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Cost-benefit analysis of a green electricity system in Japan considering the indirect economic impacts of tropical cyclones

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ABSTRACT

Global warming is likely to profoundly influence future weather patterns, and one consequence of this is the likelihood of an increase in tropical cyclone intensity. The present paper presents a cost-benefit analysis of introducing significant amounts of green energy in the electricity system in Japan in the light of the economic damage that an increase in tropical cyclone intensity could have on GDP growth between 2010 and 2085. Essentially the passage of a tropical cyclone will result not only in physical damage but also on a decrease in economic productivity due to precautionary cessation of the economic activity, which has an effect on GDP growth. By comparing the economic performance of different electricity system scenarios with the indirect economic damage of tropical cyclones from 2010 to 2085, based on the yearly economic data of green electricity, fossil fuel, GDP and population, it can be seen that the green scenarios are generally a cost-effective way of mitigating the effects of these weather systems, despite the large amount of initial investments necessary.

1. Introduction

Global warming as a consequence of increased CO_2 concentrations in the atmosphere is nowadays increasingly accepted as a scientific fact, and is considered one of the major challenges facing humanity in the 21st century. The 4th Intergovernmental Panel on Climate Change (4th IPCC) provides a well-established body of literature supporting this, and it is generally accepted that action must be taken to attempt to guard against the worst possible effects of climate change by reducing the emissions of CO_2 and other greenhouse gases. These ideas were enshrined in the Kyoto Protocol, which committed major industrialised countries to the reduction of CO_2 concentrations from the baseline 1990 levels. Japan, as one of the Annex 1 countries, is committed to these reductions, and Prime Minester Hatoyama pledged a 25% reduction in CO_2 emissions by 2020 (BBC, 2009).

Tropical cyclones can have devastating effects, especially in poor countries (Landsea et al., 2006). In Asia Cyclone Sidr was one of the strongest cyclones ever recorded, causing significant damage to Bangladesh in 2007 (Shibayama et al., 2009). However, the area most frequently affected by tropical cyclones is that of the western north Pacific Ocean, accounting for approximately one-third of these phenomena (Imamura and Van To, 1997). One of the worst affected places is Japan, which between 1980 and 2008 accounted for eight out of the ten costliest natural disasters in Asia (Elsner et al., 2008).

A possible consequence of global warming is an increase in the frequency and intensity of tropical cyclones due to the warming of the sea (Emanuel, 1991; Holland, 1997). Some evidence that this effect could already be happening has been given by Elsner et al. (2008) and Webster (2005). However, tropical cyclones are still not well understood and other research has argued that the data available is not reliable enough to make assertions about the relationship between climate change and tropical cyclones (Pielke et al., 2005; Landsea, 2005). The present paper does not deal with the uncertainties regarding a possible increase in tropical cyclone intensity. Rather, the authors' would like to explore what would be the economical effects if this potential increase in intensity becomes a reality and if it would be cost-effective for Japan to mitigate them by increasing the uptake of renewable energy. Webersik (2010) points out that in the future the situation could reach a point where the costs of natural hazards may potentially outpace economic growth. This assertion has so far not been sufficiently explored in literature, specially a comparison of the costs that could be expected from a quick uptake in green technology.

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To try to understand how tropical cyclones are likely to be affected by an increase in global temperatures, a number of global climate models using powerful supercomputers have been carried out, as highlighted in the 4th IPCC. This report shows how although there is a general agreement that tropical cyclones are likely to increase in intensity, there is yet no consensus on the future frequency of these events. This increase in intensity will have profound effects on coastal areas, with wave heights expected to increase at both middle latitudes and the Antarctic Ocean (Mori et al., 2010). The damage that high waves can cause to coastal areas would be exacerbated by increases in the magnitude of storm surges, which become more severe as tropical cyclones increase in intensity (Kawai et al., 2006). These two effects would magnify the effects that sea level rise would have on coastal areas (Nobuoka, 2010).

Measuring economic damage due to storms is a complex problem. This damage can broadly divided into two categories, the damage caused by the destruction of houses, infrastructure and other material objects (direct damage) and the loss in productivity due to temporary shutdown in production and because of prevention activities (indirect damage). Some research has been done on the possible effects of direct damage, such as that by Pielke (2007) and Hallegatte (2007), although it could be theoretically possible to increase the resilience of human societies (by improvement in building techniques, etc.) to reduce the exposure to direct damage. Hence the present paper will ignore this effect, as adaptation measures are likely to make countries more resilient to an increase in tropical cyclone intensity damage potential, and due to the fact that this effect is difficult to measure across different temporal domains.

Regarding indirect damage, Hallegatte (2008) explains how this includes "business interruption in the event aftermath, production losses during the reconstruction period, and service losses in the housing sector". This author found that the total losses due to a disaster affecting the area of Louisiana in the USA increase nonlinearly with respect to direct losses when the latter exceed $50 billion (for instance when direct losses exceed $200bn, total losses are twice as large as direct losses). The model given by Hallegatte (2008) attempts to reproduce the disruption in production that takes place after the event, and is useful to model the effects of high intensity events. However, in many countries in the Asia-Pacific, tropical cyclone related downtime is mostly due to low-intensity but high-frequency events. Hence, downtime is directly related to the duration of the event and as the tropical cyclones grow larger in the future the number of hours that a given area of a country will be affected by them will also increase. Esteban et al. (2009a,b) thus analysed the effect of downtime on the economy due to an increase in the size of future tropical cyclones. However it is very difficult to adapt against this increase in downtime, and if anything, an increase in adaptation capacity would increase indirect economic losses. Pielke (2007) noted how "decision makers (including forecasters and emergency managers) have possibly become more risk averse over time and have used advance in the science of forecasting to reduce the chances of leaving part of the population unwarned. Of course, such strategies have costs in the form of a greater number of people warned unnecessarily".

The present paper will try to estimate economic effect of this increase in downtime in Japan and will then compare it to the cost of the mitigation measures (the cost of using green energy, which at present is generally more expensive than traditional forms of electricity production). This would thus highlight if it is Japan's economic interest to further increase the uptake in renewable energy and push for other countries to curb greenhouse gas emissions, through a successor to the Kyoto Treaty, for example.

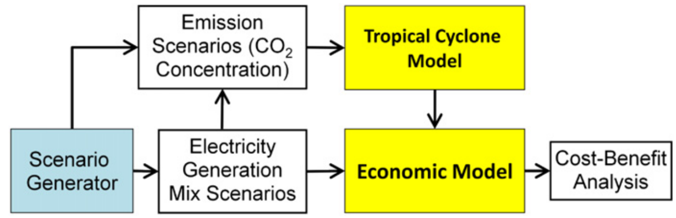

Fig. 1. Analysis method used in the present study.

2. Analysis method

The intensity of tropical cyclones would depend on the amount of CO_2 in the atmosphere, which would in turn depend on future electricity system patterns. The extra damage (in this case the indirect extra damage) could be seen as an external cost of carbon, and should really be taken into account in the calculation of the cost-benefit of renewable energies. The objective of the methodology that will be used is thus to calculate the expected cumulative economic influence of an increase in future tropical cyclone intensity between now and 2085 and compare it to the mitigation cost of increasing the usage of renewable energy in Japan, as summarised in Fig. 1. To do this a few very simple scenarios of the possible future development of renewable energy in Japan were considered, which showcased the potential benefits in mitigating the effects of climate change (compared with the "business as usual" or BAU cases). The year 2085 is chosen mainly due to the fact that the results of Knutson and Tuleya (2004), which were used to derive the probability distribution functions for storms, are only given for the year 2085.

The assumption is, however, that the Japanese increase in CO_2 emissions will be "pegged" to the global emission increase. This in itself could be considered to be an unrealistic assumption, though the only way to obtain a simple answer to the problem studied is to assume that there will be no "free riders" and that all countries will accept similar limitations to the growth in their emissions.

3. Tropical cyclone model

To calculate the expected cost of climate change only the indirect effects of tropical cyclones were considered, by using the methodology of Esteban et al. (2009a). This method uses a disaggregated computational approach, and in the present work Japan was divided into 119 grid-points, each of which is characterised by a certain population and level of economic activity. The method then used a Monte Carlo simulation, which reproduced the paths and size of individual tropical cyclones to obtain the number of expected hours that each of these grid-points is affected by winds of 30 knot strength or higher (which Esteban et al. (2009a) consider as the level of wind after which most economic activities will come to a precautionary stop). This allows the Expected Loss of Time $\hat{\vartheta}(c)$ for each grid-point in Japan to be obtained, which can be defined as the sum of each of the values of lost time due to storms for one year for all the simulation runs divided by the number of simulated runs, or

$$\hat{\vartheta}(c) = \frac{\sum_1^N \vartheta(c)}{N} \quad (1)$$

where $\vartheta(c)$ is the loss of time obtained from one simulation and N is the number of simulation runs.

The simulation starts by generating a random number of tropical cyclones for each month of the year, according to the probability distribution functions derived from best track data given in the Japan Meteorological Agency website. The path of