the Kyoto Protocol; recognized the scientific view that an increase in global temperature should be below 2°C and deep cuts in global emissions are required; made developed countries commit to (not legally binding) emissions targets for 2020; and made developing countries agree to submit and implement Nationally Appropriate Mitigation Actions (NAMAs), (iii) the 2010 Cancun agreements, which formally set a target for future global warming as below 2°C relative to pre-industrial levels; and (iv) the 2015 Paris Agreement, widely hailed as historic from a political perspective, which made clear that the world must limit global mean temperature rise to well below 2°C and pursue efforts to limit it to 1.5°C, and therefore, achieve a net-zero carbon economy in this century. It prescribed GHG emissions reduction from 2020 onwards through commitments by all 195 participating countries, including, crucially, the developing countries. The Paris Agreement has put in place a 'pledge and review' program that requires voluntary commitments from countries in the form of Intended Nationally Determined Contributions (INDCs). Countries have agreed to publicly outline the actions they intend to take under their INDCs to reduce emissions in the medium time frame, typically up to 2025 or 2030. Countries will assess their progress on reducing emissions in 2018 and revisit their climate pledges every five years, from 2020 onwards. While developed countries have been submitting detailed reports on GHG emissions to the UNFCCC for years, the Paris Agreement mandates most developing countries also to supply inventories of GHG emissions every two years. The Agreement has proposed a transparent system for measuring, reporting and verifying emissions, though many details have been left to be negotiated and worked out in 2016. The process for INDCs links the national policy making process, in which each country determines its contributions to reduce emissions while considering national priorities and domestic circumstances, with a global framework that drives collective action toward LCS. The INDCs will indicate whether the world is put on a path toward a low-carbon, climate-resilient future. Most Parties to the UNFCCC have already submitted their INDCs. A mitigation scenario analysis by NIES and MHIR (2015) indicates that implementation of INDCs is a meaningful step in movement toward an LCS, though it would not be enough to achieve an LCS.

Activities by Parties under the UNFCCC have led to an increasing number of institutions and other arrangements for international climate change cooperation. Existing and proposed international climate change cooperation arrangements vary in their focus and degree of centralization and coordination. They span multilateral arrangements, harmonized national policies, decentralized but coordinated national policies, as well as regional and regionally-coordinated policies (IPCC WG III, 2014).

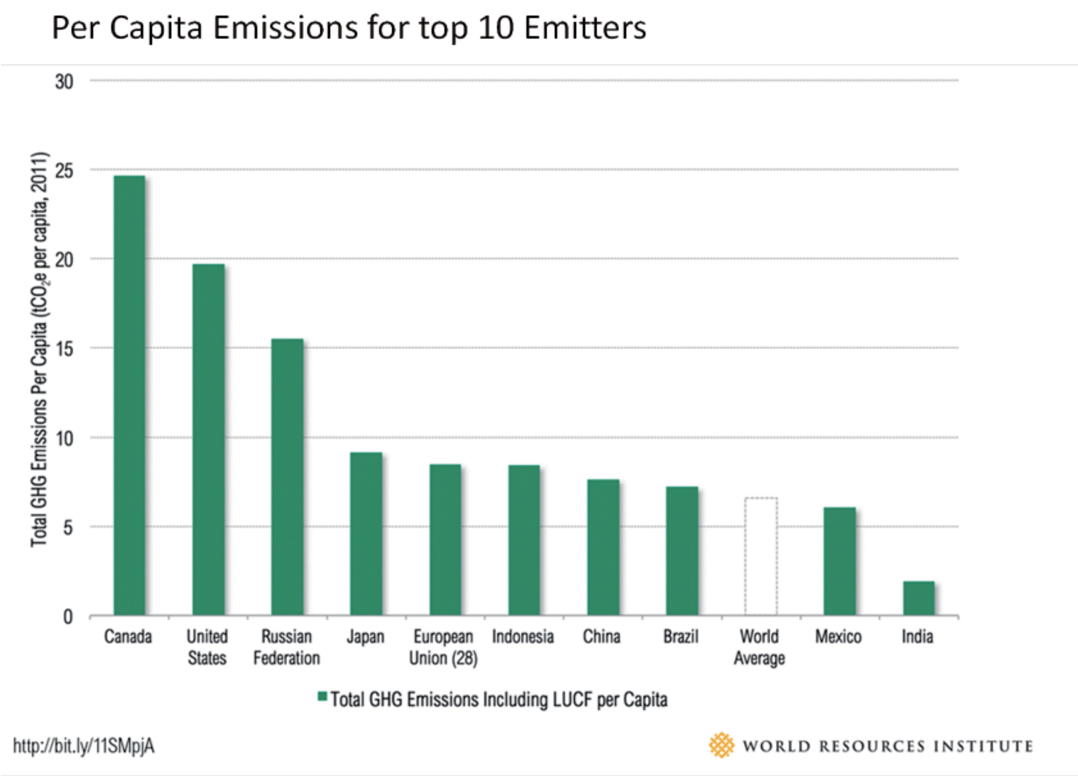


Figure 18. **Wide disparities in national per capita GHG emission in 2011 (tCO_2/capita)** (Source: WRI, 2014)

Another influential and credible international body is the Intergovernmental Panel on Climate Change (IPCC). It is an international body set up in 1988 under the auspices of the United Nations. IPCC carries out the compilation, analysis and synthesis of scientific, technical and socio-economic information relevant to climate change, and produces reports that support work related to the UNFCCC. In doing so, the IPCC draws from the works of thousands of scientists and researchers from all over the world. Delegates from more than 120 participating governments approve the 'Summary for Policymakers' contained in IPCC reports.

Under the Paris Agreement, the IPCC has been directed to study scenarios for limiting warming to 1.5°C, and to deliver a report to nations by 2018 to help them determine how much to strengthen their climate commitments (Tollefson and Weiss, 2015).

4.2 International and country-level initiatives in taxes, trading, financing and knowledge transfer

International and national low-carbon policy initiatives include commitments by several national governments and the introduction of mechanisms such as carbon trading, CDM[16], carbon taxes, and financial incentives.

Various measures to reduce low-carbon investment risks which are already under implementation are climate investment funds, carbon pricing, feed-in tariffs, green building certificates, carbon offset markets, the UK's green investment bank, and several public-private initiatives (World Bank, 2011; GIBC, 2010).

Cap and trade systems[17] for GHGs have been established in many countries and regions. However, their short-term environmental effects have been limited as a result of loose or insufficient caps. Though earlier programs relied almost exclusively on grandfathering (the free allocation of permits), auctioning permits is now increasingly being applied. If allowances are auctioned, revenues can be used to address other investment with a high social return, or reduce tax or debt burdens (IPCC WG III, 2014). A noteworthy development among developing economies is the launch of carbon trading in China. This trading already covers one-third of its GDP and one-fifth of its energy use (Wang, 2013).

In some countries, tax-based policies aimed specifically at reducing GHG emissions, in addition to technologies and other policies, have helped to weaken the link between GHG emissions and GDP. In many countries, fuel taxes have intended or unintended effects similar to sectoral carbon taxes. In some countries, revenues are used to reduce other taxes and/or provide transfers to low income groups, thereby indicating that mitigation policies that raise government revenue generally have lower social costs (IPCC WG III, 2014).

Some countries have reformed their tax and budget systems to reduce fossil fuel subsidies. However significant political barriers remain to implementing this option. Possible adverse effects of reducing subsidies on lower-income groups, who spend a large fraction of their income on energy services, is a valid concern in developing countries. In order to avoid such adverse effects, many governments have utilized lump-sum cash transfers or other mechanisms targeting the poor.

All such international and national policy initiatives have resulted in visible changes in the energy and technology markets. In general, worldwide growth in mature renewable energy technologies – solar PV, onshore wind,

16 The Clean Development Mechanism (CDM) was introduced in the Kyoto Protocol. It allowed a country with an emissions reduction commitment under the Protocol to implement emissions reduction projects in developing countries. Such projects could earn saleable certified emission reduction (CER) credits able to be counted toward meeting Kyoto targets for emissions reductions.

17 Emissions trading or "cap and trade" is a government mandated, market-based instrument that provides economic incentives as well as flexibility to the private sector to reduce emissions, while stimulating technological innovation and economic growth. Typically a governmental or regulatory body allocates a limited number of permits to discharge a specific quantity of emissions in a given time period. Emitters are required to hold permits in amounts equal to their emissions. Emitters that want to increase their emissions must buy permits from others willing to sell them.

biomass and hydro – has been high. The investment costs of most clean energy technologies, particularly solar PV and onshore wind, have fallen rapidly in recent years (IEA, 2013).

According to IPCC WG III (2014), over the next two decades (2010-2029), annual investment in conventional fossil fuel technologies associated with the electricity supply sector is projected to decline by about US$ 30 billion while annual investment in low-carbon electricity supply is projected to rise by about US$ 147 billion. This is small in comparison to present global total annual investment in energy systems, which amounts to about US$ 1,200 billion. In addition, annual incremental energy efficiency investments in the transport, buildings and industry sectors, frequently involving the modernization of existing equipment, is projected to increase by about US$ 336 billion. All current annual financial flows whose expected effect is to reduce net GHG emissions and/or enhance resilience to climate change are about US$ 343 to 385 billion globally. Out of this, total public climate finance that flowed to developing countries was estimated at between US$ 35 and 40 billion per year in 2011 and 2012, while international private climate finance flowing to developing countries was estimated at between US$ 10 and 72 billion per year, including foreign direct investment as equity and loans. In light of LCS goals, these flows are utterly inadequate and have not yielded sufficient diffusion of low-carbon technologies.

Clearly, a much greater market penetration of low-carbon technologies – on both the energy supply and the end-use sides – is necessary in order to achieve LCS targets. Therefore more aggressive policies are needed to provide adequate long-term signals to manage risks and create value of capital invested in low-carbon technologies across sectors and countries.

More specifically, strong incentives are required to guide energy investment decisions toward low-carbon solutions in cases of high capital costs offset by lower operating costs, and in the early stages of deployment before economies of scale are achieved. However this capital will not be mobilized automatically, requiring policies which reduce the risks for private investors in low-carbon technologies. It is important to note that the investment required in low-carbon technologies does not represent a large increase compared with investment in the absence of climate policy, but rather, a shift away from fossil fuels toward low-carbon technologies and higher efficiency technologies (DDPP, 2015). Kainuma *et al*. (2013) also point out that the investment required for the research and development (R&D) and the deployment of LCS technologies is a small fraction of currently available private sector capital stock. Moreover, total savings in energy and fossil fuels are likely to offset additional initial costs to a considerable extent.

Munoz and Bunn (2013) recommend an extra risk premium as part of policy incentives for new investments in intermittent renewable technologies which might increase financial risk in a decarbonizing power market. Also, new innovative financial mechanisms that incentivize investments to explicitly align development and climate goals will need to be devised. For instance, Hourcade and Shukla (2013) suggest a carbon finance mechanism – and carbon certificates as its instrument – as part of the reform of financial systems and overseas aid, to address both climate and financial crises. However, this poses the political challenge of securing global agreement on the social cost of carbon, so that the possibility of carbon leakage by relocation of industrial activity is avoided (Reilly, 2013).

Market barriers to adoption of low carbon technologies in developing countries is a real concern since the capital costs of these technologies are high and the majority of those countries are in the process of enhancing infrastructure based on fossil fuels, threatening to lock these countries into a high-carbon path. DDPP (2015) suggests that high-income countries can play a crucial role in breaking these barriers by accelerating investment in low-carbon technology development, thereby bringing down capital costs, and expanding international trade in such technologies, besides assisting developing countries in local technology development. Drastically increasing government spending in clean energy R&D could go a long way to drive down the cost of low-carbon technologies and unlock potential solutions. There is enormous scope for increasing national R&D

budgets. For instance, the USA's US$ 4 billion energy research portfolio is a fraction of what it could raise by a small carbon tax or what it already spends on defence R&D and health R&D (Nature, 2013).

In addition to R&D, it is important to promote investment in infrastructure that avoids locking in to high-carbon futures (Skea, Hourcade, and Lechtenbohmer, 2013). Kainuma and Pandey (2015) suggest that such infrastructure includes logistical chains of a diverse mix of energy carriers like electricity, biofuels and hydrogen on the one hand, and of equipment, components and spares related to efficient, renewable energy and clean technologies for different supply and demand sectors on the other hand. It also includes long distance efficient passenger transportation systems based on railways, long distance efficient freight transportation systems involving multi-modal, containerized movements with railways as the dominant mode, and urban mass transit systems and electric vehicle (EV) charging infrastructure, which induce individuals and firms to use public and energy-efficient modes of transportation.

International cooperation aimed at developing markets for low carbon technologies can reduce costs and barriers for all countries, relative to a go-it-alone approach, by achieving economies of scale in R&D, manufacturing and logistics much earlier and speeding the transfer of learning and innovation. Kainuma and Pandey (2015) suggest creating institutional network channels which facilitate easy transfers of knowhow of technological and management practices between (i) nations, (ii) research organizations, (iii) companies and (iv) research organizations and companies. Kanie, Suzuki, and Iguchi (2013) argue that in order to remove barriers to rapid technology development, international institutional networks need to have both decentralized and centralized components – fragmented governance architecture to provide decentralized, information-rich and flexible systems, coordinated by a hub that is capable of quickly accessing usable information and transmitting it to appropriate institutional nodes in the network. Such international networks and partnerships could be aided by sustained funding from intergovernmental organizations.

4.3 Other national and sector-level policies

In 2012, 67% of global GHG emissions were subject to national legislation or strategies as compared to 45% in 2007. In recent years there has been an increased focus on policies designed to integrate multiple objectives, increase co-benefits, and reduce adverse side effects. Sector-specific policies have been more widely used than economy-wide policies. This could be due to the fact that administrative and political barriers make economy-wide policies harder to design and implement, and sector-specific policies might be better suited to address sector-level barriers and may be bundled in packages of complementary policies (IPCC WG III, 2014).

Regulatory approaches and information measures, for example energy efficiency standards and labeling programs, are widely used and found to be environmentally effective.

In several countries direct technology support policies have been used to promote the innovation and diffusion of new technologies. Such policies, including technology push (for example, publicly funded R&D) and demand pull (for example, government procurement programs), address market failures related to innovation and technology diffusion (IPCC WG III, 2014).

4.3.1 Pushing renewable energy and other low-carbon energy options through regulatory incentives and targets

Germany offers one of the best examples of sustained energy policy-induced low-carbon transition (see Box 3). It is actively converting its national electricity system toward a fully renewable one, with the target of providing 80% of electricity from renewables by 2050. Since it ruled out nuclear power and fossil-fuel-based power with CCS options in 2011, renewable electricity generation together with electricity savings are the primary focus for achieving decarbonization (Lechtenbohmer and Luhmann, 2013). Germany's Energiewende – the world's most ambitious LCS transition project – enjoys the support of all its political parties and most of the population (Schiermeier, 2013).

More countries, such as China and Japan, have strengthened their domestic policies, incentives and targets for renewable energy (IEA, 2013). Sweden, Austria, Brazil and China have made good progress in the development and use of biofuel technologies while linking their benefits with rural employment, sustainability and energy security (Kopetz, 2013).

Many countries have emerged as established solar PV markets, largely due to strong policy incentives and other regulatory efforts implemented by their governments. In 2014, the top five countries with largest installed capacity of solar PV were Germany (38,200 MW), China (28,199 MW), Japan (23,300 MW), Italy (18,460 MW), and the USA (18,280 MW) (IEA PVPS, 2015). Other countries and regions with established PV markets include the UK, France, Spain Belgium, Australia, South Korea, Thailand, Taiwan, South Africa, Switzerland, the Netherlands and Greece. The total installed capacity of PV globally was 177 GW at the end of 2014, generating about 1% of the world's electricity demand, with 23 countries accounting for 153 GW. In 2014, China and Japan were the leading countries adding new PV capacities, of 10.6 GW and 9.7 GW, respectively (IEA PVPS, 2015). This indicates the strong role played by individual country governments in promoting PV through various financial incentives on the one hand, and the enormous, still-untapped potential for market growth on the other hand. Domestic policy incentives such as feed-in tariffs and strong pushes by the government have led to a step increase in the installation of grid-interconnected solar PV systems in Greece, with an increasing share of systems larger than 150 kW. Despite its economic crisis, Greece exceeded its 2014 national PV target capacity of 1500 MW (Tsilingiridis and Ikonomopoulos, 2013).

The experience of China, Japan, Germany and other countries provides evidence that a strong governmental policy push in the initial phase is crucial in achieving reasonable scale and economies for new renewable energy technology systems before they become competitive in domestic and international markets. Indeed, cost gains in certain technologies have already kicked in due to both policy pushes in some countries and/or markets witnessing signs of growth. For example, Trancik (2015) reports that the price of photovoltaic modules for solar energy has fallen by 85% since 2000 as markets have grown; electricity costs from wind are now comparable to those from coal; and energy-storage technologies are improving.

4.3.2 Pushing end-use efficiency and technology options through regulatory standards, incentives and targets

Governmental policies and incentives have played an equal role in driving up efficiencies in end-use sectors such as transport, industry, commercial and residential buildings, appliances and agriculture. For example, Germany's Energiewende includes initiatives to increase energy savings in several end-use sectors, besides energy supply changes (see Box 3).

Among various demand sectors, the transport sector shows encouraging trends. Sales of hybrid-electric vehicles (HEV) and electric vehicles (EV) have grown rapidly in recent years, with the former surpassing 1 million in 2012 and the latter 100,000. While Japan and the USA lead the HEV market, some developing countries such as India have set ambitious targets for HEV and EV (IEA, 2013). Examples of existing national or state-level policies to decarbonize transportation fuels are the US Renewable Fuel Standard (RFS2), which sets a minimum biofuels use target and GHG emission reduction threshold for each category of biofuels; California's Low Carbon Fuel Standard (LCFS), which mandates a 10% reduction by 2020 in carbon intensity of transportation fuels sold in the state; European Commission's Fuel Quality Directive (FQD), which incorporates an LCFS-like target; and British Columbia's Renewable and Low Carbon Fuel Requirements Regulation (RLCFRR), which sets targets for both renewable content in transportation fuels and reduction in their carbon intensity (Yeh and Sperling, 2013).

Box 3. **Germany's Energiewende: A Case of Sustained Energy Policy Leading to LCS**

Germany, the world's fourth largest economy, is on a path of transforming its energy system through 'Energiewende' – an energy revolution that it began several years ago. Change on the ground accelerated after the 2011 Fukushima nuclear power plant disaster in Japan, which led the German government to announce the shutdown of all its nuclear reactors by 2022. By 2015 Germany had shut 9 of its 17 reactors. The other trigger was the aggressive GHG reduction target Germany set for itself – a 40% cut by 2020 and 80% cut by 2050, from 1990 levels.

The first phase of Germany's transformation has been very encouraging. In 2014, 27% of its electricity came from renewable energy sources such as wind and solar power, three times what it got a decade ago and more than twice what the US gets today, on a percentage basis. In addition, the use of biogas and solar energy to produce heat has increased. On July 25, 2015, when it was windy in the north (where the majority of wind turbines are located) and sunny in the south (where the majority of solar PV units are located), for a few hours renewables yielded about 75% of country's electricity.

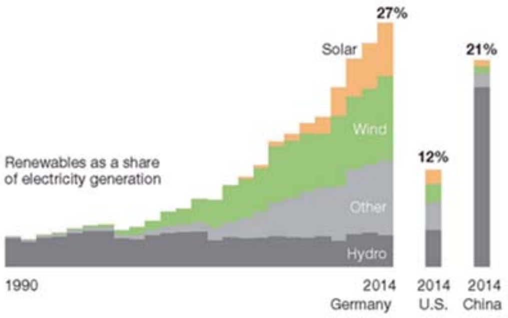


Figure: Renewable energy in Germany's electricity generation (source: Kunzig, 2015)

An interesting characteristic of Germany's ongoing transition toward LCS is that individual citizens and local citizen associations played an important role, both in initiating pressure on the government to launch this energy revolution and in contributing to the change. These grass roots individuals and groups have made about half the investment in renewables. New regulations allow citizens to profit from selling their energy to the grid. At present, about 1.5 million individuals sell renewable electricity to the grid. Even though energiewende has hiked consumer electricity prices, it enjoys enormous public support. Part of this support can be explained by a deep-rooted and collective eco-friendly culture.

The beginnings of Energiewende date back to 1990 when the first law recognizing renewable energy producers' right to feed electricity into grid, and utilities' obligation to pay them, was passed; subsequently in 1993 when the Hammelburg City Council passed an ordinance obliging the municipal utility to guarantee a price that ensured profit to any renewable energy producer; and laterin 2000 when a nationwide law was promulgated along similar lines. The first association of local investors to build a 15 kW solar power plant was organized in Hammelburg in mid-1990s. Today there are hundreds of such associations in Germany. Several of them, for instance the village of Wildpoldsried, produce far more electricity than they consume, thanks largely to wind turbines, solar panels, and biogas.

However, the rate of new renewable capacity addition has dropped, and the challenge for Germany is to involve more citizens, get its large fossil fuel-based electricity utilities to switch to a low carbon energy supply, and transform its transportation and heating sectors. The utilities are beginning to invest in renewable energy. For instance, the city of Munich, whose municipal utility owns a stake in large offshore wind power, now produces enough renewable electricity to supply its households, subway and tram lines. Germany has set goals of having a million electric cars on the road by 2020 and making all buildings carbon-neutral by 2050.

Sources: Kunzig (2015); Schiermeier (2013); Lechtenbohmer and Luhmann (2013)

While energy efficiency in other demand sectors is yet to show significant improvement, several governments have implemented policy measures to promote energy efficient buildings and appliances. These include the EU Energy Efficiency Directive (EED), the UK's Green Deal, Japan's Innovative Strategy for Energy and Environment, India's energy performance standards and mandatory labeling program for certain appliances, Australia's phase-in policy for best-available lighting products, and 46 countries' 'en-lighten' initiative to phase out incandescent lamps by 2016 (IEA,2013). Germany's building standards and regulations regarding energy performance have been successful in decreasing the energy consumption of new buildings (Schade *et al.*, 2013).

China has set strict targets for carbon intensity and energy intensity and has so far been able to achieve them in the short term through a Target Responsibility System which involves distribution of national targets to local governments and enterprises and identification of responsibilities (Jin, Kuramochi, and Asuka, 2013).

4.4 Local level initiatives

There are inspiring initiatives at the local scale as well. Some regional and municipal governments are demonstrating serious involvement to engage with local stakeholders to generate awareness and push for concrete low-carbon changes in infrastructures, institutions, and behaviors. For instance, Iskandar Regional Development Authority – a planning body in charge of developing the Iskandar region of Malaysia – has been working closely with climate change researchers from Universiti Teknologi Malaysia (UTM) and the AIM team of Japan to set an LCS target, prepare an LCS blueprint, implement its recommendations, and interact with local stakeholders including communities, schools and businesses to spread awareness (Ho and Matsuoka, 2012) (see Box 4).

The local governments of certain Midwestern counties in the USA have played an important role in the development of wind farms in their rural communities and enhance community acceptance by raising awareness about local benefits to the economy and environment (Mulvaney, Woodson, Prokopy, 2013). Several 'eco-cities' like Heidelberg in Germany and Vaxjo in Sweden have reported significant cuts in CO_2 emissions by implementing multiple local measures like a shift to public transport, an increase in renewable energy, waste recycling and reuse (Joss, 2010).

The Tokyo Metropolitan Government's program of combining a cap and trade system with a system of monitoring and reporting energy efficiency and carbon intensity performance of commercial buildings in Tokyo has led to several innovative measures and significant savings. It has attracted worldwide attention and is viewed as a benchmark of what a city government can do to enable commercial buildings to move toward low carbon practices (see Box 5).

Initiatives such as C40 Cities (a network of the world's megacities focused on addressing climate change) and WMCCC (World Mayors Council on Climate Change – an alliance of local government leaders concerned about climate change) have helpedseveral urban centers to integrate climate objectives into current policy and long-term planning. The Cities for Climate Protection campaign run by the global cities network ICLEI, for example, has prevented emissions equivalent to some 54 million tons of carbon dioxide from more than 1,000 cities (Agarwala, 2015).

Damso, Kjaer, and Christensen (2016) report widespread adoption of ambitious climate action plans among local governments and authorities in Denmark, transcending different types of municipalities. Although target types and mitigation actions varied highly (possibly due to an absence of links with the national planning framework), overall target levels were high.

Box 4. Iskandar Malaysia's Roadmap for LCS

Iskandar Malaysia LCS is one of the most ambitious urban decarbonising projects in Southeast Asia, designed for Malaysia's emerging metropolis – Iskandar Malaysia. It has the active support of the Malaysian government and Iskandar Regional Development Authority (IRDA). A low carbon society initiative was conceived as one of the mechanisms deployed to achieve the objectives of developing Iskandar Malaysia as a region of economic growth, societal well-being, and sustainable development, while contributing to the achievement of Malaysia's voluntary commitment to reduce CO_2 emission intensity by 40% in 2020. It is also an excellent example of cooperation at multiple levels – capacity building among Malaysian institutions through support from the Japan International Cooperation Agency (JICA) and other organizations (bilateral policy cooperation), international research collaboration between Japanese and Malaysian researchers and institutes (bilateral research cooperation), collaboration among researchers and national/regional policymakers, and participation of local stakeholders such as IRDA, other local authorities, and communities (research-policy-local stakeholder cooperation). Research findings have been translated into an LCS blueprint of workable development policies in the form of 12 Actions, over 280 Programs, and a roadmap for implementation. The blueprint sets a benchmark for designing low carbon, climate resilient, liveable and vibrant cities.

Results from modeling and analysis show that in the LCS scenario it is possible to achieve a 58% reduction in GHG emission intensity and a 40% reduction in emissions by 2025, as compared with business as usual (BaU), based on viable countermeasures. Most of the countermeasures are based on technologies such as energy-efficient equipment in all sectors, photovoltaic (PV) power generation, biomass utilization, and energy-efficient buildings. They also include urban planning policies such as a modal shift, compact city development, and behavioral changes in the community through education and awareness campaigns.

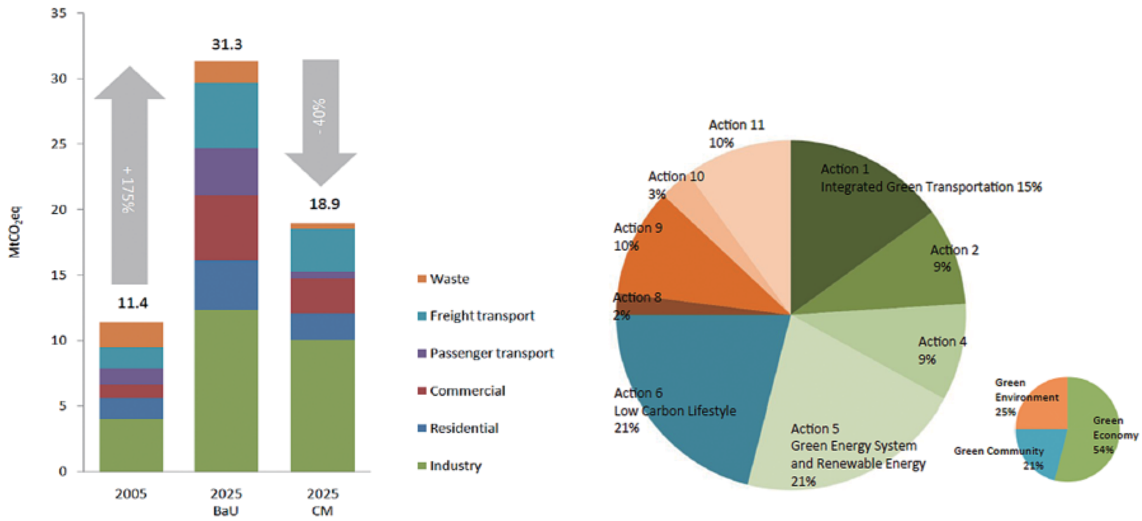


Figure: (L) GHG emissions by sectors in Iskandar Malaysia in 2005 and in 2025 under the BaU and LCS scenarios; (R) Contribution of direct actions to CO_2 reduction

These countermeasures were translated into feasible actions and programs by IRDA and local authorities, and through intensive consensus building workshops involving stakeholders such as business communities, non-government/non-profit organizations, interest groups and individuals. Twelve actions were classified into three categories – green economy, green community and green environment. The actions that contribute the most toward CO_2 reduction are agreen energy system and renewables (21%), a low carbon lifestyle (21%), integrated green transportation (15%), smart urban growth (10%), sustainable waste management (10%), green industry (9%), and green buildings (9%). Some actions, such as low carbon urban governance and community engagement, do not directly reduce emissions but enhance implementation of programs that are part of other actions. The blueprint requires local authorities to estimate an inventory of energy and emissions and continuously implement and monitor the progress of the programs.

Source: UTM-Low Carbon Asia Research Center (2013)

Besides reducing risks for large private investors in clean technologies (as discussed in Section 4.2), it is useful to reduce risks for local entrepreneurs in starting up decentralized economic activities based on renewable energy. The availability of financing options for entrepreneurs to engage in low-carbon activities such as the supply and maintenance of decentralized renewable energy technologies and related services to end-users in residential, commercial, industrial and agricultural sectors has the potential to generate multiple benefits in terms of employment, economy, and climate.

4.5 Need for comprehensive policies

Nakamura, Hayashi, and Kato (2013) emphasize the importance of a comprehensive policy package consisting of 'avoiding' unnecessary energy demand, 'shifting' to low-carbon modes, and 'improving' efficiency. This insight is also supported by the characteristics of low carbon energy and socio-economic systems outlined in Chapter 3. A package comprising multi-pronged policies designed to create complementary and mutually reinforcing effects between the energy supply and demand sectors, rather than a collection of individual policies designed in isolation from each other, is likely to be more successful in nudging a society toward LCS.

Interactions among mitigation policies may be synergistic. For instance, a carbon tax can have an additive environmental effect to policies such as subsidies for the supply of renewable energy (IPCC WG III, 2014). Huang *et al*. (2013) demonstrate that in comparison with individual policies, the imposition of carbon pricing in combination with Renewable Fuel Standard (RFS) and Low Carbon Fuel Standard (LCFS) policies leads to larger net economic benefit, energy security, fuel conservation, and GHG emissions reductions in the transportation and agricultural sectors. The fact that technology policies complement mitigation policies by addressing market failures related to innovation and technology diffusion, as discussed in Section 4.3, is yet another example of synergy. Such synergistic policies can bring about greater total mitigation impacts at lower net cost.

Some mitigation policies raise the prices for some energy services and could hamper the ability of society to expand access to modern energy services to underserved populations. These potentially adverse side-effects can be avoided with the adoption of complementary policies (IPCC WG III, 2014). Such complementary policies can also yield co-benefits. For instance, by providing greater access to rural households in developing countries to modern energy services, sustainable development objectives of reduced air pollutant emissions and increased health benefits can be achieved alongside the mitigation of CO_2 emissions.

Another important facet of comprehensiveness of policies is cross-sector and cross-stakeholder integration. Integrated policy making processes are required to efficiently resolve multiple stakeholder conflicts, design an effective combination of policies and arrive at consensual decisions at the international and national levels. This is an institutional policy challenge since, in many countries, the existing institutional structures of policy making, planning and governance, particularly in the realms of economic and infrastructure sectors including energy, are compartmentalized. This problem of non-integrated, narrowly focused planning is more pronounced in developing countries. Policy makers and planners in charge of different sectors and sub-sectors typically work with independent and conflicting goals and targets. In this process the overriding, common and cross-sector goals which are society-wide and economy-wide such as those of efficiency, energy access, environment and sustainability are often compromised in favor of narrower goals such as sector-specific investment and growth. For instance, in India, the sectors of power, new and renewable energy, coal, oil and gas, nuclear energy, highways, railways, shipping and ports and aviation, have their respective ministries and policy institutions which are politically more powerful than the few cross-sector institutions concerned with integrated planning.

Such compartmentalized institutional structures and processes need to be replaced with or dominated by integrated, cross-sector institutions of policy making which take on society-wide and economy-wide goals such

Box 5. Tokyo Metropolitan Government's Regulatory Effort to Cut Urban Emissions

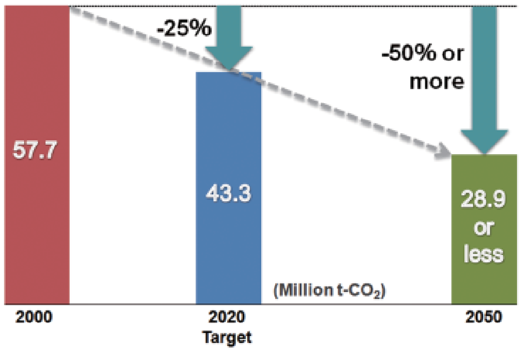


Figure. GHG emissions reduction targets for Tokyo

Tokyo has set a GHG emissions reduction target of 25% in 2020 and 50% or more in 2050, as compared to the 2000 level. A 25% reduction in 2020 is expected to come through measures in the industrial, commercial, residential and transport sectors. Demand side measures in these sectors would account for the majority of this reduction.

The Tokyo Metropolitan Government (TMG) has initiated admirable efforts toward meeting these targets. Through new ordinances, the TMG has made it mandatory for large-size industrial and commercial facilities to comply with an emissions reporting and reduction program and participate in a cap and trade scheme for reduction ("large-size" facilities are factories and office buildings that consume 1,500 kl or more crude oil equivalent of energy per year). These large facilities number about 1,400 and account for 40% of the GHG emissions from industrial and commercial sectors in Tokyo. For medium-size facilities, numbering about 20,000 and accounting for 20% of GHG emissions, reporting is mandatory whereas reduction is voluntary. Thus, over 30,000 facilities in Tokyo are currently reporting their energy use, emissions and reduction measures on a regular basis. For small facilities, both reporting and reduction are voluntary. Medium and small facilities get incentives in the form of tax credits and subsidies if they reduce emissions.

The TMG launched these programs in 2002. During 2002-2009, large facilities were subjected to only mandatory reporting of energy use, emissions and reduction measures, but reduction itself was voluntary. By working closely with companies, facility managers and energy experts, the TMG identified 12 measures that were easiest to implement and would yield return through energy savings in three years or less. Participation in the emissions reduction cap and trade program was made mandatory for large facilities from 2010 onwards. Reflecting its growing experience, a more comprehensive list of over 60 specific measures, in areas such as lighting, air conditioning operation, air conditioning equipment, substation equipment, water supply and drainage equipment, pumps and fans, boilers and other appliances, has been drawn up. The TMG also facilitates the participation of medium and small facilities in reduction by providing free services such as awareness seminars, sector-specific brochures, energy audits, and consultations. Regular feedback is provided to facilities so they can compare their performance over time and benchmark with other similar facilities.

Thus far the TMG has focused primarily on industrial and commercial sectors, which account for about half of Tokyo's emissions. In the future it plans to tighten regulations affecting small and medium facilities, and also extend its programs to the residential and transport sectors.

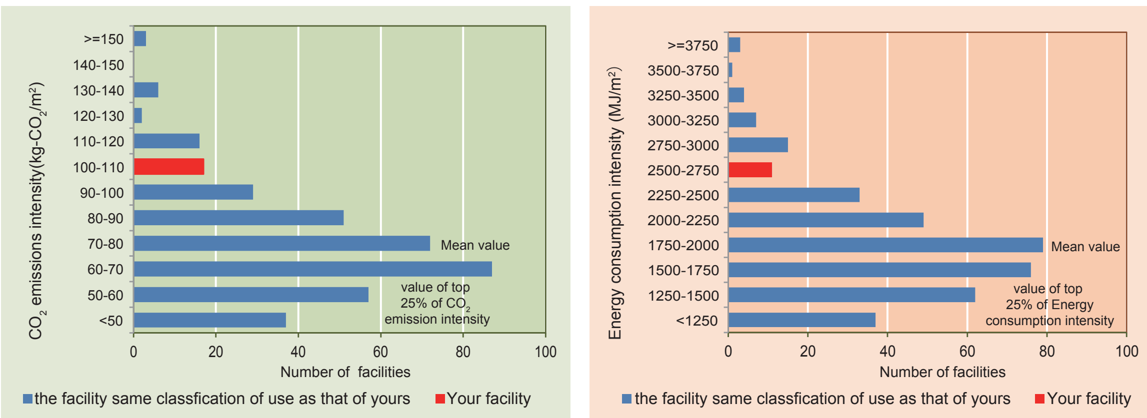


Figure. An example of aggregated comparative feedback provided by TMG to a user facility

Source: TMG (2015)

as energy efficiency, energy access, environment and climate change (Kainuma and Pandey, 2015). In an integrated approach to energy system design for sustainable development, energy policies need to be coordinated with policies in sectors such as industry, buildings, urbanization, transport, food, health, environment, climate, security and others in order to make them mutually supportive (GEA, 2012). An integrated, cross-sector policy making process could also help in evaluating inter-sector effects and designing a more effective combination of policies.

It must be noted that integrated and comprehensive policy making processes are needed to ensure that cross-sector, developmental and environmental externalities are internalized in the process of evaluation of not only high-carbon options but also low-carbon ones. As Reilly (2013) notes, the push for renewable energy in Europe in the first decade of this century is generally viewed as premature because of its 'non-sustainable' impacts on land-use change and food prices. CCS, with its requirement for large volumes of water for cooling, could potentially impact river flows. An integrated, cross-sector process of policy making would facilitate a judicious strategy and mix of renewable energy and other low-carbon systems, one that creates multiple societal benefits and minimum conflicts.

Yet another aspect of comprehensiveness of policies is including the concerns and the consent of local communities in the process. Not only fossil fuel and nuclear power technologies but also renewable energy technologies such as biomass, hydro, solar and wind exert pressure on land use, and some of these projects have faced local resistance in both developed and developing countries. As Kainuma and Pandey (2015) note, the long experience of public resistance to various industrial and energy projects could offer hints to resolve such conflicts in cases of renewable energy projects. Besides disseminating a cost-benefit analysis among the public in a transparent manner, viewing local communities as important stakeholders and inviting their representation in decision making process for approving LCS projects and sharing their benefits would go a long way toward enhancing public acceptance and implementation.

Furthermore, combining low-carbon energy deployment projects with the direct generation of benefits locally at the levels of communities, villages and cities could enhance the acceptability of projects and obviate conflicts. As pointed out by GEA (2012), energy policies and projects need to be designed to generate multiple societal benefits such as enhanced access of rural and poor households, especially women, to electricity and cleaner cooking fuels, improved local environment conditions, increased employment options, strengthened local economies through new business opportunities, productivity gains, improved social welfare and decreased poverty and improved energy security.

05 Changes in Behavior and Paradigm as Demand-side Approaches to LCS

IPCC WG III (2014) acknowledges that behavioral changes together with end-use efficiency enhancements, aimed at reducing energy demand without compromising development, constitute a key mitigation strategy in scenarios reaching atmospheric GHG concentrations of 450-500 ppmCO_2eq by 2100, i.e. in LCS or near-LCS scenarios. Kainuma *et al*. (2013) also identify a key challenge for meeting the mitigation target in an LCS scenario without nuclear power and CCS as the reduction of energy service demand that, in turn, relies primarily on behavioral change.

In addition, the reduction in energy demand from such behavioral changes has the potential to ease the burden on the energy supply side and heighten the feasibility and economic viability of achieving an LCS. As Lechtenbohmer and Luhmann (2013) demonstrate from a review of Germany's decarbonization experience, energy savings are a significant and cost-efficient strategy for low-carbon electricity.

However, the very fact that behavioral and other demand-side changes are now being emphasized with increasing frequency is a reflection of the somber realization that there are formidable barriers to achieving an LCS. These barriers are not only in terms of inadequate policies but also, and more crucially, behavioral, institutional and structural. They inhibit or slow down the diffusion of low-carbon measures. The sense of urgency has been heightened by the reality that, while ongoing initiatives of low carbon policies, technologies, businesses, and community practices are encouraging steps, much more needs to be done to overcome these barriers and move toward LCS goals. This is all the more so as there is a strong consensus among climate scientists, policy makers and environmental groups that drastic and early actions are needed in order to prevent or substantially reduce the possibility of dangerous climate trends being set irreversibly.

As the IEA (2013) report notes, for a majority of technologies that could save energy and reduce CO_2 emissions, progress is alarmingly slow, and the world is not on track to realize the interim 2020 targets for the IEA 2DS scenario. Coal continues to dominate growth in the power sector, especially in large developing countries such as China and India. Owing to high costs and the lack of policies and incentives, ground-level progress on CCS-projected optimistically by several LCS scenarios including the 2009 roadmap from IEA-has been very slow, with no large CCS system yet in operation at a power plant anywhere in the world (Van Noorden, 2013). On the energy efficiency side, despite tremendous savings to be expected, potential user countries are not taking full advantage, and the uptake of efficient technologies remains slow due to factors such as behavior, high costs, and split incentives between investors and beneficiaries (Gillingham and Kotchen, 2013). In several cases, efficiency gains have been offset by unsustainable habits. For instance, 30 years of engine efficiency gains in passenger cars have been eclipsed by our preferences for ever-larger cars that are often 20 times heavier than the passengers (Allwood, 2016).

The Green Climate Fund, which has approved just eight projects in more than five years, is still trying to collect the funding promised by nations. The US Supreme Court has put US President Barack Obama's regulations for power-plant emissions on ice, pending a legal challenge. Policymakers in the UK are still debating how to proceed in the wake of a government decision in November 2015 to pull the plug on a program supporting the development of CCS technologies. And in another branch of the UN, the International Civil Aviation Organization has proposed a rule on aircraft emissions that is so weak as to be irrelevant (Nature, 2016). There are many more similar stories of tardy progress and failed expectations.

Therefore, let us first look at the major barriers and then the possible changes needed in underlying structures, institutions and behaviors.

5.1 Barriers to LCS

Kainuma and Pandey (2015) identify seven distinct layers of barriers to effective adoption of low-carbon solutions (Figure 19). These barriers are rooted in the absence of adequate structures, institutions, processes, mechanisms and behaviors to facilitate LCS and sustainability actions. Some of the 'direct' barriers can be overcome by taking appropriate steps in the short term, whereas others – more deep-rooted and 'indirect' barriers – require more radical and/or longer-term changes.

For instance, barriers of an absence of adequate financing mechanisms could be overcome by designing and implementing appropriate financing channels, instruments and incentives. Some of these were discussed in Section 4.2 of Chapter 4. Similarly, low carbon infrastructures, such as those of public transportation systems, EV charging networks, and logistical chains for the supply of low-carbon energy carriers and related equipment and components could be set up through direct investments by governments or by providing suitable incentives for investments by the private sector.

However, overcoming indirect barriers would require changes in behaviors and prevailing socio-economic paradigms that govern structures and institutions. Paradigms, structures and institutions in turn shape and reinforce behaviors. Such changes must therefore be considered an inherent part of the demand-side approach to LCS.

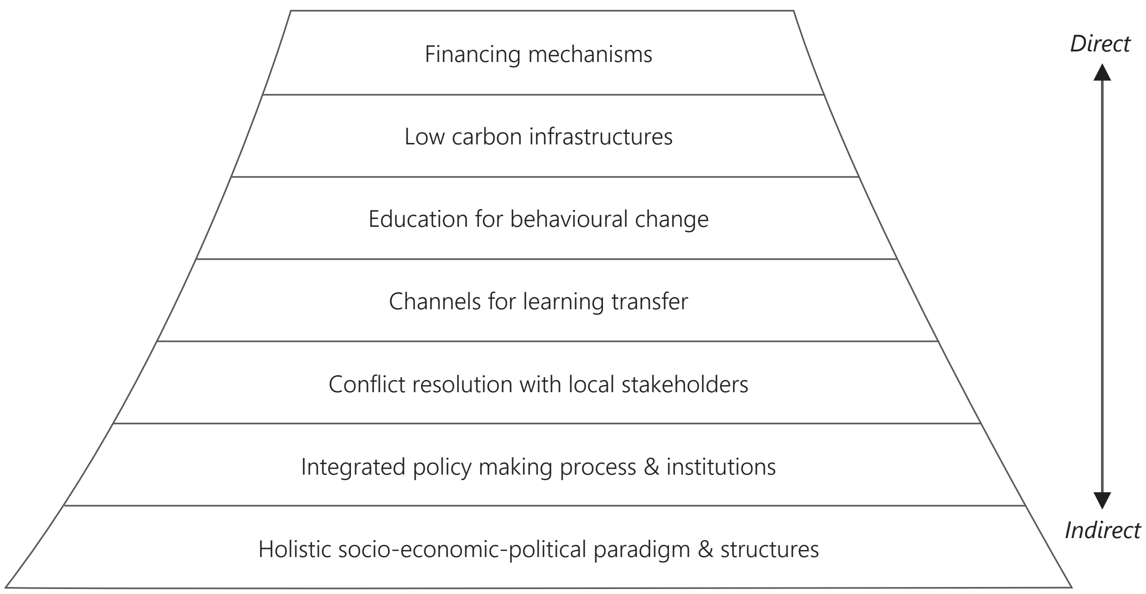


Figure 19. Layers of changes needed in structures, institutions, processes and behavior
(Source: adapted from Kainuma and Pandey, 2015)

5.2 Changes in behavior and the socio-economic paradigm

Most LCS scenarios, especially those at the local and city scales, emphasize the role of behavioral change toward eco-friendly lifestyles in the end-use sectors. IPCC WG III (2014) states that behavior, lifestyle and culture have a considerable influence on energy use and associated emissions, in particular when complementing technological and structural change. Emissions can be substantially lowered through changes in consumption patterns such as mobility demand, transport mode, energy use in households, choosing longer-lasting products, dietary changes, and reductions in food waste.

However, people's energy consumption practices are embedded in everyday life and are determined by social norms, established routines, and individual choice (Shove, 2004). For instance, a survey of owner-consumers of residential heating systems (RHS) in German households, which account for a substantial amount of carbon emissions, revealed that those who were more aware of and concerned about negative consequences (at both the global and individual levels) of fossil fuel use and had greater knowledge of the benefits and functions of systems based on renewable energy, were more likely to switch to renewable RHS (Michelsen and Madlener, 2016). As another example, in an empirical study of the adoption of solar hot water systems in Australian households, Gill *et al*. (2015) highlight that technology use is dependent on interrelations between cultural norms, systems of provision, the material elements of home and practice. They report that even though the government provides subsidies and assists with installation, the lack of pre-purchase advice, installation quality, post-installation support regarding system operation and interaction with patterns of hot water use deter people from adopting these systems or from using them optimally and to their satisfaction. Many other studies with similar conclusions have been reported from different sectors and countries.

Therefore, according to Kainuma *et al*. (2013), in order to induce the required behavioral change a wide range of socio-economic and political interventions, such as enhancing awareness through communication and education about the consequences of existing practices and the benefits of switching to low-carbon alternatives, offering incentives that affect individual choice, regulating the performance of energy-using goods, and investing in infrastructures such as public transport, will become necessary. In addition to designing such wide-ranging interventions, involving users of technologies and services will be a major challenge. Thus, changes in cultures, lifestyles and values will be vital. Effective strategies will need to be adopted and integrated into the fabric of national socio-cultural, political, developmental and other contextual factors (GEA, 2012).

Both the role of governments to create awareness from the top through strong and sustained policies, as well as the role of non-governmental organizations, citizens and people's movements to generate awareness from the bottom via grass roots mobilization efforts, are crucial to steer a society's dominant values in a desired direction. These dominant values have the potential to drive not only individual choices such as lifestyles of people and preferences for certain end-use devices, but also major institutional decisions such as those of governments in favor of, or against, certain technological investments (Kainuma and Pandey, 2015).

The importance of values driving individual lifestyles is underscored by Cole *et al*. (2008), who in their analysis of green building strategies conclude that the goal of LCS has created a new context for comfort, from its conventional emphasis as automated, uniform and predictable, to a broader notion that takes into consideration dynamic, integrated and participatory aspects. This latter notion of comfort involves engagement of inhabitants with new conditions and new types of interactions (feedback and dialogue) between them and building systems and unfamiliar technologies, right from the green building strategy and design to delivery and management processes. Such a broadening of the notion of comfort would require intensive and persistent effort toward educating people.

In addition to engaging local citizens and inhabitants, enhancing the capacity to identify technologies, practices and policies suited to local conditions is important in both developed and developing countries, as part of designing and implementing demand-side efforts. According to Kainuma *et al*. (2013), enhancing capacity building, especially in developing countries, to support locally suited technologies and practices will be central to achieving LCS.

Skea, Lechtenbohmer, and Asuka (2013) note that the German government's strong and sustained policy efforts in favor of renewable energy, combined with an anti-nuclear movement led by non-government groups, enabled Germany to take quick and decisive steps immediately after the 2011 Fukushima accident to phase out nuclear power within 10 years. This is a good example of top-down and bottom-up awareness generation efforts paving the way for value-led decisions in society.

Finally, we must realize that the transition toward an LCS is most notably a political process. As Dessai, Afionis, and Alstine (2013) point out, while scientific research is crucial, it cannot replace what is inherently a political process. Therefore, in the longer run, the fundamental economic and political structures in society need to change from the existing consumption growth-led paradigm to one led by goals of sustainable development and widespread economic contentment.

Griggs *et al*. (2013) correctly emphasize that the stable functioning of the Earth's systems is a prerequisite for a thriving global society. As the Earth's systems are under serious threat by the ways humans are transforming the planet, they suggest including the security of people and the planet in the definition of sustainable development. They have put forward a new socio-economic paradigm in which the driving principles of human society are to reduce poverty and hunger, improve health and well-being, and create sustainable production and consumption patterns. But none of this is possible without changes to the economic playing field (Biermann *et al*., 2012). The changes required in the economic paradigm are fundamental and structural in nature.

Changes in values and structures are a prerequisite also for the drastic demand reductions and end-use efficiency improvements required under LCS scenarios. For instance, the broadening of the notion of "comfort" as a precondition for LCS, as described by Cole *et al*. (2008), from building inhabitants being passive recipients of physiological comfort conditions to them becoming active participants in a bidirectional and interactive comfort provisioning, is a major change in value systems.

A change in value systems will necessarily be accompanied by a change in our definition of "success". Allwood (2016) points out that "success" today is largely associated with derivative measures of increasing gross domestic product, profitability, speed or salary, yet our deeper value systems are based on integral measures of quality and stock: reputation, heritage, journeys and relationships. She recommends that we need to expand the dialogue of climate mitigation to reflect these values, and challenging our habits of energy use should be the first priority of climate policy. Such a change in value systems and habits can come about through a paradigm shift in the economic-cultural foundations of a society.

06 Concluding Remarks: Time to Act

It is widely agreed that humankind must undertake a definite and early transition toward an LCS while simultaneously pursuing economic prosperity and sustainable development. This will necessitate drastic cuts in global GHG emissions, which can come about through steep improvements in efficiencies and across-the-board changes in technology and energy systems in both developed and developing countries (Figure 20). That will, in turn, require radical changes in production and consumption patterns, infrastructures, institutions and international and inter-sector collaborations, behaviors and lifestyles.

While, as briefly described in Chapter 4, a number of positive changes are taking place in terms of new technologies, international policies, national policies, initiatives by companies, non-profit organizations, and local stakeholders, these efforts do not add up to the level required.

Concurring with this grim reality, Nature (2016) claims it is no secret that the actions that governments have committed to thus far fall well short of those needed to limit warming to 2°C, l*et al*one to 1.5°C, which is the stated goal of the Paris Agreement. Nor, it says, is it clear that the world is urgently moving forward. Instead of recommending concrete actions for deep and early reductions in energy demand and rapid substitution of zero-carbon alternatives for fossil fuels, the Paris Agreement seemed to rely excessively on the promise of futuristic industrial-scale technologies like BECCS (biomass energy carbon capture and storage) whose techno-

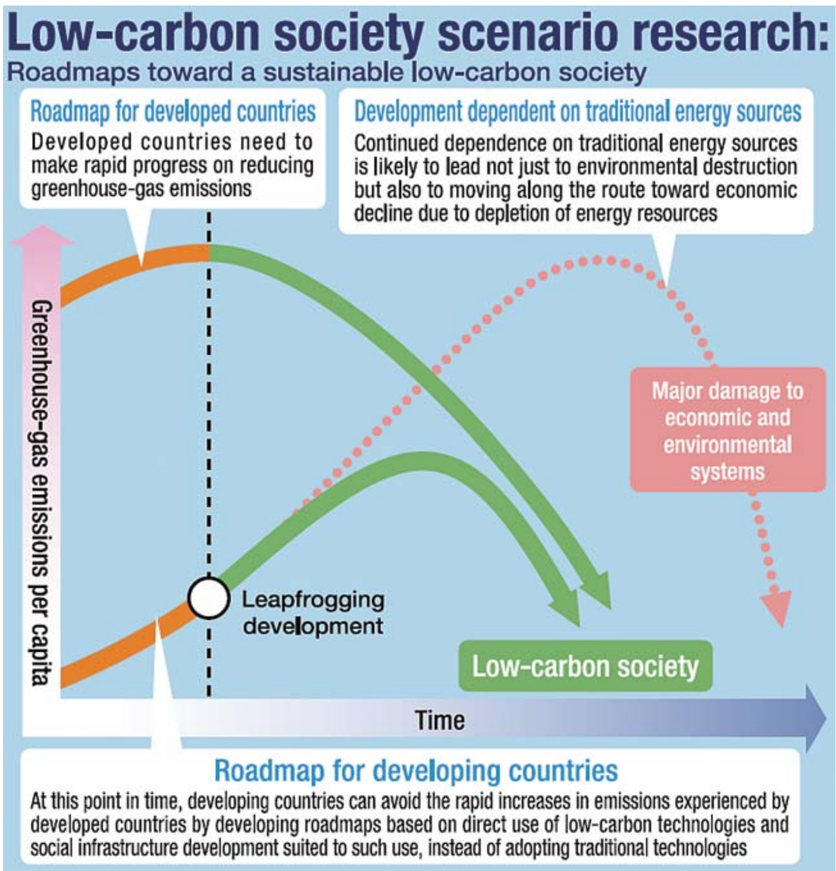


Figure 20. Roadmap toward a sustainable low carbon society (source: LCS-RNet, 2010)

economic viability and unintended impacts on land-use and other sectors are uncertain (Anderson, 2015). NIES and MHIR (2015), through a global scale analysis of INDCs and the 2°C target, conclude that while the implementation of INDCs will be a meaningful step toward reducing global GHG emissions until 2030, this alone will not lead to further GHG cuts. In order to meet the 2°C target, INDCs will have to be revised, with additional long-term countermeasures implemented.

Therefore, a transition toward an LCS demands many more early efforts designed and implemented in a concerted and consistent manner. As the Executive Secretary of the UNFCCC said in her letter to the governments on the conclusion of the Paris Agreement, the world is now transitioning into a phase of "urgent implementation". The Secretary General of the United Nations expressed similar sentiment when he said, "What was once unthinkable has now become unstoppable!"

In other words, it is time to act. Below is an inexhaustive list of the directions in which an urgent movement is needed.

- **Radical international agreements and a monitoring mechanism under the UNFCCC.** While INDCs and national commitments made in the lead-up to the Paris Agreement are a positive step forward, crucial details about the framework for reporting and monitoring commitments must be urgently negotiated (Nature, 2016). In order to verify that countries are living up to their promises, they need to set up processes to gather reliable and transparent data. To assure the success of this system, Tollefson (2016b) highlights the importance of building capacity to produce a network of carbon accountants across the world, especially in developing countries. In addition, accelerated negotiations are required to arrive at agreements on unresolved and vexing issues such as making countries commit to drastic emission reduction targets and designing and implementing more ambitious policies that meet the expectations of LCS. Further, as Covington, Thornton, and Hepburn (2016) note, countries must translate the promises made in the Paris agreement into their own legal systems, otherwise they will remain largely voluntary.

- **A strong policy push, a legal framework and financial incentives to ramp up investment in low-carbon technology R&D, innovation, entrepreneurship, manufacture, distribution and marketing.** Achieving a net-zero carbon economy will require policies that drive innovation, investment and entrepreneurship in low-carbon systems and technologies (Stern, 2016). Direct governmental support for low-carbon technology R&D, entrepreneurship and manufacturing, together with support for the creation of markets and distribution channels by the private sector, requires a rapid ramp-up in order to achieve breakthrough innovations and scale economies. While investments in low-carbon systems must be boosted through strong incentives, investments in high-carbon systems must be de-incentivized and legally challenged. Investors need to be educated about the reduction in the value of stocks due to climate risks, should an investment portfolio's economic output be expected to be damaged by future warming. New laws need to be framed and legal experts and courts also need to be educated about this (Covington, Thornton, and Hepburn, 2016).

- **Institutional channels for cooperation and the quick transfer of learning in the R&D and manufacturing of low-carbon technology systems.** An international channel backed with strong financial and political support from high income countries needs to be established for cooperation (rather than competition) and easy transfers of knowhow and capital between countries, especially between high-income and low-income countries, so as to enable widespread and quick dissemination of low-carbon technology systems.

- **Establishment and scale-up of low-carbon infrastructures.** Low-carbon infrastructures, such as public and efficient transportation systems for both long-distance and intra-city movement, a facilities network for EV charging and a supply of other low-carbon energy carriers, logistical chains for procurement and a supply of equipment and spares for low-carbon technologies, smart grid systems and systems for recycling and sustainable waste management need to be urgently established. This will enable the majority of people to access such energies, technologies and systems at low marginal costs.

- **Integrated institutional structures and policy making processes to enable holistic decisions.** Integrated structures of governance and policy making institutions and processes that have oversight on sector-level institutions are required to smoothly resolve conflicts between multiple stakeholders, permit holistic evaluations of trade-offs and decisions, and internalize social and environmental costs.
- **Networks to spread local-scale and city-level decarbonization through local governments and leaders.** Covering just 3% of the Earth's surface but home to more than half of its population, the world's cities account for 70% of global energy demands (Agarwala, 2015). Initiatives such as C40, WMCCC and ICLEI have demonstrated that networks and actions involving local level government leaders and civil society organizations are less prone to bureaucratic procrastination, faster to implement, and yield concrete results. As Damso, Kjaer, and Christensen (2016) suggest, climate action plans designed and implemented by local municipal governments, coordinated horizontally among a network of multiple local authorities and vertically with a national LCS planning framework, and integrated into other societal values (for example, job creation), can result in greater mitigation and output.
- **A full spectrum of pre-installation, installation and post-installation support to end-users for low-carbon devices and systems.** Several empirical studies, for instance Gill *et al.* (2015), have reported that a policy of providing installation and subsidies for the purchase of low-carbon technologies to end-users is often not enough to boost adoption. One of the barriers is the absence of pre-installation advice and awareness about benefits, functionality and operation of the new system, and limited awareness of benefits of the new system or the negative impacts of older systems. Another barrier is the lack of good quality installation service and post-installation support for optimal operation, integrated operation with end-users' living environment and routines, maintenance and upgrade. If markets for a new low-carbon technology system have not matured to a level of providing this full range of services, the governmental agencies must gear up to offer these services by themselves or in collaboration with other organizations.
- **Transformation of business and corporate practices to embrace sustainability.** Sustainability thinking must penetrate the entire corporate value chain, starting with the sourcing of raw materials and services, through to transport, employment practices and environmental steward¬ship in production. It must extend to packaging and delivering, the use of products and services by customers, and product disposal, reuse or recycling. While, as discussed before, policy and legal frameworks are needed to push low-carbon systems, businesses need to simultaneously and autonomously start changing practices on the ground. All new investments in research and development should undergo a sustainability assessment. Truly sustainable companies must embrace emissions reductions and green energy, and control their use of non-renewable resources. They must stop selling goods that are not biologically degradable, and develop alternatives that are. And, they must have the same environmental and social standards at all production sites (Leisinger, 2015). Indicating that investors and business leaders bear a profound responsibility in directing markets toward a low-carbon path, the Secretary General of the United Nations remarked at the conclusion of the Paris summit, "Markets now have the clear signal they need to unleash the full force of human ingenuity and scale up investments that will generate low-emissions, resilient growth."
- **Education and incentives for behavioral change.** The values of low-carbon living, such as cooperation between individuals, communities, organizations and countries; reduce-recycle-reuse; sustainable city and village designs favoring pedestrianization and cycling; dietary changes; harmony with nature; primacy of pursuing satisfying human relationships and happiness over material and consumerist accumulation; and emphasis on comprehensive human development measures that include progress on poverty, health and environmental goals rather than only GDP, need to be imparted in schools and colleges, and eventually in larger cultural, economic and political platforms in societies. Widely showcasing best practices of LCS and sustainable development on various fronts such as national policy, city-level policy, private sector initiatives in different industries, energy supply systems, end-use systems, consumption behaviors, and community

initiatives would help to spread awareness. Some examples of such best practices are Germany's Energiewende, the Tokyo Metropolitan Government's energy and emissions monitoring and regulation of buildings, Iskandar Malaysia's roadmap for LCS, and the city of Kyoto's roadmap for LCS.

- **Inter-disciplinary climate modeling and research to estimate real costs and benefits.** Researchers across a range of disciplines must work together to help decision-makers in public, private and non-profit sectors to rise to the challenge of climate change and of achieving LCS. Both the adverse impacts of unmanaged global warming and the wider and deeper socio-economic benefits of low-carbon growth need to be correctly estimated. At present, the potential consequences of inadequate action or delayed action, such as catastrophic events, tipping points and large-scale human migration, are underestimated or not sufficiently analyzed (Stern, 2016). Besides, changes in regional extreme temperatures on land, which are often much greater than changes in associated global mean, are not widely reported. Translating GHG emissions into quantified regional- and impact-related targets could be a more powerful way to convey the criticality of drastic and early action (Seneviratne *et al*., 2016). At the same time, significant positive feedbacks of low-carbon innovations beyond avoided climate risks, such as knowledge spillover to the wider economy, the emergence of new infrastructure networks, economies of scale and the inducement of institutional and behavioral change, might also be underestimated (Stern, 2016). Inter-disciplinary climate research that combines natural sciences and engineering with economics and other social sciences would help to correctly emphasize these costs and benefits, and thereby communicate both the urgency and the desirability of reducing GHG emissions.

References

Agarwala, M. (2015) Climate policy: Push to decarbonize cities after Paris talks. Nature, 528, 193.
Allwood, J. (2016) Energy: Technology alone won't save climate. Nature, 530, 281.
Anderson, K. (2015) Talks in the city of light generate more heat. Nature, 528, 437.
Asia-Pacific Integrated Modeling Team (2007) Aligning Climate Change and Sustainability: Scenarios, Modeling and Policy Analysis. CGER, CGER-I072-2007.
Biermann, F., Abbott, K., Andresen, S., Bäckstrand, K., Bernstein, S., Betsill, M.M., Bulkeley, H., Cashore, B., Clapp, J., Folke, C., Gupta, A., Gupta, J., Haas, P.M., Jordan, A., Kanie, N., Kluvankova-Oravska, T., Lebel, L., Liverman, D., Meadowcroft, J., Mitchell, R.B., Newell, P., Oberthür, S. dr., Olsson, L., Pattberg, P.H., Sanchez-Rodriguez, R., Schroeder, H., Underdal, A., Carmago Vieira, S., Vogel, C., Young, O.R., Brock, A., and Zondervan, R. (2012) Navigating the anthropocene: improving earth system governance. Science, 335 (6074), 1306–1307.
Brundtland Commission (1987) Report of the world commission on environment and development: Our common future. Oxford University Press.
Cole, R.J., Robinson, J., Brown, Z., and O'Shea, M. (2008) Recontextualizing the notion of comfort. Building Research and Information, 36 (4), 323–336.
Covington, H., Thornton, J., and Hepburn, B. (2016) Global warming: Shareholders must vote for climate-change mitigation. Nature, 530, 156.
Csatho, B. M. (2015) Climate science: A history of Greenland's ice loss. Nature, 528, 341-343.
Damso, T., Kjaer, T., and Christensen, T.B. (2016) Local climate action plans in climate change mitigation – examining the case of Denmark. Energy Policy, 89, 74-83.
DDPP (2015) Pathways to deep decarbonization 2015 report - executive summary. Deep Decarbonization Pathways Project. SDSN - IDDRI.
Dessai, S., Afionis, S., and Alstine, J.V. (2013) Science alone cannot shape sustainability (Correspondence). Nature, 493, 26.
ETP (2012) Energy Technology Perspectives 2012: Pathways to a Clean Energy System, OECD/International Energy Agency, Paris, France.
Fujimori, S., Masui, T., and Matsuoka, Y. (2013) Global low-carbon society scenario analysis based on two representative socioeconomic scenarios. Global Environmental Research, 17 (1), 79–87.
GEA (2012) Global Energy Assessment: Toward a Sustainable Future. Cambridge University Press, Cambridge, UK and New York, USA and the International Institute for Applied Systems Analysis, Laxenburg, Austria.
GIBC (2010) Unlocking Investment to Deliver Britain's Low Carbon Future. Green Investment Bank Commission, London.
Gill, N., Osman, P., Head, L., Voyer, M., Harada, T., Waitt, G., and Gibson, C. (2015) Looking beyond installation: Why households struggle to make the most of solar hot water systems. Energy Policy, 87, 83-94.
Gillingham, K. and Kotchen, M.J. (2013) The rebound effect is overplayed (Comment). Nature, 493, 476.
Gomi, K., Deshpande, A., and Kapshe, M. (2013) Aligning low carbon society scenario with city development goals in Bhopal, India. Global Environmental Research, 17 (1), 129–138.
Gomi, K., Ochi, Y., and Matsuoka, Y. (2011) A systematic quantitative backcasting on low-carbon society policy in case of Kyoto city. Technological Forecasting and Social Change, 78 (5), 852–871.
Gomi, K., Shimada, K., and Matsuoka, Y. (2010) A low-carbon scenario creation method for a local-scale economy and its application in Kyoto city. Energy Policy, 38 (9), 4783–4796.
Griggs, D., Mark, S.-S., Owen, G., Rockstrom, J., Ohman, M.C., Shyamsundar, P., Steffen, W., Glaser, G., Kanie, N., and Noble, I. (2013) Sustainable development goals for people and planet. Nature, 495, 305–307.
Guivarch C. andHallegatte, S. (2011) Existing infrastructure and the 2°C target. *Climatic Change*. (DOI: 10.1007/s10584-011-0268-5).
Hashimoto, S. and Moriguchi, Y. (2013) Resource management for carbon management: A literature review. Global Environmental Research, 17(1), 39-46.
Ho, C.S. and Matsuoka, Y. (eds) (2012) Low Carbon Society Blueprint for Iskandar Malaysia 2025 - Summary for Policymakers, Low Carbon Asia Research Center.
Hourcade, J.-C. and Shukla, P.R. (2013) Triggering the low-carbon transition in the aftermath of the global financial crisis. Climate Policy, 13 (S01), S22–S35.
Huang, H., Khanna, M., Onal, H., and Chen, X. (2013) Stacking low carbon policies on the renewable fuels standard: Economic and greenhouse gas implications. Energy Policy, 56, 5–15. IEA (2011). World Energy Outlook 2011, International Energy Agency, Paris.

IEA (2013) Tracking Clean Energy Progress 2013, International Energy Agency, Paris, France.

IEA PVPS (2015) Snapshot of Global PV 1992-2014. Photovoltaic Power Systems Programme. International Energy Agency.

Ilyina, T. (2016) Climate science: Hidden trends in the ocean carbon sink. Nature, 530, 426-427.

IPCC WG I (2007) Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC WG I (2013) Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC WG II (2014) Summary for policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1-32.

IPCC WG III (2014) Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment. Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C.Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Jaccard, M. and Rivers, N. (2007) Heterogeneous capital stocks and the optimal timing for CO_2 abatement. Resource and Energy Economics, 9 (a) 1-16.

Jiang, K., Zhuang, X., Miao, R., and He, C. (2013) China's role in attaining the global 2°C target. Climate Policy, 13 (S01), S55–S69.

Jin, Z., Kuramochi, T., and Asuka, J. (2013) Energy and CO_2 intensity reduction policies in China: Targets and implementation. Global Environmental Research, 17 (1), 19–28.

Joss, S. (2010) Eco-cities: A global survey 2009. The Sustainable City VI: Urban Regeneration and Sustainability (eds. C.A. Brebbia, S. Hernandez, E. Tiazzi), 239–250. WIT Press Southampton, UK.

Kainuma, M., Miwa, K., Ehara, T., Akashi, O., and Asayama, Y. (2013) A low-carbon society: Global visions, pathways, and challenges. Climate Policy, 13 (S01), S5-S21.

Kainuma, M. and Pandey, R. (2015) Energy and socioeconomic systems to realize low carbon society (LCS). Chapter 31 of Handbook of Clean Energy Systems (Ed. Yan, J.). John Wiley & Sons.

Kanie, N., Suzuki, M., and Iguchi, M. (2013) Fragmentation of international low-carbon technology governance: An assessment in terms of barriers to technology development. Global Environmental Research, 17 (1), 61–80.

Kopetz, H. (2013) Build a biomass energy market. Nature, 494, 31.

Kunzig, R. (2015) Germany could be a model for how we'll get power in the future. National Geographic, October 15, 2015.

La Rovere, E.L., Dubeux, C.B., Pereira, A.O., Jr., and Wills, W. (2013) Brazil beyond 2020: From deforestation to the energy challenge. Climate Policy, 13 (S01), S70-S86.

Lechtenbohmer, S. and Luhmann, H.-J. (2013) Decarbonizationand regulation of Germany's electricity system after Fukushima. Climate Policy, 13 (S01), S146-S154.

Lee, D.K., Park, C., Matsuoka, Y., Gomi, K., and Kainuma, M. (2012) Low carbon development towards 2030 in Gyeonggi Province, Seoul National University, Korea.

Leisinger, K. (2015) Business needs to embrace sustainability targets. Nature, 528, 165.

Limmeechokchai, B. (2010) Thailand's Low-Carbon Society Vision 2030. Sirindhorn International Institute of Technology, Thammasat University.

Low-Carbon Asia Research Project (2013) Realizing Low-Carbon Asia– Contribution of 10 Actions, National Institute for Environmental Studies (NIES). http://2050.nies.go.jp/file/ten_actions_2013.pdf

LCS-RNet (2010) Introduction to Low Carbon Societies – The Challenges of the International Research Network for Low Carbon Societies. LCS-RNet Secretariat, Japan.

Michelsen, C.C. and Madlener, R. (2016) Switching from fossil fuel to renewables in residential heating systems: An empirical study of homeowners' decisions in Germany. Energy Policy, 89, 95-105.

Mulvaney, K.K., Woodson, P., and Prokopy, L.S. (2013) A tale of three counties: Understanding wind development in the rural Midwestern United States. Energy Policy, 56, 322–330.

Munoz, J.I. and Bunn, D.W. (2013) Investment risk and return under renewable decarbonization of a power market. Climate Policy, 13 (S01), S87–S105.

Nakamura, K., Hayashi, Y., and Kato, H. (2013) Macroscopic design of measure to realize low-carbon land-use transport systems in Asian developing cities. Global Environmental Research, 17 (1), 47–60.

Nature (2013) Editorial: Change for good. Nature, 493, 577.

Nature (2016) Editorial: Climate changes. Nature, 530, 382.

NIES and MHIR (2015) Assessment of INDCs using AIM/CGE[Global] (Ver.1). http://www-iam.nies.go.jp/aim/projects_activities/indcs/file/20151009_indcs_leaflet_eng.pdf

Reilly, J. (2013) Achieving a low-carbon society. Climate Policy, 13(S01), S155-S158.

Schade, J., Wallstrom, P., Olofsson, T., and Lagerqvist, O. (2013) A comparative study of the design and construction process of energy efficient buildings in Germany and Sweden. Energy Policy, 58, 28-37.

Schiermeier, Q. (2013) Germany's energy gamble. Nature, 496, 156–158.

Seneviratne, S.I., Donat, M.G., Pitman, A.J., Knutti, R., and Wilby, R.L. (2016) Allowable CO_2 emissions based on regional and impact-related climate targets. Nature, 529, 477-483.

Shove, E. (2004) Efficiency and consumption: Technology and practice. Energy & Environment, 15 (6), 1053–1065.

Shrestha, R. and Shakya, S.R. (2012) Benefits of low carbon development in a developing country: Case of Nepal. Energy Economics, 34, S503–S512.

Shukla, P.R., Dhar, S., and Mahapatra, D. (2008) Low carbon society scenarios for India. Climate Policy, 8, 156–176.

Shukla, P.R., Bazaz, A.B., Agarwal, P., Pathak, M., and Sharma, S. (2011) India low carbon society roadmap 2050. Indian Institute of Management, Ahmedabad.

Skea, J. and Nishioka, S. (2008) Policies and practices for a low-carbon society. Climate Policy, 8, S5-S16 Supplement.

Skea, J., Hourcade, J.-C., and Lechtenbohmer, S. (2013) Climate policies in a changing world context: Is a paradigm shift needed? Climate Policy, 13 (S01), S1–S4.

Skea, J., Lechtenbohmer, S., and Asuka, J. (2013) Climate policies after Fukushima: Three views. Climate Policy, 13 (S01), S36–S54.

Stern, N. (2016) Economics: Current climate models are grossly misleading. Nature, 530, 407-409.

TMG (2015) Presentations made by Tokyo Metropolitan Government (TMG) officials at the Training Workshop on Emissions Reporting and Reduction System, held at TMG Building, Tokyo, 10-12 June, 2015.

Tollefson, J. (2016a) Paris climate deal hinges on better carbon accountability. Nature, 529, 450-451.

Tollefson, J. (2016b) 2015 declared the hottest year on record. Nature, 529, 450.

Tollefson, J. and Weiss, K. R. (2015) Nations approve historic global climate accord. Nature, 528, 315-316.

Trancik, J.E. (2015) Innovation: Clean energy enters virtuous cycle. Nature, 528, 333.

Tsilingiridis, G. and Ikonomopoulos, A. (2013) Five results of incentives policy on grid interconnected photovoltaic systems development in Greece. Energy Policy, 58, 303–311.

UN (2015) Transforming our world: The 2030 Agenda for Sustainable Development. https://sustainabledevelopment.un.org/post2015/transformingourworld

UNFCCC (2010) Report of the Conference of the Parties on its sixteenth session, held in Cancun from 29 November to 10 December 2010. UNFCCC/CP/2010/7/Add.1.

UTM-Low Carbon Asia Research Center (2013) Low Carbon Society Blueprint for Iskandar Malaysia 2025 – Summary for Policymakers. UTM-Low Carbon Asia Research Center, Universiti Teknologi Malaysia (UTM), Malaysia.

Van Noorden, R. (2013) Europe's untamed carbon (News in Focus). Nature, 493, 142.

Wang, Q. (2013) China has the capacity to lead in carbon trading (Worldview). Nature, 493, 273.

Watts, N., Adger, W., N., Agnolucci, P., Blackstock, J., Byass, P., Cai, W., Chaytor, S., Colbourn, T., Collins, M., Cooper, A., Cox, P.M., Depledge, J., Drummond, P., Ekins, P., Galaz, V., Grace, D., Graham, H., Grubb, M., Haines, A., Hamilton, I., Hunter, A., and Jiang, X. (2015) Health and climate change: Policy responses to protect public health. The Lancet, 386, 10006, 1861-1914.

WEO (2012) World Energy Outlook 2012. International Energy Agency, Paris, France.

Witze, A. (2016) Speedier Arctic data as warm winter shrinks ice sea. Nature, 531, 15-16.

World Bank (2011) Mobilizing climate finance. Paper prepared at the request of G20 Finance Ministers, 6 October, 2011. World Bank, Washington, DC.

WRI (2014) World Resources Institute's website: http://www.wri.org/blog/2014/11/6-graphs-explain-world%E2%80%99s-top-10-emitters

Yeh, S. and Sperling, D. (2013) Low carbon fuel policy and analysis. Energy Policy, 56, 1–4.

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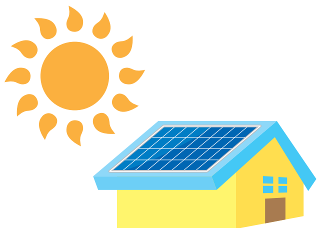
Authors: Rahul Pandey, Mikiko Kainuma, Tomoko Ishikawa, Shuzo Nishioka
Publisher: Institute for Global Environmental Strategies (IGES)

LCS-RNet Secretariat c/o Institute for Global Environmental Strategies
2108-11, Kamiyamaguchi, Hayama, Miura, Kanagawa, 240-0115, Japan
Email: lcs-rnet@iges.or.jp Fax: 81-46-855-3809 Web: http://lcs-rnet.org



International Research Network for Low Carbon Societies (LCS-RNet)

(c/o) Institute for Global Environmental Strategies (IGES)
2108-11 Kamiyamaguchi, Hayama, Miura, Kanagawa, 240-0115, Japan
Email: lcs-rnet@iges.or.jp Fax: +81-46-855-3809 Web: http://lcs-rnet.org

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