Climate Change and Renewable Energy
Implications for the Pacific Islands
of a Global Perspective

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ABSTRACT

The 2007 Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) implies that to avoid dangerous climate change it will be necessary to hold temperature rises to less than about 2°C above pre-industrial values. To achieve this goal will require global greenhouse gas emissions to be 50% to 80% lower in 2050 than in 2000, and to begin declining by 2015. This is a major challenge to the world.

Consequently, the IPCC published in 2011 a Special Report on Renewable Energy, which reviewed the state of the art, the current status and the technical potential of each of the main renewable energy (RE) technologies, and thus the feasibility and cost of meeting these climate change targets through much increased use of RE.

This paper outlines some key findings of that Special Report, and their implications for the Pacific Islands. It concludes that the required global increase in RE in place of fossil fuels is technically and economically possible, especially if coupled with increases in efficiency of energy use. But it will require significant investment, substantial institutional and social change, and the political will to drive such change. Such changes in the global energy system would flow through to Pacific Island countries in the form of lowering the cost to them of renewable energy technologies and would bring benefits in terms of environmental and economic security. Nevertheless, some further climate change is inevitable, and the Pacific Islands will still need to adapt to more severe climate extremes. Recent research suggests that without a rapid reduction of global greenhouse gas emissions, the atoll countries of the region may become uninhabitable by about 2040 because of salt-water inundation.
INTRODUCTION

Internationally, both the United Nations Framework Convention on Climate Change (UNFCCC, 1992, Art 4.8) and IPCC (2007a, b) recognise the Pacific Islands as particularly vulnerable to climate change. Consequently, authoritative analyses that bear on the extent of future climate change are of high importance to all the small island countries of this region.

The United Nations set up the IPCC (Intergovernmental Panel on Climate Change) in 1990 to provide authoritative scientific and technical advice to governments about climate change, its observed impacts, and measures to adapt and mitigate it. The IPCC does this by convening groups of experts (lead authors, nominated by governments) to draft reviews of the relevant technical literature; these drafts are then further reviewed by other experts and governments before publication of the reports and their summaries. This makes the process lengthy, but means that afterwards no government or scientist represented can say that they disagree with the finished findings; the IPCC sees this as a key strength of its operations.

In its most recent Assessment Report, IPCC (2007d) clearly attributed the observed global warming over the past few decades to human influence, and in particular to the increased global emissions of greenhouse gases (GHGs) from the burning of fossil fuels (i.e. oil, coal and gas) since the Industrial Revolution of the nineteenth century. IPCC (2007d) went on to project that ‘significant’ climate change would occur over the coming century as GHGs continued to accumulate in the atmosphere, and the higher the emissions of GHGs, the worse this change would be.

In particular, one consequence of global warming would be a rise in sea levels around the world. More recent scientific reviews suggest that the sea-level rise associated with a given level of GHGs would more likely be double what IPCC (2007d) suggested – that is, up to a 2-metre rise in sea level by the year 2100, if anything like the present pattern of global energy use continues (Allison et al., 2009). Such a rise threatens the very survival of low-lying (atoll) island countries, with recent research, discussed in section 9, suggesting that some atolls may become uninhabitable as soon as 2040. But there would be serious consequences for other Pacific Islands as well, as outlined in Section 2 of this paper.

Given the close link between energy use and climate change, the IPCC has devoted considerable effort in all four of its Assessment Reports to date to analysing options to mitigate climate change by reducing GHG emissions (e.g. IPCC, 2007c). One of the most promising options is the replacement of energy systems based on fossil fuels by systems based on renewable energy (RE), since renewable energy sources (such as solar, wind, hydro and biomass) emit no GHGs as they are used. Pressed by governments to produce more detail and more recent data on renewable energy systems, the IPCC decided in 2008 to commission a Special Report on Renewable Energy. This report was approved and published in May 2011 (Edenhofer et al., 2011; hereinafter referred to as SRREN).

The thrust of the present paper is to outline some key findings of the SRREN, and to point out their main implications for the Pacific Islands. To this end, the paper looks in order at projections of climate change, global energy demand and use, the main renewable energy resources and
technologies, and scenarios for future global energy supply and use (including their costs), both
globally and in the Pacific Islands. A major benefit of a global move from fossil fuel to renewable
energy is to reduce the severity of climate change and thus its cost to all economies (section 8), but
some climate change remains inevitable and thus the need to adapt to it (section 9).

The perspective of this paper is mainly the implications, rather than the engineering detail of
technologies or the analytical details of the economic analyses. Therefore the material from
SRREN discussed here comes mainly from only two of its 11 chapters: the introduction (Moomaw
et al., 2011) and the chapter on mitigation potential and costs (Fischedick et al., 2011). Nor do
we attempt to analyse here the related international treaty negotiations in any depth, but rather
give background to them.

PROJECTIONS OF CLIMATE CHANGE

WHAT ARE CLIMATE AND CLIMATE CHANGE?

To a scientist, the ‘climate’ of a particular place or region means essentially the average of
its weather. Thus one can say that in all Pacific Islands the climate is warm and humid in all
seasons (on a world scale that is, for example, compared to the climate of southern New Zealand
or central Australia). This can be statistically quantified in terms of such physical variables as
average monthly rainfall or average minimum temperature. Conventionally, the ‘averages’ are
taken over a 30-year period. Meteorologists also statistically quantify variability in climate, i.e.
the variations from year to year, particularly in extremes (e.g. length of dry spell or maximum
wind speed).

Climate change refers to trends or other systematic changes in either the average state of the
climate, or in its variability (including extreme events), with these changes persisting for an
extended period, typically decades or longer (Hay et al., 2003 p.3).

There is a vast scientific literature about climate change. Fortunately this literature has been
extensively reviewed by IPCC Working Group 1, who in their reports summarise the key
conclusions on which there is wide agreement and also the quantitative results, which are still
evolving (Solomon et al., 2007; IPCC, 2007d). IPCC also point out some issues where results are
not yet conclusive, and provide a useful glossary of technical terms.

Notwithstanding the efforts of vested interests to deny it (as damningly documented by Oreskes
and Conway, 2010) almost all climate scientists agree on the core of this science, namely that
greenhouse gases have a significant influence on the Earth’s climate, that the amount of such
gases in the atmosphere is increasing due to human activity, and that this increase will have
an effect on the climate, most notably to produce an increase in average temperatures (‘global
warming’). The only major scientific issue is: how much warming and what are the local effects,
since just as climate varies from place to place so will changes in the climate. Clearly the degree
of warming will depend on both the amount of GHGs emitted into the atmosphere in future (a
socioeconomic uncertainty) and the responsiveness of the climate to a given increase in the stock
of GHGs in the atmosphere (a scientific uncertainty).
A commonly used measure of the extent of climate change is the change in Global Mean Surface Temperature (GMST), i.e. the annual average of temperatures measured by meteorological stations around the world.

**IMPACTS OF CLIMATE CHANGE?**

It is clear from the summary by IPCC Working Group 2 (2007a) that a rise in GMST of a modest-sounding 4 or 5 degrees would have consequences for ecosystems, water supply, food, coasts and health that would be unacceptable – indeed dangerous – to a large proportion of the world’s population. These include hundreds of millions of people exposed to increased water stress (e.g. droughts in Africa), but also millions more people exposed to coastal flooding each year in low-lying regions such as deltas and atolls. The consequences of such frequent flooding by salt water threaten the very survival of atoll nations, as discussed in section 8 of this paper. Natural and crop ecosystems would suffer significant extinctions of both terrestrial and marine plants and animals, with about 30% of global coastal wetlands lost and decrease of cereal productivity in low latitudes (e.g. rice). A substantially increased burden on health services (e.g. from widening spread of malaria) is also projected. These impacts could be even worse if the climate system passes certain ‘tipping points’, where abrupt changes occur such as irreversible melting of the Greenland ice shelf, or bulk release of methane from permafrost regions. Though the precise increase in GMST required for these tipping points is still uncertain, it is likely that some such potentially catastrophic changes could occur following increases in GMST of 4°C or more (Schellnhuber et al., 2006; Smith et al., 2009).

Worryingly, increases in GMST of this magnitude are within the range of projections summarised in Figure 1, and could occur if global fossil fuel use continues to increase without constraint.

Even smaller increases in GMST of 4°C or more can have quite severe impacts on vulnerable systems. For example, a prolonged temperature rise of only 2°C for more than a few weeks takes many coral species outside their range of tolerance, which is likely to lead to death and weakening of many coral reefs. This has occurred sporadically in the Pacific Islands in the past 20 years, but global warming would make it widespread across the Pacific Islands. These temperature effects are worsened by the increase in CO$_2$ in the atmosphere that caused them, because more CO$_2$ then dissolves in the ocean, making it more acidic and thereby chemically attacking the reef structure. Given the importance of these reefs as protection from storms, as sources of food and as attractions for tourists, these ecological impacts have grave consequences for Pacific peoples. Another consequence of global warming is an increase in the severity of tropical cyclones: because cyclones are driven by evaporation from regions of warm sea water, the warmer the ocean, the more likely it is to generate a severe cyclone. As cyclones like Ofa and Val (Samoa in 1990–91), Kina (Fiji in 1993) and Zoe (Solomon Islands in 2002) cause severe economic and social damage, this is another worrying prospect for Pacific Islanders.

All this explains why negotiators for the Pacific Island Countries (PICs) at the 2009 climate change treaty negotiations in Copenhagen pushed hard, though without success, for ‘legally binding’ emissions reductions that would limit the increase in GMST to less than 1.5°C.
PROJECTIONS OF GMST FOR VARIOUS EMISSION SCENARIOS

Suppose we know how many tonnes of a particular GHG such as carbon dioxide (CO₂) are emitted by human activity in each year. Knowing the lifetime of CO₂ in the atmosphere (in effect, the number of decades on average it takes for natural processes such as photosynthesis to remove a tonne of CO₂ from the atmosphere) we can calculate how many tonnes will be in the atmosphere in future years. Climate scientists can calculate the increase in GMST that would arise from having a given tonnage of GHGs in the atmosphere, so we can calculate the corresponding temperature increase in each year.

But future annual GHG emissions are highly dependent on various future factors, including, among other things, economic growth, population growth, the associated demand for energy, energy resources and the future costs and performance of energy supply and end-use technologies. Unfortunately it is not possible to know today with any certainty how these different key forces might evolve decades into the future. Therefore IPCC developed a range of scenarios covering factors such as those listed from which scientists can project a range of possible emissions and concentrations, and hence a range of possible changes in the climate. Scenarios are alternative pictures of how the future might develop; they are not predictions, but allow analysts to say, ‘if these factors developed in this way, what would be the effect on climate’. Each of these scenarios is a plausible description of the future corresponding to a particular set of assumptions (‘story line’) about development. The IPCC Special Report on Emissions Scenarios (SRES) covers a range of scenarios in which emissions in year 2100 range from 60% to 320% of those in 2000 (Nakicenovic & Swart, 2000).

Using these scenarios in global climate models, IPCC projected that global average temperature will rise during this century by between 1.1°C and 6.4°C above the 1980 to 1999 average (IPCC, 2007d). This range of uncertainty also allows for uncertainty about the responsiveness of the climate to a given increase in the stock of GHGs in the atmosphere. From this analysis, IPCC concluded that in order to be confident of achieving an equilibrium temperature increase of only 2°C to 2.4°C, atmospheric GHG concentrations would need to be in the range of 445 to 490 ppm CO₂-eq. This in turn implies that global emissions of CO₂ will need to decrease by 50 to 85% below 2000 levels by 2050 and begin to decrease (instead of continuing their current increase) no later than 2015, as indicated in Figure 1 (IPCC, 2007b).
**REGIONAL CONTRIBUTION TO GHGS**

Note that of the global emissions of CO₂ in 2007, 23% came from China, 21% from the USA, 22% from Europe and less than 0.03% from the PICs collectively (WRI, 2010). Thus to have any measurable impact on climate change, the necessary emission reductions will have to come from the big emitters. Efforts by the PICs to reduce their own emissions can perhaps be used to persuade the big emitters to do their part ("we are doing the best we can, what about you?"), although the concomitant savings of imported fuel can also have economic benefits.

**GLOBAL ENERGY DEMAND AND USE**

GHG emissions depend on the amount of fossil fuels used to satisfy energy demand around the world.

But what people demand is not the fuel itself but the energy services it provides, such as lighting or transport. The ratio of the energy actually used in these services to the energy content of the input (primary) energy used is called the energy efficiency of the system. (Primary energy could be, for example, the chemical energy content of the fuel or the energy flow of solar radiation going into a device.) There are many conversion steps along the way, often including the conversion of primary energy into electricity, and the efficiency of all of them can be improved, for example...
by using a more fuel efficient vehicle or compact fluorescent lights instead of incandescent ones. Such improvement of the energy efficiency of any part of the system reduces the demand for primary energy and thus the GHG emissions.

The demand for end-use energy can also be reduced, for example by building designs that allow enough day-lighting and ventilation rather than needing so much (or even any) electric lighting and/or air conditioning. Reducing energy demand by either of these routes (conversion efficiencies or changes of end use) is often financially beneficial for the end-users. Switching off air conditioners or lights when they are not needed not only saves fuel imports for the electricity supplier and foreign exchange for the country, but also reduces electricity bills for the end-user.

Figure 2 shows that fossil fuels accounted for 85% of global primary energy supply in 2008, so there remains much scope (at least in principle) for their replacement by low-emission renewable energy sources.

![Figure 2: Global total primary energy supply (TPES) in 2008: percentages. Renewable energy sources (broken out on the right of the chart) account for 12.9% of TPES, using the direct equivalent method of energy accounting, as in SRREN. The total TPES was 492 Exajoules (EJ), roughly equivalent to the energy that would be carried by 600 000 loaded supertankers each carrying 200 000 tonnes of oil. [Data from SRREN, Fig 1.10]](image-url)
RENEWABLE ENERGY SOURCES AND TECHNOLOGIES

Renewable energy (RE) is so called because it draws on naturally occurring flows of energy that are renewed continually by natural processes, in contrast to fossil energy sources, which (as the name implies) were stored over millions of years but are being used up in a few decades or centuries. SRREN (Box SPM.1) gives an outline of the main renewable energy technologies, which it categorises as bioenergy, direct solar, geothermal, hydropower, ocean energy and wind energy. The main part of that report has a separate chapter reviewing the state of the art, the current status and the ‘technical potential’ of each of these resources (i.e. the amount of usable energy that each could supply at reasonable cost, with full implementation of technologies already demonstrated or likely to be developed in the next few years). Table 1 gives a brief indication of the main characteristics and current status of the main RE technologies. Twidell and Weir (2006) describe the physical basis and engineering of each technology in more detail.

GLOBAL SCENARIOS FOR FUTURE ENERGY SUPPLY AND USE

Drawing on Krey and Clarke (2011), Chapter 10 of SRREN provides context for understanding the role of RE in climate mitigation through a review of 164 medium- to long-term scenarios from 16 large-scale, integrated models of the global economy (Fischedick et al., 2011).

The important methodological characteristics of the scenarios reviewed there and the models used to generate them are: (1) they take an integrated view of the energy system so that they can capture the interactions, at least at an aggregate scale, between competing energy technologies; (2) they have a basis in economics in the sense that decision making, particularly between energy alternatives, is largely based on economic criteria; (3) they are long-term and global in scale, but with some regional detail; (4) they include the policy levers necessary to meet emissions outcomes; and (5) they have sufficient technology detail to explore RE deployment levels at both regional and global scales.

In the context of the SRREN, scenarios are thus a means to explore the potential contribution of RE to future energy supplies and to identify the drivers of renewable deployment. The benefit of scenarios generated using large-scale, integrated models, such as those reviewed by Fischedick and co-authors (2011), is that they capture many of the key interactions with other technologies (including competing mitigation technologies such as fossil energy with carbon capture and storage (CCS), nuclear energy, and demand reduction options), other parts of the energy system, other relevant human systems (e.g., agriculture, the economy as a whole) and important physical processes associated with climate change (e.g. the carbon cycle) that serve as the environment in which RE technologies will be deployed. This integration provides an important degree of internal consistency. In addition, they explore these interactions over at least several decades to a full century into the future and at a global scale.

Note that these energy scenarios are not necessarily the same as the emission scenarios in Figure 1. In particular, these energy scenarios (models) contain much more detail about the geographical and technological distribution of both energy supply and energy demand.
Replacing high-emission fossil fuels by low-emission RE will obviously reduce total GHG emissions, provided the total energy supply remains the same. This is illustrated by Figure 3, which shows the range of analysed scenarios as they have developed by year 2030. Scenarios with hardly any RE by 2030 are at the bottom of the chart. Those with the lowest GHG emissions are at the left. Those closest to the bottom left of the chart have the lowest total energy use (i.e. both low RE and low fossil fuel). The spread away from bottom left in any direction reflects the range of views about future demand for energy, which (as noted earlier) can be reduced by improvements in conversion efficiencies and by changes in end use. Broadly speaking, the scenarios at lower right have a lower proportion of RE in the projected mix than those at the upper left. The chart confirms that the scenarios with lowest emissions tend to be those with a high proportion of RE. Note that the vast majority of scenarios indicate that RE deployment will be much greater than the 63 EJ used in 2008.

**Figure 3** Global RE primary energy supply (direct equivalent) from 161 long-term scenarios as a function of fossil and industrial CO₂ emissions in 2030. Coding is based on categories of atmospheric CO₂ concentration in 2100. 
[Source SRREN Fig10-2.]
Figure 4  Four illustrative scenarios for the development of the global economy through to year 2050, showing (a) global energy demand, (b) global CO₂ emissions from energy use and (c) percentage of RE in global energy supply. [Source Based on SRREN Table 10-3]
To illustrate better the impact of assumptions on scenario outcomes, and in particular on GHG mitigation, Fischedik and others (2011) chose four particular scenarios, which represented the range of policy intervention, from almost none (scenario IEA-WEO) to strong intervention (scenario ER 2010), and analysed them in considerable detail, including by technology and region. Figure 4(b) shows the key finding: the impact on global CO$_2$ emissions.

The IEA-WEO scenario is effectively the baseline: it shows what is expected to happen without any substantial changes in government policy and only moderate increases in fossil fuel prices. With rising population and economic activity, energy demand continues to rise (see Fig. 4(a)). Although the absolute amount of RE in use also increases by 80%, it barely changes as a percentage of the energy supply (Fig. 4(c)). Consequently, global emissions increase substantially and climate change becomes worse.

Although based on the same exogenous assumptions about growth of GDP and population as IEA-WEO, the ER scenario explores how a target to reduce global emissions to 3.7GtCO$_2$/y by 2050 could be achieved. As indicated by Figure 1, such a dramatic reduction (to less than 14% of the emissions in 2007) could be required to keep the future increase in GMST to a ‘safe’ amount of less than 2 degrees. To achieve this, the scenario includes significant efforts to exploit the large potential for energy efficiency, using currently available best practice technology, and to foster the use of RE, beyond that likely to arise in any case because of economies of scale, improving technology and falling prices. Consequently, in this scenario, by 2050 RE supplies 77% of the global energy demand, which requires an increase of 410% in capacity from 2007 (Teske et al., 2011). This scenario is the basis of the widely publicised conclusion of the SRREN that ‘close to 80 percent of the world’s energy supply could be met by renewables by mid-century if backed by the right enabling public policies. The upper end of the scenarios assessed, representing a cut of around a third in greenhouse gas emissions from business-as-usual projections, could assist in keeping concentrations of greenhouse gases at 450 parts per million’ (IPCC, 2011).

The two intermediate scenarios shown in Figure 4 differ mainly in their proportion of RE; in mini-CAM about half the emission reduction is attributable to the use of nuclear power and carbon capture and storage.

GLOBAL COSTS OF INCREASING RE

Globally, RE is already increasing rapidly, even though from a relatively small base. For example, in 2009, the global installed capacity of wind power increased by 32% (with 38GW added), grid-connected photovoltaics by 53% (with 7 GW added). Hydropower increased also by 31GW, but this represented only a 3% increase from its larger base as an ‘established’ technology (REN21, 2010). Renewables accounted for almost half of the 208GW electric power capacity added globally in 2011 (REN21, 2012).

Given the greater upfront capital cost of renewable energy per GW, it is likely that the value of investment in renewable energy capacity (excluding large hydro) in 2009 was comparable to that in fossil-fuel generation, at around US$100 billion each. If investment in some 28GW of large hydro-electric is included, then total investment in renewables exceeded that in fossil-fuel
generation for the second successive year, and the gap in favour of renewables was greater than in 2008 (UNEP, 2010).

Globally, the energy industry is large and capital intensive. The scale of annual global investment in the energy sector far exceeds the GDP of the small island states, and is comparable to the GDP of Australia (~US$1000 bn in 2009). But this scale of investment is already taking place, though slowed to some extent by the ‘Global Financial Crises’ of 2009 and 2011. Thus the funds are available to bring in much more RE; all that is required is to use them for this purpose rather than building new coal-fired power stations. In China, for example, a new coal-fired power station has come on stream at least once per month in recent years, because of the increasing demand for electricity there as industry expands and general prosperity increases. On all the scenarios analysed in SRREN, the scale of investment in energy increases with the increasing demand for energy, and so do the national incomes required to pay for it.

Fortunately, as the scale of use of a new technology increases, its unit cost tends to come down, as has happened for both wind-power and photovoltaic (PV) systems. Such cost decreases have positive feedback, driving yet further increases in use, especially compared to more established technologies. For example, the price of PV modules has fallen from US$65/W in 1976 to $1.4/W in 2010, while that of wind turbines in Denmark fell from US$2.8/W in 1985 to $1.0/W in 2004. Likewise the production cost of ethanol fuel from sugar cane in Brazil fell from US$40c/L in 1975 to US15c/L in 2004, largely driven by improvements in sugar mill efficiency and agricultural productivity, to which those in Fiji make a sad contrast. (All these costs, taken from Edenhofer and others (2011, Figure SPM-6) are in USD of 2005, i.e. adjusted for inflation).

Some indicative costs for the production of a unit of electricity from various technologies are shown in Figure 5. These figures are for the USA and are for new installations (Gigaton Throwdown Initiative, 2009). Costs would be higher in the Pacific Islands, not least because of diseconomies of scale. The bars show ranges for costs in 2008. For the renewable sources, these costs vary strongly from place to place, depending on the resource – the cost of wind power in particular varies strongly with wind speed, which can vary markedly over only a few km. Costs are shown only for the locations where the technology is a serious option.
Figure 5 shows that (in the USA at least) power from geothermal and wind systems is cost-competitive with that from coal- or gas-fired systems. (So too is that from hydropower, but they are not shown on this chart, as there is little scope for new hydro systems in the USA.) This is even more so if a carbon price is added into the cost of the fossil fuel systems, as shown by the bars in the chart for those systems. The idea of a carbon price is to allow for the social (external) cost of these systems, the biggest part of which is the social cost of climate change, as briefly discussed below.

Also shown in Figure 5 are some estimates of future costs (in this case for 2020), allowing for the continuing decrease in cost of RE systems as they become more widely used.

One of the most common ways to present the global cost of measures to mitigate climate change is as a percentage of GDP. This measure can be calculated from an integrated economic model of the global economy by calculating the difference in GDP of two different scenarios, one with the measures and one without.
The results for three particular models are shown in Figure 6. For scenarios that aim to achieve a ‘safe’ concentration (≤ 400 ppm CO\textsubscript{2}-eq) according to 3 different economic models. According to these models, this goal can be attained with global economic consumption (GDP) only 1 to 2\% less than it would otherwise be. ‘All Options’ refers to the standard technology portfolio assumptions in the different models, while ‘Biomax’ and ‘Biomin’ assume double and half the standard technical potential of biomass of 200 EJ, respectively. ‘No CCS’ excludes CCS from the mitigation portfolio and ‘No Nuclear’ and ‘No RE’ constrain the deployment levels of nuclear and RE to the baseline level, which still potentially means a considerable expansion compared to today. The ‘x’ in the right panel indicates non-attainability of the 400 ppm CO\textsubscript{2}-eq level in the case of limited technology options.

[Source SRREN, Figure 10-11, reproduced with permission.]

Figure 6 The global cost of reducing GHG emissions to the extent necessary to achieve a ‘safe’ concentration (≤ 400 ppm CO\textsubscript{2}-eq) according to 3 different economic models. According to these models, this goal can be attained with global economic consumption (GDP) only 1 to 2\% less than it would otherwise be. ‘All Options’ refers to the standard technology portfolio assumptions in the different models, while ‘Biomax’ and ‘Biomin’ assume double and half the standard technical potential of biomass of 200 EJ, respectively. ‘No CCS’ excludes CCS from the mitigation portfolio and ‘No Nuclear’ and ‘No RE’ constrain the deployment levels of nuclear and RE to the baseline level, which still potentially means a considerable expansion compared to today. The ‘x’ in the right panel indicates non-attainability of the 400 ppm CO\textsubscript{2}-eq level in the case of limited technology options.

The results for three particular models are shown in Figure 6. For scenarios that aim to achieve a ‘safe’ concentration of CO\textsubscript{2}-eq by 2100, most models calculate this ‘cost’ as around 2\% of global GDP. This means that the global GDP in 2100 would be 2\% lower than otherwise, which sounds like a lot of money. But the same models also have GDP rising over the years, so if GDP is increasing at 2\% per year anyway (which many national Finance Ministers would regard as a modest aim), then another way to interpret this result is that the expected doubling of GDP is merely ‘delayed’ by 12 months, which almost no consumer would actually notice (Hamilton & Quiggin, 1997). The ‘cost’ of achieving a less stringent target of 550 ppm CO\textsubscript{2}-eq will obviously be less: 0.4\% to 0.8\% according to the same models (Fischedick et al., 2011).
RENEWABLE ENERGY PATHWAYS IN THE PACIFIC

From the summary above, one can fairly conclude that the SRREN shows that the global increase in RE in place of fossil fuels required to keep GHGs below dangerous levels is technically and economically possible, especially if coupled with increases in efficiency of energy use. But it will require significant investment, substantial institutional and social change, and the political will to drive such change.

This prompts the question: how might such a transition occur in the Pacific Islands? As indicated in Table 1, only three RE resources are available on a substantial scale in the Pacific, namely biomass, solar energy and hydropower.

There is scope for greater use of hydroelectricity in the hilly islands. The technology is well established and reliable. Many systems in the Pacific are still working well 30 or more years after installation, and have paid for themselves many times over in terms of diesel fuel saved. But hydropower is capital intensive. Those electricity utilities that are structured well enough to collect sufficient revenue to cover the required loans, and have enough users within reach of the resource, continue to install new and upgraded hydropower systems (e.g. the Nadarivatu 40MW scheme commissioned in Fiji in 2012).

An application of solar energy, with important social potential although perhaps not so much potential to reduce GHG emissions, is photovoltaic solar lighting systems in place of kerosene lamps, for rural (off-grid) households. Several thousand of these are in use already in various Pacific Islands. The main issues for the sustainability of these systems are not so much technical as financial (spreading the cost over time) and institutional (how to ensure maintenance, especially of the ancillary components such as batteries). Valuable experience has been gained with a variety of institutional arrangements (Dornan, 2011; Mala et al., 2009; Wade et al., 2005b; Weir & Prasad, 2012). The strong growth in grid-connected photovoltaic systems in Europe and China continues to drive the price of modules down as manufacturers realise economies of scale; the unit cost for large-scale buyers fell by ~60% in 2011 alone. Coupled with the wider use of LED lights (which use only about 30% as much electricity to produce the same light as a compact fluorescent lamp) this lowers the cost of a solar home system, thus easing the financial and institutional barriers. It is therefore not unreasonable to think that most rural households in the PICs will have such systems in the next 10–15 years.

For utility use on-grid, industry experts anticipate that continuing cost reductions will render large-scale photovoltaic (PV) systems competitive with coal-fired systems in sunny countries by 2020 (EPIA, 2011; Gigaton Throwdown Initiative, 2009; see Figure 5). The cost (per MW) for island utilities of PV systems would be higher than in larger markets, but so too is the cost of the ‘competition’, which here is diesel-fired systems. Therefore we can expect to see more island utilities installing substantial PV systems by around 2020. Already the utility on Tongatapu has opened a 1MW PV system, but it was able to do so only because New Zealand paid for the entire capital cost of NZ$7.9m (Migone, 2012).

The viability of large-scale use of biomass for energy requires that the bulky raw material be already collected for other purpose (e.g. at timber mill or sugar mill). Unfortunately the Fiji sugar
industry lags industry best practice by decades, and is only now beginning to install the modern technology needed to make its energy output into a profitable and substantial commercial product (compare the Brazilian industry described by Zuubier and van der Vooren (2008)).

Production of liquid biofuels faces a further barrier: the raw material is not being collected on the scale needed for substantial production, with the exception of sugar (from which ethanol could be made). Proposals to make ethanol from cassava would require growers to grow and deliver large quantities of cassava at a much lower price than they receive for it as food. Similarly, to produce biodiesel from coconut oil on a substantial scale would require growers to deliver coconuts (or copra) at a price no higher than that for which most currently find it not worth their while. Neither seems likely to happen.

Government policies on excise, agriculture, rural development and utility regulation significantly affect the development of renewable energy (Singh, 2012). Pacific Energy Ministers announced, in 2010, a ‘Framework for Energy Security’ (FAESP, 2010). This is a step in the right direction, but without more specific national policies and plans it will have little effect. The UN declared 2012 to be the Year of Sustainable Energy for All, which prompted several island governments to announce national targets for renewable energy, usually along the lines of ‘X% of energy [or electricity] to be from renewable sources by year Y’, with X often 50% or more. Without detailed plans of engineering and finance to back these up, most such targets are no more than ‘vapourware’. An honourable exception is the Fiji Electricity Authority target of 90% renewable by 2015, illustrated in Figure 7, in which each slice of the annual outputs represents particular identified projects that are in the pipeline, although some of these projects are from Independent Power Producers and thus not under FEA control (except for their electrical output).

**Figure 7** Actual and planned electricity generation in Fiji, by category of source 2009–2015. [Author chart, based on Fiji Electricity Authority presentation to SORET 2011 conference, FNU, Suva, which listed each installation individually.]
GLOBAL AND LOCAL BENEFITS OF ACTION

The previous section found that the global costs of action to mitigate climate change, particularly by increased use of RE instead of fossil fuels, would be around 1 to 2% of global GDP by 2100. But for a fair appraisal – even a purely economic one – this needs to be weighed against the costs of inaction, i.e. the costs to the world of the climate change that is expected to occur in the absence of strong mitigation measures. Avoiding these impacts is the main benefit of such actions, though there are also significant side benefits, as discussed below.

Such a calculation is not easy because climate change represents perhaps the greatest and widest-ranging market failure ever seen. The economic analysis must therefore be global, deal with long time horizons, have the economics of risk and uncertainty at centre stage, and examine the possibility of major, non-marginal change (Stern, 2007).

Nevertheless, a range of economic models has been used to estimate the damage caused by a certain degree of climate change, by monetising the changes from a baseline scenario, sector by sector and region by region, and aggregating these. For example, one calculates the change in agricultural production arising from changes in rainfall and from loss of productive land to rising sea level, and similarly for other sectors where the biophysical impacts can be estimated. Such calculations can be done for a range of projected rises in GMST.

GLOBAL COST OF CLIMATE CHANGE

Though the results obviously depend on the assumptions and methodology, the review by Yohe and others (2007) summarises the findings of such models as global mean losses between 1 and 5% of GDP for 4°C of warming in GMST. In all such studies, the percentage GDP losses are higher in developing countries, not least because of their lower capacity to adapt (see next section). For increases in GMST of less than about 3°C above 1990 levels, the globally aggregated losses are projected to be significantly less because some regions would enjoy ‘benefits’ such as increases in agricultural production and lower winter heating bills in North America. No such ‘benefits’, unfortunately, are expected for tropical countries, including the PICs.

The coverage of most such studies is limited to market-based sectors, and few of them include the possibility of strongly non-linear climate change (e.g. threshold changes that cut in at higher changes in GMST – see Section 2 above). An exception is the major study by Stern and his team (2007), which took account of a full range of both impacts and possible outcomes, weighted by their estimated probability of occurrence, i.e. using the economics of risk premiums. Consequently he estimated much greater potential economic impacts of climate change. Stern found that the economic effects of unmitigated climate change could reduce welfare (in effect global GDP) by at least 5%. Including the non-market impacts of the direct effects of climate change on health and environment raised this damage estimate to 11% of global GDP. Including evidence (summarised by Solomon et al. 2007, Box10-2, on p. 798) that the climate system may be more responsive to greenhouse gases than previously thought increased their estimate further to 14% of global GDP. Using equity weights to reflect the greater burden that climate change imposes on poorer countries increased the estimated reduction in equivalent consumption per head to 20%.
On these figures, it is clear that the global cost of inaction (and especially the cost to poorer countries including the PICs) far exceeds the global costs of action to mitigate climate change summarised in the previous section. Thus the poorer and more vulnerable countries of the world – notably including the PICs – have a very strong case, not only morally but also economically, for urging the more industrialised countries to lower their GHG emissions. In fact, as they too would suffer damage from climate change (e.g. repeats of the decade-long drought in Australia 2000–2009, which produced water shortages in most Australian cities and fatal bushfires, or of the massive Queensland floods of 2010-11) there is a strong self-interest for them to take action.

**ECONOMIC BENEFITS FOR PICS**

In addition to the climate benefits that would flow from a global reduction in GHG emissions, there is a significant benefit for the PICs in taking their own action in the form of improved energy efficiency and substitution of RE for fossil fuels, namely a dramatic reduction in the cost of imports and an improvement in energy security. In the PICs, all fossil fuel is imported. In the smaller island states, fuel imports account for around 30% of GDP, and in the larger PICS around 7–15% of GDP (SPC, 2011). With oil prices continuing to increase, this vulnerability will worsen in the absence of significant action. And of course, renewable resources are inherently sustainable and not exhaustible like fossil fuels – particularly oil, for which some experts believe that world production has already peaked or will do so in the next decade or so (Newby, 2011; Leggett, 2006).

**ADAPTATION ISSUES**

Adaptation refers to ‘a process by which strategies to moderate and cope with the consequences of climate change, including variability, are developed and implemented’ (Lim et al., 2004).

Climate variability, in particular extreme events such as floods, droughts and cyclones, has always affected the Pacific Islands. Island people developed a range of ways to live here in the face of these climate extremes, i.e. to adapt. Such adaptations include housing that can either be rebuilt quickly or withstand the extremes, reserve food supplies, and a diversity of crops so that not all fail at once.

Some climate indicators already show clear effects of climate change in the PICs over the past 50 years, for example a steady increase in mean temperatures across the region of about 0.7°C over the past 50 years (PCCSP, 2011) and an increase in the number of very hot days per year (Mataki et al., 2006). The fact that the stock of GHGs in the atmosphere is greater than it has been for millennia, coupled with the long time it takes for warming of the atmosphere to affect the much greater mass of the oceans, imply that further inexorable global warming (climate change) is inevitable (IPCC, 2007d).
Therefore the IPCC Synthesis Report (2007b, sn 5) concludes that:

Adaptation is necessary in the short and longer term to address impacts resulting from the warming that would occur even for the lowest stabilisation scenarios assessed. There are barriers, limits and costs, but these are not fully understood. Unmitigated climate change would, in the long term, be likely to exceed the capacity of natural, managed and human systems to adapt. The time at which such limits could be reached will vary between sectors and regions.

Many of the physical effects of climate change will affect PI populations mainly by making the existing extreme climate events either more intense or more frequent or both. Adapting to these effects of climate change will require similar techniques to those used now for climate extremes, but a more concerted effort. It will be like the step up from playing club football to playing in the world cup: it is the same basic idea but your opponents are stronger and faster! For this reason, developing good practice, including the necessary community and government structures, is an important part of the pilot adaptation projects that have taken place in the Pacific so far (Limalevu et al., 2010).

A major challenge in the PICs will be to move adaptation efforts from a few pilot projects into the mainstream of sustainable development. No development project can be sustainable if it is not ‘climate proof, at the very least against current extremes of climate, let alone the more severe extremes expected under climate change. Donors (metropolitan countries) making increased funds available for this purpose as part of their obligations under the UNFCCC can and do help. But one key will be for Island governments to ‘mainstream’ climate change so that it becomes a factor considered as automatically as budget in the work plans of all levels of government (Nunn, 2009). Communities (villages) likewise will have to take climate-related issues more into account than many do now. The ubiquitous churches could well offer a channel to encourage such thinking and action; a few are already doing so.

SEA-LEVEL RISE AND ATOLLS

The level of the sea rises with global warming for two reasons: (a) sea water expands with increasing temperature, and (b) ice that was on land (e.g. as part of the Greenland ice shelf) melts into the sea. It is well known that this threatens low-lying islands, such as the atolls of the Pacific (IPCC, 2007a).

Less well known is recent scientific work on the time frame available for atoll dwellers. An atoll will become uninhabitable long before it is totally submerged, because salt-water incursion will pollute its fresh water supply, which is held underground, in a ‘lens’ floating on top of the sea level. Salt-water incursion from below is aggravated by extra high tides (king tides) and storm surges, which bring in salt water from above as it washes over the land. This is already happening to many atolls in the Pacific, the Carteret Islands (of Papua New Guinea) and Funafuti (Tuvalu) being well-publicised cases. Currently this occurs only every 2–3 years in Tuvalu. Modelling of the water lens (Chui & Terry, 2012; Terry & Chui, 2012) and observations in Cook Islands (Terry & Falkland, 2010) and Tuvalu (K. O’Brien, personal communication) both suggest that the lens
takes about 12 months to recover to fresh water in the absence of further salt-water influx.

Therefore it is reasonable to infer that if sea level rises to the stage that salt-water inundation occurs much more frequently (e.g. at the highest tide of most months) then the lens will remain salty and the island will become effectively uninhabitable, with little fresh water available and crops unable to grow. At current rates of sea-level rise this could occur as early as 2040.

RESETTLEMENT

Several PICs consist almost entirely of atolls, notably Kiribati, Tuvalu and Marshall Islands. Because of these impacts of sea-level rise, all or most of the tens of thousands of inhabitants of these countries will probably have to migrate to other countries, either legally or illegally, by about 2040 (Weir & Virani, 2011).

Some analysts regard such large-scale forced migration as an extreme adaptation to climate change (Nunn, 2009) while others argue it should be classified as an impact on the small islands and compensated accordingly by the countries whose emissions caused the problem (Barnett & Campbell, 2010). Some PIC governments, notably Kiribati under President Tong, face this issue squarely and try to lessen its impact on both the sending and receiving countries by seeking a much increased legal migration to nearby metropolitan countries, most likely through gradual labour migration (Nadkarni, 2008; Tong, 2011).
CONCLUSIONS

Socioeconomic development in the Pacific Islands has often been set back by current climate variability – notably in the form of destructive cyclones. Such cyclones in particular are expected to become more severe with global warming, which is why sustainable development in the islands is impossible unless climate change is mitigated.

To mitigate climate change requires renewable energy (RE) to replace a large proportion of global fossil fuel use. The IPCC Special Report on Renewable Energy (SRREN) discussed in this paper demonstrates that such an increase in RE is technically and economically possible, especially if coupled with improved efficiency of energy use and supply. But this will require significant investment, substantial institutional and social change, and the political will to drive such change, especially in those countries that use most of the world’s commercial energy (i.e. the large industrialised countries). The policy environment required to bring about such changes is outlined in chapter 11 of SRREN (Mitchell et al., 2011) but is beyond the scope of this paper.

Such changes in the global energy system, applied also in the Pacific Islands, would bring benefits to the region in terms of environmental and economic security, and thus of sustainable development. The main specific policies required to do this in the Pacific Islands are well known (Singh, 2009; Wade et al., 2005a; Newcombe et al., 1982) but though some progress is being made in the region, much more is required.

Nevertheless, some further climate change is inevitable, and the Pacific Islands will still need to adapt to more severe climate extremes. Worse, there is a real possibility that in the absence of a rapid reduction of global greenhouse gas emissions, all or most of the inhabitants of the atoll countries of the region may be forced to migrate to other countries by about 2040 because of sea-level rise and the salt-water inundation it brings.

As Stern (2006, p.ii) concluded in his seminal review of the economics of climate change:

To continue to pursue the current fuel-intensive path of economic growth] over the coming few decades could create risks of major disruption to economic and social activity, later in this century and in the next, on a scale similar to those associated with the great wars and the economic depression of the first half of the 20th century. And it will be difficult or impossible to reverse these changes. Tackling climate change is the pro-growth strategy for the longer term, and it can be done in a way that does not cap the aspirations for growth of rich or poor countries. The earlier effective action is taken, the less costly it will be. At the same time, given that climate change is happening, measures to help people adapt to it are essential. And the less mitigation we do now, the greater the difficulty of continuing to adapt in future.

ACKNOWLEDGEMENTS

I thank the Government of Vanuatu for nominating me to IPCC as a lead author for the SRREN. For most of the time that I was working on the SRREN, I was on the staff of the University of the South Pacific (USP). A version of this paper was presented to the International Conference on Renewable Energy and Climate Change, held at USP in Suva in December 2010.
NOTES

1 The present author was one of only two from the Pacific Islands among the 120 lead authors of the SRREN.

2 This is a slightly simplified version of the ‘official’ definition by IPCC. The UNFCCC use a more restricted definition of climate change, which is much harder to apply scientifically, though it may be more convenient legally.

3 Although a change of 5°C does not sound like much – the change from daytime to night-time temperatures in many Pacific Islands is about 5°C – it is also the difference in GMST between the last Ice Age and now. In the last Ice Age (~20,000 years ago), the sea level was 120 meters lower than now and where New York is now was under 1000 metres of ice! That is certainly a significant change in climate!

4 ppm means parts per million, so a concentration of 490 ppm CO$_2$ means 490 molecules of CO$_2$ per million molecules of gas in the atmosphere. 490 ppm CO$_2$-eq means the concentration of total GHGs that would produce the same amount of warming as 490 ppm of CO$_2$ alone.

5 See SRREN section 1.2 for a fuller discussion of ‘renewable’.

6 See caption of Figure 2 about units.

7 The costs shown in Figure 6 are levelised costs, i.e. averaged over the working life of the installation (usually taken as 20 years), unlike the capital costs quoted in the previous paragraph. Levelised costs enable a fair comparison of systems with high initial cost and low running cost (most RE) against systems with relatively low capital cost but high running cost (e.g. fossil fuel). Electricity from older installations with capital costs already written down costs less.

8 The standard method of estimating the economic impact of loss of life is to calculate the loss of potential earnings by those who die. This strongly under-weights the impact of loss of a life in a poor country compared to one in a rich country. ‘Equity weights’ are an attempt to counterbalance such effects, by giving more weight to losses in poorer countries.
TABLE 1 CHARACTERISTICS AND CURRENT STATUS OF VARIOUS RE TECHNOLOGIES

<table>
<thead>
<tr>
<th>Technology</th>
<th>Main characteristics and global status</th>
<th>Current status in Pacific Islands</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro-power</td>
<td>Mature and reliable technology, available any time of day. ~16% of world electricity generation. Remaining untapped opportunities mostly in developing countries.</td>
<td>In use in hillier PICs. ~50% of Fiji electricity generation and ~35% in PNG. Zero potential in low-lying countries.</td>
</tr>
<tr>
<td>Wind power</td>
<td>Use in on-grid wind farms for electricity rapidly expanding in many countries. Cost-competitive at good sites, which are mostly at moderate latitudes ('roaring forties').</td>
<td>One wind farm in Fiji, several in New Caledonia. Wind in PICs tends to be either too little (gentle sea breeze) or too much (cyclone!). Precise site selection critical.</td>
</tr>
<tr>
<td>Solar cells (photovoltaics)</td>
<td>Rapidly developing technology for electricity generation. Use increasing rapidly both on- and off-grid. Now very reliable. Works in bright or dull sunshine.</td>
<td>Very modular. Can be installed separately for each house. Technically well suited to all rural areas in Pacific, but up-front cost and on-site maintenance are issues.</td>
</tr>
<tr>
<td>Solar water heating</td>
<td>Mature technology, widely used in sunny countries (e.g. Greece, China, Australia).</td>
<td>In use for hotels and middle-class houses in sunny sites; scope for greater use.</td>
</tr>
<tr>
<td>Traditional biomass</td>
<td>Firewood for cooking. Accounts for ~9% of world energy use. Current use inefficient and unsustainable in many places (faster than regrowth). Smoke a health hazard.</td>
<td>Nearly universal in rural areas of PICs.</td>
</tr>
<tr>
<td>Modern biomass</td>
<td>Larger scale uses include electricity generation (co-generation) using steam turbines or gasifiers. Household smoke-free cooking stoves strongly promoted in some countries.</td>
<td>Viability of large-scale uses requires that the bulky raw material be already collected for other purpose (e.g. at timber mill or sugar mill). Such uses expanding in PNG and Fiji.</td>
</tr>
<tr>
<td>Biofuels (liquid)</td>
<td>Liquid biofuels that can replace diesel or petrol. Important that crops grown for energy do not displace food crops.</td>
<td>Biodiesel based on coconut oil promoted in Fiji and Samoa. Many studies on ethanol from sugar cane or cassava in PICs but no action.</td>
</tr>
<tr>
<td>Geothermal</td>
<td>A mature technology suitable only for a few locations world-wide, e.g. geothermal areas (e.g. Iceland, New Zealand).</td>
<td>In use at Placer mine in PNG. Energy resource of ‘hot spring’ areas in Fiji and Tonga not yet assessed.</td>
</tr>
<tr>
<td>Concentrated solar</td>
<td>Electricity production from solar energy focused by mirrors. Requires consistent bright sunshine. Potential for large use in desert areas.</td>
<td>PICs mostly too cloudy for this technology.</td>
</tr>
<tr>
<td>Wave power</td>
<td>Pilot plants offshore from Europe, Korea, and USA.</td>
<td>USP research project in progress to assess resource in PICs.</td>
</tr>
<tr>
<td>Tidal currents</td>
<td>Uses ‘fast’ tidal flows through natural channels. A few pilot plants.</td>
<td>A few potential sites in PICs, still to be assessed.</td>
</tr>
<tr>
<td>Tidal range power</td>
<td>Used at a dozen or so sites where tidal range is ~7m.</td>
<td>Tidal range too small in all PICs for this technology.</td>
</tr>
</tbody>
</table>

[Data from SRREN (chapters 2 to 7); Wade et al (2005); author information.]
REFERENCES


