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Economic and environmental impacts of greenhouse gas mitigation: An integrated assessment

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Abstract: Despite an increasing likelihood of considerable global warming over the coming century, there is limited greenhouse mitigation action undertaken by the international community (Carraro and Massetti 2011). It is in individual and collective socio-economic and environmental interest to embark on strong mitigation action globally. The present study analyses alternative global carbon pathways to achieve greenhouse gas emission reductions in the form of an illustrative and exploratory exercise. The potential economic and environmental implications of the alternative global carbon pathways are then assessed. The alternative carbon pathways analysed in this study include a high, medium and low carbon pathways that represent small, modest and large improvements in technological advancements in low emission intensive stationary and transport energy generation and energy efficiency respectively. These alternative carbon pathways are then compared to a reference case that corresponds to the baseline scenario used in the 2008 Garnaut Climate Change Review (Garnaut 2008). We use CSIRO's current version of the Global Integrated Assessment Model (GIAM-XP) (Gunasekera et al., 2008, Harman et al., 2008, Garnaut, 2008 and Scealy et al., 2011) to undertake the impacts of the alternative carbon pathway scenarios.

Our analysis indicates that concerted efforts towards improvements in technological advancements in low emission intensive stationary and transport energy generation and energy efficiency could help reduce the atmospheric CO_2 concentration levels, radiative forcing and global temperature over time in a progressive manner across the scenarios analysed in this paper. Failing to do so is likely to have significant adverse impacts associated with increasing atmospheric CO_2 concentration levels, radiative forcing and global temperature over the coming decades. For example, failing to reduce greenhouse gas emissions substantially over the coming decades will have significant consequences in terms of increases in temperature across many parts of the world relative to what would otherwise be.

Key parts of the human-earth system including water, coastal communities, natural ecosystems, and agriculture are likely to be highly vulnerable to the projected climate change illustrated in our analysis unless significant mitigation measures are undertaken in the foreseeable future to set the global economy on a low to medium carbon pathway. This would require a portfolio of mitigation measures including significant improvements in technological advancements in low emission intensive stationary and transport energy generation and energy efficiency, at national, regional and global levels.

It is important to recognize that global economic output continues to increase over time, albeit at a slower rate of growth under the alternative carbon pathway scenarios compared with the reference case. However, in the long term, productivity changes and the structural adjustments underpinning the global economic activity tend to have a more favorable impact overall, particularly, in the presence of significant improvements in technological advancements in low emission intensive stationary and transport energy generation and energy efficiency. We argue in the paper that there is an increasing need for additional research into improving our understanding of inter-fuel substitution possibilities and of the less emission/energy intensive technologies available for particular industries.

Keywords: *Global integrated assessment, Climate change, Climate impacts, Socio-economic impacts.*

1. INTRODUCTION

There is growing scientific evidence on the increased likelihood of considerable global warming over the coming century. Despite that, there is limited greenhouse mitigation action undertaken by the international community (Carraro and Massetti 2011). However it is in individual and collective socio-economic and environmental interest to embark on strong mitigation action by countries across the world. Yet, for many countries, particularly in the developing world, climate change mitigation is a major challenge. Many communities in developing countries continue to aspire to better living conditions and economic prosperity, which require increasing amounts of energy. Current energy generation in many countries is fossil fuel based and hence is greenhouse gas intensive. Energy is crucial in both developed and in developing countries. Growth in energy consumption is expected in all regions over the coming decades and this trend is particularly important in developing countries.

Achieving sustainable and equitable growth and prosperity requires developed countries to reduce their emissions and developing countries to avoid the carbon intensive path followed by the former group of countries. Such an approach requires fundamental changes in lifestyles for developed countries and a leapfrogging to new development models for developing countries. Achieving these goals requires reconciliation between what is adequate to prevent dangerous climate change with what is technically achievable at acceptable costs (World Bank, 2010). Within this context, this paper analyses the potential economic and environmental implications of alternative global carbon pathways to achieve greenhouse gas emission reductions. These pathways represent different growth and development, technological advancements, energy efficiencies and human behavioral dynamics.

2. MODELLING FRAMEWORK

To understand the socio-economic impacts of climate change, and to analyse alternative carbon pathways, we make use of the CSIRO's current version of the Global Integrated Assessment Model (GIAM-XP). The model structure and the key assumptions are in Gunasekera *et al.*, 2008; Harman *et al.*, 2008, Garnaut, 2008 and Scealy et al., 2011 (see Figure 1). GIAM-XP consists of a global economic module coupled to a climate module. The economic module is the Global Trade and Environment Model (GTEM) which takes account of energy production, technological advancement, and economy wide adjustment, along with policy intervention instruments (Pant 2007, Gurney *et al.*, 2009 and Clarke *et al.*, 2009). It allows projections for the major human induced factors influencing climatic conditions (such as greenhouse gas emissions) to be developed after accounting for regional and global production and consumption decisions and international trade. It also allows for analysis across 13 regions, 21 industries, four primary factors and six greenhouse gas emissions (see Sealy *et al.*, 2011 for details).

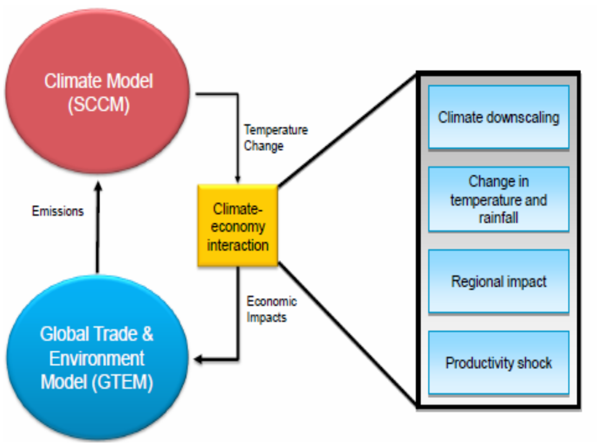


Figure 1. GIAM-XP model framework.

The climate module used is known as the Simple Carbon Climate Model (SCCM) that translates global emissions into global and regional warming (Raupach *et al.*, 2011). GIAM-XP couples these two modules in the following way. The GTEM module provides the greenhouse gas emissions based on economic activities. These emissions are then fed into the SCCM module. The SCCM module converts the emissions into greenhouse gas concentrations and then into global changes in temperature. A statistical procedure as per Raupach *et al* (2011) has been used to down scale the global mean temperature to regional temperatures.

A climate-economy response function is used to take account of the regional climate change impacts. The climate-economy response function estimates and translates regional changes in temperature through time to changes in factor productivity at the economy wide level in each country or region represented. Regional climate change impacts are assumed to be a function of regional changes in average temperature (relative to

2000 levels), and the vulnerability of a region to change in temperature. Vulnerability of a regional economy is expressed in relative terms by a proxy, which is the ratio of gross national product (GNP) per person of the economy relative to that of a benchmark economy (the United States). This aims to capture the notion that the relative economic impacts of climate change for a given change in temperature will be higher in developing economies than in more developed economies (see Pearce *et al.*, 1996 and IPCC, 2007). The climate-economy response function allows economic impacts (i.e. damages in many cases) to increase gradually for small changes in temperature before increasing more rapidly until a catastrophic temperature level is reached (see Harman *et al.,* 2008 for more details). The GIAM-XP framework can be easily expanded to take into account other impact functions. For example Scealy *et al.*, (2011) used sector specific climate-economy impact functions, to model the effects of climate change driven change in temperature on agricultural sector. In the near future we plan to expand this framework to include: (a) sector specific impacts for the energy sector, manufacturing sectors, and other sectors; (b) impacts on human health, through heat stress, and the redistribution of diseases; (c) impacts on critical infrastructure; and (d) rare events and catastrophes.

3. SCENARIO ANALYSIS

The economic and environmental impacts of greenhouse mitigation under alternative carbon pathways are analysed here by undertaking the following scenarios:

- A reference case (baseline) scenario which corresponds to the A1FI IPCC SRES scenario used in the 2008 Garnaut Climate Change Review (Garnaut, 2008). Under this scenario, global economic growth over the period out to 2030 is projected to be more expansive and stronger than in the 1950s and 1960s. In terms of climate change, this scenario equates to a global temperature increase of 4.4^{o}C from 2000 levels, and an atmospheric CO_2 concentration of 1000ppm at 2100.
- A high carbon pathway scenario that reflects a small (relative to the baseline) improvement in technological advancements. Under this scenario, well-targeted policies to reduce greenhouse gas emissions lead to a small reduction in emissions relative to the reference case. These policies achieve this by inducing a small amount of reallocation of resources to less emission intensive activities, substitution within industries to less emission intensive production options and energy efficiency improvements relative to the reference case. These structural changes within the economy are achieved at the expense of a small loss in economic output but with a small gain from avoided greenhouse damages. This results in a global temperature increase of 2.8^{o}C from pre-industrial levels and an atmospheric CO_2 concentration of 595ppm at 2100.
- A medium carbon pathway scenario that reflects a modest (relative to the baseline) improvement in technological advancements. Under this scenario, well-targeted policies to reduce greenhouse gas emissions lead to a moderate reduction in emissions relative to the reference case. These policies achieve this by inducing a moderate amount of reallocation of resources to less emission intensive activities, substitution within industries to less emission intensive production options and energy efficiency improvements relative to the reference case. These structural changes within the economy are achieved at the expense of a moderate loss in economic output but with a moderate gain from avoided greenhouse damages. This results in a global temperature increase of 1.8^{o}C from pre-industrial levels and an atmospheric CO_2 concentration of 440ppm at 2100.
- A low carbon pathway scenario that reflects a large (relative to the baseline) improvement in technological advancements. Under this scenario, well-targeted policies to reduce greenhouse gas emissions lead to a larger reduction in emissions relative to the reference case. These policies achieve this by inducing a larger amount of reallocation of resources to less emission intensive activities, substitution within industries to less emission intensive production options and energy efficiency improvements relative to the reference case. These structural changes within the economy are achieved at the expense of a larger loss in economic output but with a larger gain from avoided greenhouse damages. This results in a global temperature increase of 1.4^{o}C from pre-industrial levels and an atmospheric CO_2 concentration of 390ppm at 2100.

Analysis of all the scenarios incorporates climate change impacts with respect to change in temperature. The alternative carbon pathway scenarios represent three broad configurations of structural changes in the economy toward lower emission intensive technologies, especially in stationary and transport energy generation, and greater energy efficiency, designed to reduce greenhouse gas emissions. These scenarios are broadly consistent with the ranges of long term CO_2 concentration goals which have been canvassed in the recent domestic and international climate change policy debates (Garnaut 2008, 2011).

4. SIMULATIONS RESULTS

4.1. Environmental Impacts

Figure 2 illustrates the projected changes in key climatic variables including global temperature, atmospheric CO_2 concentration levels and radiative forcing under the reference case and the alternative carbon pathways. It is clear that concerted efforts towards improvements in technological advancements in low emission intensive stationary and transport energy generation and energy efficiency could help reduce atmospheric CO_2 concentration levels, radiative forcing and the global temperature over time in a progressive manner across the scenarios analysed in this paper. Failing to do so is likely to have significant adverse impacts associated with increasing atmospheric CO_2 concentration levels, radiative forcing and global temperature over the coming decades.

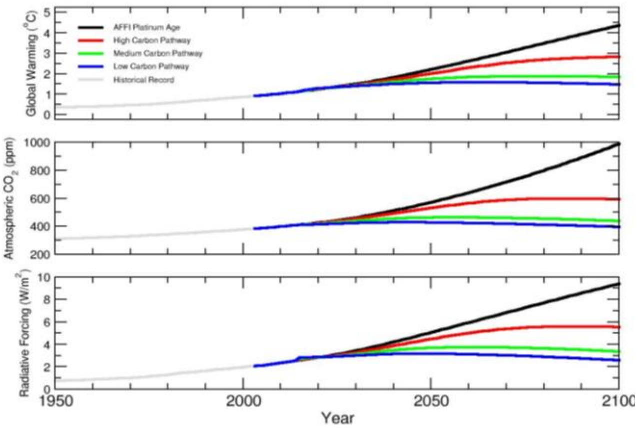
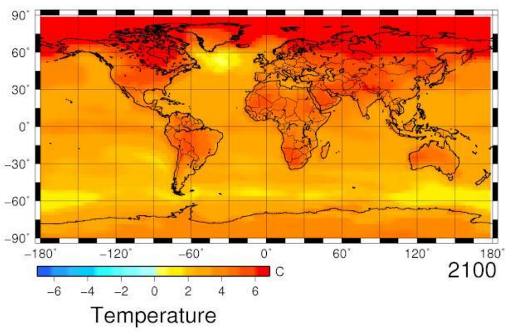
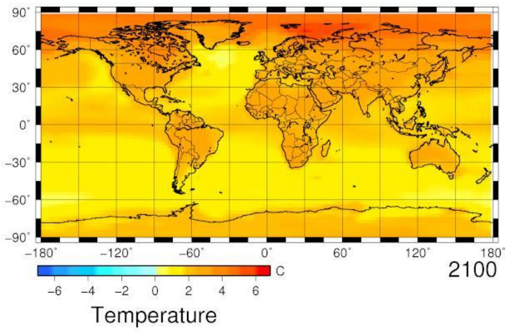


Figure 2. Projected changes in climatic variables. From top to bottom: (1) Global Warming pathway (°C); (2) Atmospheric CO_2 concentrations (ppm); and (3) Radiative forcing (W/m^2).

Projected changes in temperature in 2100 across different regions of the world under the reference case and alternative carbon pathways analysed in this paper are presented in Figure 3. It is evident from Figure 3 that failing to reduce greenhouse gas emissions substantially over the coming decades will have significant consequences in terms of increases in temperature across many parts of the world relative to what would otherwise be.



(a)



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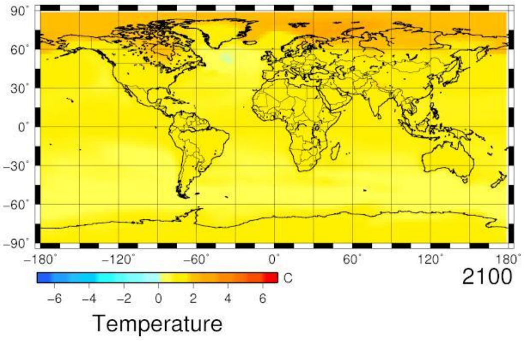

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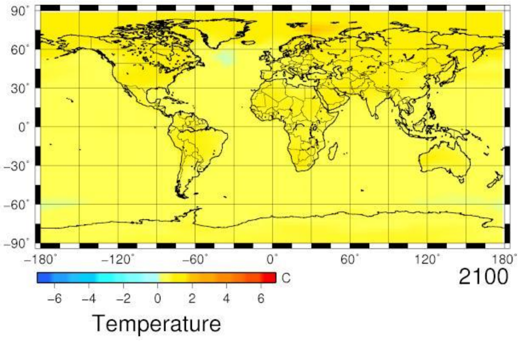

(d)

Figure 3. Projected changes in temperature: (a) Reference case of A1FI Platinum; (b) High Carbon Pathway Scenario; (c) Medium Carbon Pathway Scenario; (d) Low Carbon Pathway Scenario.

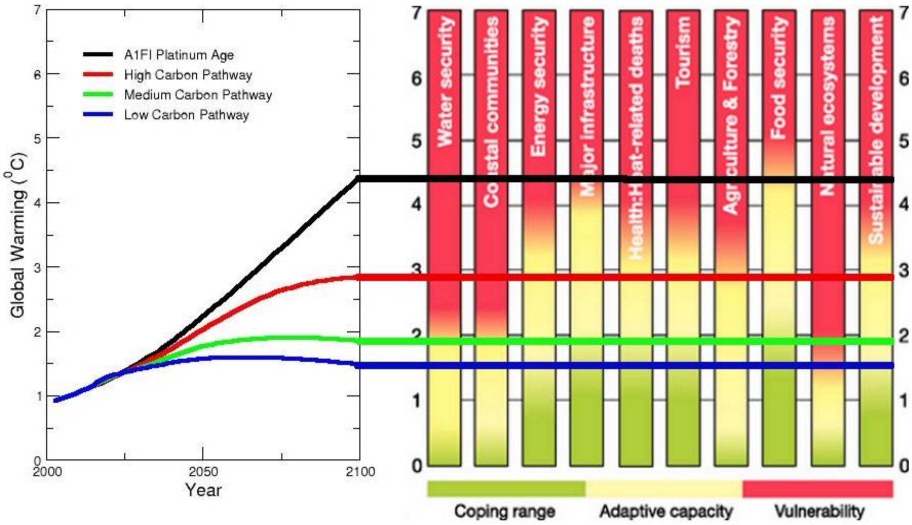

Figure 4. Relative vulnerability to climate change under the reference case and alternative carbon pathway scenarios. This figure is based on the IPCC's Fourth Assessment Report (IPCC (2007).

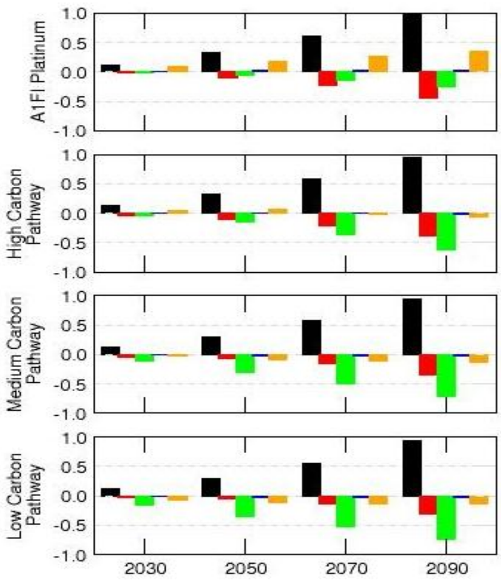

Figure 5. Decomposition of emissions growth (normalized). Economic growth (black), Between industry structural change (red); Within industry structural change (green); Residual (blue); and Global emissions (orange).

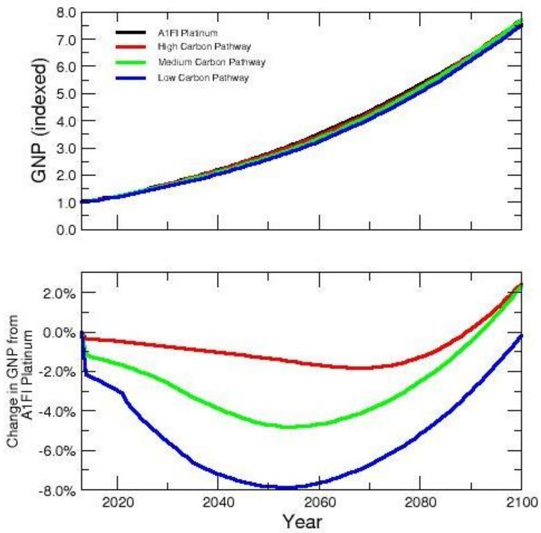

Figure 6. Change in world economic output.

Figure 4 indicates the extent to which key sectors of the global human-earth system are vulnerable to various projected global temperature change outcomes under the reference case and alternative carbon pathway scenarios. The colour bars on Figure 4 indicate how much change the key sectors in the human-earth system can cope with normally (green), how much they can adapt to autonomously (yellow), and when it becomes vulnerable (red) (see Stafford Smith and Ash, 2011). According to Stafford Smith and Ash (2011), at the green end of the temperature bars, we are able to cope as much as we do at present, up to about 1-1.5°C. According to our analysis, this would require at least undertaking improvements in technological advancements in low emission intensive stationary and transport energy generation and energy efficiency compatible with the 'low carbon pathway' considered in this study. On the other hand, the yellow spectrum between 1.5°C and 3-4° C highlights the need to undertake additional extensive measures in the various sectors listed to adapt to the changing conditions (Stafford Smith and Ash, 2011). As illustrated in Figure 4, under the reference case, at a global mean temperature rise above 4^{o}C, conditions in the human-earth system become far more difficult and make our societies and economic sectors highly vulnerable. According to Stafford Smith and Ash (2011), in Australia, sectors such as water, coastal communities, natural ecosystems, and to some extent, agriculture is likely to come under stress at lower temperature changes than the others.

4.2. Economic Impacts

Within the four scenarios, global emissions are influenced by economic growth, changes in the industry composition of the economy, changes in efficiency and the technologies and inputs used within industries and some adjustments in final consumption behaviour and land use. The sequence of scenarios embodies increasingly more stringent policies to steer the world economy, in a cost-effective way, to increasingly lower levels of emissions. These lower levels of emissions are realised by changes in the aforementioned influences on emissions. This is illustrated for the four scenarios in Figure 5. The vertical axis in Figure 5 is the contribution of economic growth, and inter- and intra-industry structural changes to the cumulative percent change in emissions from 2012 onwards. The bar for global emissions (orange) can be interpreted as a cumulative percent change, as can the bar for economic growth (black), which is the cumulative percent change in world real GNP from 2012 onward. The latter is also what emissions growth would be if there were no change in the structure of the economy or technical progress - just a "scaling-up" of the 2012 economy. Plainly the gap between economic output growth and emission growth is substantial in all four scenarios, and this is where the other influences on emissions come into play. The three other bars in the graphs cannot be interpreted as percent changes. Rather, they are the contribution to emissions growth from each of the three sources, which will be described in more detail presently. The sum of these three values, plus the value shown for economic growth, equals the value shown for emissions growth. That is, emissions growth has been additively decomposed. The contribution to emissions labeled "Between industries structural change" (red) is based on the calculation of emissions under the assumption that industries grow at the same rates as in the respective scenarios but with constant emission intensity. The difference between emissions calculated this way and emissions that just grow in line with world GNP (the "Economic growth" contribution) is expressed relative to global emissions to give the "Between industries structural change" contribution. This captures the contribution to emissions growth from the reallocation of resources between industries, which across the scenarios is steered increasingly towards less emission intensive activities.

The contribution to emissions labeled "Within industry structural change" (green) is calculated as the difference of total world industry emissions and the emissions calculated under "Between industries structural change" relative to global emissions. So it captures the contribution to emissions growth from the changing structure of input use (such as from inter-fuel substitution and technical efficiency changes) within industries. Noteworthy is that this contribution increases in magnitude more rapidly than the "Between industries structural change" contribution across the four scenarios, that is, as emission reduction policies become more stringent. This perhaps points the way to where future research effort could be better directed- in refining estimates of inter-fuel substitution and knowledge of the less emission/energy intensive technologies available for particular industries rather than refining estimates of factor mobility between broad sectors. The contribution labeled "Residual" (blue) is, as the name implies, a category that captures the difference between total global emissions and total world emissions from industries. It includes the contribution of emissions from government and private consumption of fossil fuels, solid and liquid waste and changing land use and land clearing (the latter being specified exogenously in GIAM-XP at present). It also includes the emissions of high-global warming potential gases in the GIAM-XP model, the growth of which is assumed to move in line with economic and population growth. Although governments and private individuals can take steps to reduce the emissions for which their consumption is responsible, much of this is picked up in the other contributions. For example, more efficient use of electricity impacts on electricity output and hence the "Between industries structural change" contribution.

Figure 6 illustrates the global economic growth pathways under the reference case and the alternative carbon pathway scenarios. It is important to recognize that global economic output continues to increase over time, albeit at a slower rate of growth under the alternative carbon pathway scenarios compared with the reference case. In the case of the low carbon pathway scenario, global economic output is estimated to decline until about the middle of the century and trend upwards thereafter, relative to the reference case. In general, Figure 6 indicates the relative economic costs associated with achieving a low carbon pathway in the short to medium term. However, in the long term, total factor productivity changes and the structural adjustments underpinning the global economic activity tend to have a more favourable impact overall, particularly, in the presence of significant improvements in technological advancements in low emission intensive stationary and transport energy generation and energy efficiency.

5. CONCLUDING REMARKS

The analysis in this study highlights the economic and technological tasks that lay ahead to achieve substantial emission reductions and the associated formidable environmental and economic challenges. The simulation results of the study highlight vulnerabilities and areas where we need to adapt. For example, we illustrate the different carbon pathways that are required to help adapt and cope with potential climate change impacts and also the areas where less ambitious emission reduction targets could increase the vulnerabilities of key sectors of our economies. It is clear that forward looking planned adaptation is required as a key strategy to cope with the degree of climate change that is already locked in due to past emissions. Key parts of the human-earth system are likely to be highly vulnerable to the projected climate change illustrated in our analysis unless significant mitigation measures are undertaken in the foreseeable future to set the global economy on a low to medium carbon pathway. This would require a portfolio of mitigation measures including significant improvements in technological advancements in low emission intensive stationary and transport energy generation and energy efficiency, at national, regional and global levels.

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