ENVIRONMENTAL SCIENCE & POLICY 14 (2011) 1079–1090

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Climate change effects on mitigation measures: The case of extreme wind events and Philippines' biofuel plan

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ARTICLE INFO

Published on line 11 August 2011

Keywords:
Wind damage
Climate vulnerability
Biofuel
Energy policy
Rural development

ABSTRACT

Biofuel production has increased dramatically over the past decade, among other to mitigate climate change. However, climate change vulnerability may currently not be sufficiently accounted for in national biofuel strategies, hence neglecting a possible link between mitigation and adaptation to climate change. To the best of our knowledge this potential link has received very little attention in the literature. One example is the Philippines, which is currently implementing an ambitious program of biofuel production. Its aim is to reduce dependency on imported fuel, increase rural employment and incomes, and mitigate greenhouse gas emissions. The Philippines is frequently battered by tropical typhoons and from 1975 to 2002 the annual average damage to agriculture was 3.047 billion pesos. We calculate wind damage on biofuel feedstock production, and assess the effect that a future potential increase in tropical cyclone intensity would have on energy security, rural development and climate change mitigation in the Philippines. A Monte Carlo simulation is used to obtain the future expected development of typhoon impacts. Based on the Philippines legislated target of 10% biodiesel blend in gasoline by 2011, simulation of the affected area for each feedstock, and expected biofuel feedstock damage is computed for the Philippine's 80 provinces in 2050, for two different typhoon climate change scenarios. Additional indirect economic effects are assessed in a tentative way. The results suggest a modest decrease in biofuel feedstock productivity at the national level, but with strong local differences that are shown to affect the Philippine's policy goals. In a broader perspective the paper accentuates a so far little described link between climate change mitigation and climate change adaptation. This link may merit further attention by policy makers and development planners in order to ensure that policies are economically sound not only in the short but also medium term.

1. Introduction

Global biofuel production based on agricultural commodities increased more than threefold between 2000 and 2008, when it accounted for approximately two percent of the world's consumption of transport fuels (FAO, 2009). While biofuel is often seen as the green alternative to fossil fuel which could reduce greenhouse gas emissions in the transport sector necessary to combat climate change, biofuel production, as well as the whole agriculture sector, is exposed to risks from the effects of climate change.

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1462-9011/$ – see front matter
doi:10.1016/j.envsci.2011.06.004

Climate change in general has been shown to have significant economic impact (e.g. Hertel et al., 2010; Karim and Mimura, 2008), not least on agriculture in developing countries (Berry et al., 2006; Mendelsohn et al., 2000; Winter et al., 1996). Tropical cyclones can have devastating effects especially in poor countries, such as the 1970 Bangladesh cyclone where between 300,000 and 500,000 people were killed (Landsea et al., 2006).

Tropical cyclones currently appear most frequently in the western north Pacific Area, which accounts for approximately one-third of all typhoons in the world (Imamura and Van To, 1997). One of the fears of global warming is that it may increase the frequency and intensity of tropical cyclones due to the warming of the surface of the sea (Nordhaus, 2006). This trend has been confirmed by a thirty-year satellite record of tropical cyclones (Webster et al., 2005), with trends in the upper quantiles of maximum wind speeds having a significant upward trend for wind speed quantiles above the 70th percentile (Elsner et al., 2008). However, the understanding of tropical cyclones is still not perfect, and some authors (e.g. Landsea et al., 2006) have disputed the accuracy of satellite-based pattern recognition.

A number of global climate models using powerful super-computers have been run, as highlighted in the 4th Assessment Report of the Intergovernmental Panel on Climate Change, or IPCC (Randall et al., 2007), to try to understand how tropical cyclones are likely to be affected by an increase in global temperatures. That report highlights much of the state-of-the-art knowledge about these meteorological phenomena, showing that 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.

Another challenge is to calculate the economic damage that tropical cyclones cause. Generally speaking the damage can be divided into two components, the direct damage relating to the cost of the physical destruction, and the indirect damage due to other socio-economical losses. Hallegatte (2008) explains how the indirect costs include for example business interruption before, during and after the event, and productive losses during the reconstruction period. Other such losses could include increases in energy prices, loss of workers income or increases in insurance premiums following the passage of major events. Thus, according to this author, total socio-economic damage can be much larger than direct economic impacts.

Moreover, very little research has estimated the indirect economic damage of tropical cyclones, such as due to downtime in economic activities and in the transportation system. Hallegatte (2008) 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 USD 50 billion. The model given by this author 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 most of the tropical cyclone related downtime is due to low-intensity but high-frequency events where the downtime is directly related to the duration of the event. As the tropical cyclones grow larger due to the effects of climate change (lower central pressures will result in increased radius, as shown in Appendix), the number of hours that a given area of a country will be affected by them will increase in the future.

The Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) considers that there is no significant trend in the number of tropical cyclones forming or entering the Philippine Area of Responsibility (PAR) in the past 58 years (1948–2005).[1] However, it appears that the frequency of occurrence of strong typhoons is becoming alarming. The Philippines has been battered on average by around 20 tropical typhoons per year and from 1975 to 2002, the annual average damage to agriculture was 3.047 billion pesos (Greenpeace, 2005). In 2006, three super typhoons entered the Philippines – Milenyo (Xangsane) in September, Paeng (Cimaron) in October and Reming (Durian) in November – which caused the loss of hundreds of lives and millions of USD from heavy damage to properties highlighting the catastrophic impacts of extreme weather events.[2] Typhoon Reming (Durian) alone left 800 people dead (Munich Re, 2007) and typhoon Milenyo (Xangsane) ranked fifth[3] in the Philippine history of typhoons, and caused the heaviest damage to property, amounting to 6.61 billion pesos. Typhoon damage to productivity in agriculture is usually in the order of 1% of the country's GDP. It is important for long-term planning of for example the agricultural sector to consider uncertainty stemming from possible disruption and reduction in productivity due to stronger typhoons (Greenpeace, 2005). The same source highlights that although the profitability of crops such as sugar cane and coconut has shown some sensitivity to climate variability, with increases during La Niña years and decreases during El Niño years, much remains to be understood regarding the link between typhoons and agricultural income.

In this paper we assess how climate change can affect a climate change mitigation measure. Specifically, we set out to assess the implications from wind damage on biofuel feedstock production, and comment on the implications for energy security, rural development, and climate change mitigation. The motivation to study wind damage is its potentially great economic impact and yet the relatively little attention it has received in the climate change literature (e.g. Hitz and Smith, 2004; Barker, 2003). We analyse biofuel because this climate change mitigation measure is expanding dramatically worldwide. Moreover, many first and second generation biofuel feedstocks can be expected to be vulnerable to extreme wind events.[4] As a case study we chose the Philippines, which recently has adopted an ambitious plan for biofuel feedstock production, and which is currently highly exposed to typhoons. As in many other countries, the Philippines' Biofuel Plan aims to reduce dependency on imported fuel, increase rural employment and incomes, and mitigate greenhouse gas emissions (RA 9367). The analysis reveals substantial distributional effects when disaggregating

[1] The Philippine Atmospheric Geophysical and Astronomical Services Administration website, http://kidlat.pagasa.dost.gov.ph/cab/main.htm (accessed 13.08.09).

[2] Very intense typhoons with expected winds of more than 185 kph.

[3] http://kidlat.pagasa.dost.gov.ph/cab/tc_frame.htm (accessed 13.08.09).

[4] Not only second generation but also first generation biofuel production will expand significantly in developing nations in the short to medium term (OECD-FAO, 2011), including in South East Asia (Ölz and Beerepoot, 2010).

the climate effects across localities, feedstocks and production systems.

2. Methods

Through a Monte Carlo simulation the future expected increase in tropical cyclone impacts is obtained. The Philippines has a legislated target of minimum 2% biodiesel blend and 10% bioethanol blend in gasoline by 2011, respectively (RA 9367). Based on this target a simulation of the affected area for each feedstock, and expected biofuel feedstock damage for each region of the country is computed for the period 2014–2050, for two different typhoon climate change scenarios. Additionally, the indirect economic effects are also assessed in a tentative way (stemming from number of productive hours lost). The results suggest a marked decrease in biofuel feedstock productivity, for example in the north eastern regions of the country. Below follows details about the case study and methodology.

2.1. *Case study: the Philippine biofuel plan*

The Alternative Fuels Program is part of the Philippines' Energy Independence Agenda, aiming at 60% energy self-sufficiency by 2010. As a part of that program, in 2006, the Biofuels Act was ratified, mandating a minimum 1% biodiesel blend and 5% bioethanol blend by volume in all diesel and gasoline fuels that are distributed and sold in the country, by 2009. The plan is to further raise the requirements to a minimum 2% biodiesel blend and 10% bioethanol blend in gasoline by 2011 (EIA, 2008). This will be enabled by for example expanding the country's production capacity with 10 new ethanol plants (EIA, 2008). Currently the Philippines is one of the few countries in the Asia-Pacific region mandating biofuel use and only Philippines, China and Thailand produce ethanol in significant volumes.

Sugarcane is the Philippines' main feedstock for ethanol production. However, major investments are being made to diversify into coconut, cassava, sweet sorghum, and corn, while camote is considered for future biofuel expansion. Unlike the neighbouring countries Indonesia and Malaysia, the Philippines' biofuel program is focused on the domestic instead of the export market. The Philippine Department of Energy estimates that approximately 39 million litres of bioethanol were produced in 2008 from the combined production of the San Carlos Bioenergy and Leyte Agri-Corp. There is a huge deficit to comply even with the 5% blend, hence currently the Philippines is a net importer of ethanol from China, Thailand, Brazil, Australia, and India (EIA, 2008).

Biodiesel production is limited to coco methyl ester (CME) produced from coconuts. In 2008, there were 11 biodiesel refineries with combined output capacity of 348 million litres per year. Between the years 2004 and 2007, the quantity of coconut oil used for biofuel production increased from 500 to 35,000 tonnes. In 2007, 1000 tonnes was imported and 1000 tonnes exported (USDA, 2007). The Philippine Department of Energy estimates that biodiesel consumption was 78.8 million litres in 2008 and that it was expected to increase to 163.9 million litres in 2009. With the current production, it can meet the 2% mandate which requires 119 million litres (USAID, 2009). Biofuels are estimated to be about 1.5 times more expensive than fossil fuel products (EIA, 2008).

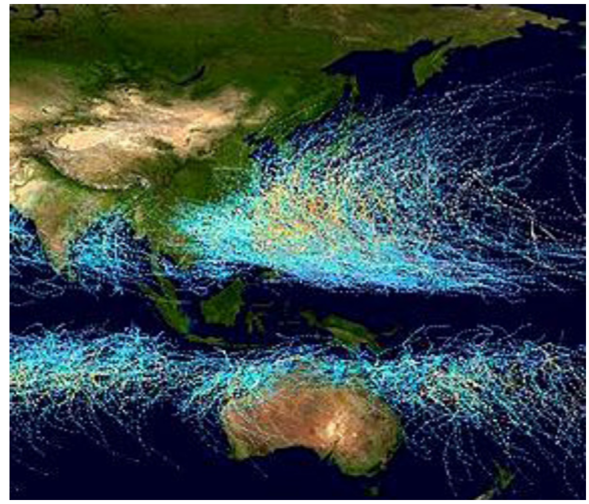

Fig. 1 – Tropical cyclone tracks in Australasia (produced by Nilfanion of the Wikipedia Website and released into the public domain).

2.2. *Data*

The data of tropical cyclone paths, radius of 30 and 50 knot winds and maximum central wind speeds was obtained from the website of the Japan Meteorological Agency (2008), which provides best track data for tropical cyclones in the western North Pacific and South China Sea.[5] Fig. 1 shows, for each storm, snapshots of the storm geometry and wind speed at various intervals.

Sugarcane, coconut, cassava (manioc) and camote (sweet potato) are studied here because they are the target feedstocks of the Philippine biofuel policy, and represent two plantation crops (sugarcane and coconut) and two typical small holder crops (cassava and camote) (Javier, 2008). Especially in the analysis of policies for rural development it is important to distinguish between those feedstocks in the Philippines that are cultivated by smallholders, often through outgrower schemes (for example cassava and camote), in contrast to those cultivated at a plantation scale (such as sugarcane and coconut). Here we refer to outgrowers as contract farmers, often resource poor but with their own land, who deliver their produce to one buyer as stipulated in a written agreement. This is the typical alternative to large scale plantations for biofuel feedstock schemes in developing countries.[6,7]

[5] Data prior to 1977 could not be used because the satellite data available only shows the storm paths and not the radius or wind speeds. Nevertheless, the remaining 30 years of useful data provides a total of 831 tracks of tropical cyclones, which cover the area well, as can be seen by Fig. 1.

[6] That buyer may or may not provide certain production inputs (for example technology such as seed and agrichemicals).

[7] Here we use the term small holders to refer to farmers with relatively small resource endowments as compared to other farmers in the same sector.

Biofuel production data for sugarcane, coconut and cassava was derived from the Philippines' National Academy of Science and Technology's prediction of the tonnage required to meet the country's legislated biofuel targets (Javier, 2008). This data, which is for the year 2014 only, was converted from hectares to tonnage.[8] In order to enable the calculation of the geographical distribution of the damage to the feedstocks, the national per feedstock tonnage was distributed proportionally across the localities of production for each of the four feedstocks, as for the latest available year, 2007, obtained from the Philippine Bureau of Agricultural Statistics.[9,10]

Due to the difficulty to find predicted biofuel production requirements for camote, the national tonnage produced in the year 2007 for this feedstock was used, instead of the biofuel feedstock tonnage. The production data for annual total production for the year 2007 refers to the actual harvested tonnage. Hence, it does not include the production that was lost due to the passage of typhoon Mitag in that year. Thus, the data for 2007 was reconstructed to include the estimated damage of this typhoon, so that the theoretical production level (if Mitag had not occurred) of each feedstock for the year 2007 can be used in the simulation. To this end the feedstock loss resulting from a single simulation of the loss due to the passage of typhoon Mitag was then added to the 2007 data in order to generate a representative pre-typhoon production tonnage valid for the simulation. Adding the tonnage lost due to Mitag increases the theoretical production level by less than 0.01%, as this typhoon affected mostly the north of the country. Including such data results in a more consistent approach, though omitting this effect would have had an insignificant effect on the results. Table 1 shows that the projected biofuel feedstock production of cassava in the year 2014 will exceed total tonnage of that feedstock in 2007, while the coconuts for biofuel are a very small proportion of overall production.

Table 1 – Biofuel feedstock production and total production, Philippines (k tonnes).

Feedstock	Production (non biofuel + biofuel) (2007)	Production: biofuel (2014)	%
Plantation feedstocks			
Sugarcane	22,235	6849	30.8%
Coconut	14,691	140	0.9%
Outgrower feedstocks			
Camote	558	558	100.0%
Cassava	1864	3316	177.9%
Total	39,348	10,862	27.6%

2.3. *Simulation method for future wind damage on biofuel feedstock production*

The objective of the proposed methodology is to calculate the expected biofuel feedstock damage to biofuel production and expected time loss related to a, as yet hypothetical, increase in future tropical cyclone intensity. A Monte Carlo simulation is used, which does not randomly generate the tropical cyclones tracks; instead, each of the random number of tropical cyclones in each month of the year are randomly picked from a set of 831 historical cyclones. The simulation then randomly alters the maximum wind speed at the centre and the size of each of the selected tropical cyclones according to the expected future distribution of maximum wind speeds in the year 2085, as proposed by Knutson and Tuleya (2004).[11] The resulting scenario is then compared with the control scenarios showing the expected number of hours that each area is affected by winds of a certain wind speed in 2008. The reason for using a Monte Carlo simulation is that, in the same way that an area in the Philippines might be affected by 3 typhoons in a given year and none in the next, each of the simulation runs produces a different number of typhoons each year. Hence, it is necessary to obtain an average "Expected" result. For each scenario a total of 5000 simulation runs were carried out, giving over 99% accuracy, as compared to the 100% accuracy of a 40,000 simulation run.

The method used simulates the wind speed and size of typhoons in the year 2085. However, due to the difficulty in anticipating the impact that socio-economic factors and technology will have on different energy forms including biofuels, this analysis focuses on the mid-term effects, in 2050 (following praxis from for example Parry et al., 2007). The 2050 values for the increase in average tropical cyclone intensity were obtained by simple linear extrapolation from the 2085 values. In reality tropical cyclones are believed to follow a cyclical inter-annual trend, and thus the 2050 values should be seen as an illustration of the average tropical cyclone impact in the 'middle term' rather than for the exact year 2050.[12]

The economic impact of tropical cyclones on biofuel production in the Philippines depends on several factors such as the location of economic activity, number of storms, and intensity of storms. Moreover, geographical characteristics such as topography and island areas have implications for the vulnerability to typhoons. In the Philippines, like in other countries, agricultural output varies geographically, with different regions producing different volumes and types of feedstocks. Hence the economic impact of typhoons on biofuel

[8] Although it is likely that regional differences in the ratio between hectare and tonnage exist, for the purpose of this study we use linear approximation in order to illustrate the effect of wind damage. The feedstock tonnage and feedstock area distribution for agricultural production is fairly stable in the short run (DA, 2008), hence we hold that the combination of 2007 data (total agricultural tonnage per feedstock) and 2014 (biofuel feedstock tonnage per feedstock) does not pose a problem.

[9] For the purpose of this study we assume that the feedstocks studied are currently largely cultivated in their suitable agro ecological and socio-economic areas across the provinces. Hence we hold that it is likely that future production will take place in the same or closely adjacent provinces which are similarly affected by the typhoons.

[10] http://countrystat.bas.gov.ph/ (accessed 15.06.09).

[11] These authors studied the cyclone pattern in the Pacific Basin. The results refer to the year 2085, which is the year for which Knutson and Tuleya (2004) provides the expected distribution of maximum surface wind speeds.

[12] Extrapolation of the short term increase in intensity instead of middle term impact of tropical cyclones is not advisable with the current methodology since the values would be less reliable.

production will differ depending on the type and location of biofuel feedstock cultivation. Thus, the authors followed a disaggregated computational approach to measure the economic agricultural loss caused by storms under a climate change scenario for the year 2050.

The contexts and characteristics of biofuel production will change in the middle term, due to for example increasing energy demand from a growing economy and population. Technology improvements in agriculture and energy may increase productivity. Moreover, the increased wealth may increase adaptive capacity to climate change (Raleigh et al., 2008). However, agricultural production is likely to continue to be vulnerable (e.g. Acosta-Michlik and Espaldon, 2008), for example due to financial constraints to acquire new costly climate resilient technologies such as better adapted seed and due to the common trade-off between high yields and strong climate resilience in crops. Hence the present study only considers two simplified scenarios of agriculture production.

2.3.1. *Computation of wind damage on biofuel feedstocks*

The method used did not take into account the number of hours that an area was affected by winds of a given strength, but rather the maximum wind speed that affected each area due to the passage of each tropical cyclone. Clearly, the number of hours that each area is affected would also have an impact, though this is difficult to assess.

The level of future biofuel feedstock production is highly uncertain, and depends on socio-economic development as well as technological development in biofuel and alternative energy sources. For that reason we base the simulations on the 2014 expected volume estimation (see Section 2.2).

Catastrophic feedstock damage (meaning that the crop is fully destroyed) is likely to occur beyond a certain threshold of wind speed that is reached by only few very strong storms. The low historical occurrence of such tropical cyclones poses a challenge to the researcher to specify a wind-feedstock damage function. Guard and Lander (1999) analysed damage due to tropical cyclones in various basins, and analysed the wind-damage relationships, which they incorporated into a description of the Saffir–Simpson Tropical Cyclone Scale. In their work, each tropical cyclone size is given a descriptive damage for a certain wind speed and for different agricultural products, which were used to establish the onset of damage for each crop and degrees of damage for increasing strength of wind speeds. Using this information and assuming a similar exponential link between the wind speed in a certain area and the percentage of destroyed feedstocks in the area as that assumed by Hallegatte (2007) (based on Howard et al., 1972; Pielke et al., 2006), wind damage parameters for the feedstock were derived and Fig. 2 was produced.

Fig. 2 illustrates a damage function of the type

$$C_d = c_1 \cdot e^{c_2 W_{\max}} \quad (1)$$

where C_d is the proportion of damage to each feedstock and c_1 and c_2 are damage parameters given in Table 2 for each feedstock, and e denotes the exponential wind–damage relationship.

Each time that an area is hit by the tropical cyclone, the maximum wind speed is obtained for each grid point for the whole life of the storm, and then Eq. (1) is used to obtain the

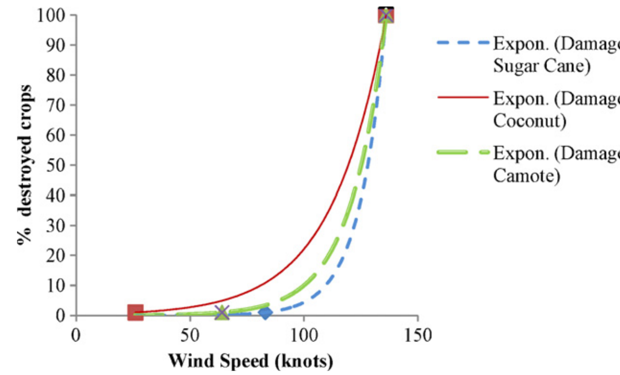

Fig. 2 – Relationship between wind speed and percentage volume of destroyed feedstocks (cassava has the same damage function as camote).

Table 2 – Feedstock damage parameters used in the simulations.

Feedstock	Length growing season	c_1	c_2
Sugarcane	12 months	0.0007	0.0869
Coconut	2 months	0.3367	0.0419
Camote	6 months	0.0167	0.064
Cassava	6 months	0.0167	0.064

damage to each feedstock. The simulation also takes into account the length of the growing season of each feedstock, and thus there is damage only to the fraction of the total annual production that can be considered to be cultivated at the time of the typhoon. Thus, for example, only 1/6th of the annual coconut production in each area can be affected by the passage of one typhoon, whereas half of the annual production of camote and cassava, and all sugar cane can be affected. In order to obtain information that is accurate for the Philippines, the information is sourced from experts on Philippine agriculture as well as from the Philippine Department of Agriculture (http://www.bar.gov.ph/ (accessed 14.05.10)). Note that the numbers are underestimates: for example coconuts are grown throughout the year and normally produce harvestable feedstock every 3–4 months. Cassava can be harvested already after 6 months but needs 9–12 months to produce maximum yields and usually gives only one harvest per year.[13] However, in order to produce moderate results and because the damage function is not certain, the harvest cycles presented here are used.

Determining the wind damage to feedstocks is a rather complicated task. Moreover, the impact of maximum wind speeds on damage is non-linear, and physical damage increases sharply with maximum winds (see Hallegatte, 2007; Howard et al., 1972; Pielke et al., 2006). However, the duration and occurrence differs greatly from storm to storm. Another effect of tropical cyclones is a localized increase in rainfall. Depending on the amount, intensity and force of rainfall there are both positive and negative effects which partially cancel out each other. Hence for the purpose of this study the focus is on the wind effect and not the rain effect. In fact the estimation of wind damage to crops is quite difficult due to the high number of parameters involved (damage can be influenced by many

[13] Pers. Comm. Jane Romero, 24th July 2009; Dr. Umehara, 3 May 2009.

Table 3 – Biofuel feedstock production and losses due to strong winds in two climate change scenarios, Philippines (k tonnes).

Feedstock	Biofuel feedstock production 2014	Loss due to wind in 2014		Loss ratio 2050: loss/production (middle scenario)	Increase in loss ratio (Ctrl versus middle scenario)
		Control scenario	Middle scenario		
Plantation feedstocks					
Sugarcane	6849	34	48	0.7%	42%
Coconut	140	2	3	2.0%	15%
Outgrower feedstocks					
Camote	558	15	19	3.5%	26%
Cassava	3316	30	39	1.2%	29%
Total	10,862	81	109	1.00%	34%

parameters such as the growth stage of the plant, the climatic condition before the typhoon or wind humidity, according to Tsuboi, 1961). Error bounds for Eq. (1) are thus dependent on the ranges of values given by Guard and Lander (1999), meaning that also these are dependent on the type of crop. For the initiation of damage alone errors for the coconut damage can be as big as 25%, though these are much lower for cassava and camote (around 12%) and sugar cane (7%). The order of magnitude of the errors for the more resilient crops is similar to that shown by Tsuboi (1961) for the case of rice (around 10%) for experiments carried out in wind tunnels.

2.3.2. *Computation of wind downtime in biofuel production*

While tropical cyclones are limited in space and time and thus do not affect areas equally, the model assumes that a tropical cyclone that reaches wind speeds of more than 30 knots (55.56 km/h) will disrupt many human activities related to agriculture. According to the Beaufort wind force scale a moderate gale (over 27 knots) makes it difficult to walk against the wind. Anything over 34 knots (‘‘fresh gale’’) causes twigs to be broken and cars to veer on the road, and would result in a Gale warning in places like the U.K. and U.S.A. From this point on normal economic activity and transport are usually disrupted, including planting, maintenance and harvesting during biofuel feedstock production. This prediction was derived using data from the CIESIN website, which was used to show the country as a number of grids for each of which the downtime due to tropical cyclones was calculated (see Fig. 7).

Although the exact impact is difficult to estimate, downtime in biofuel production activities can have significant economic effects throughout the production chain: from distortion in the agricultural cycles (preparation of land, sowing, harvesting) which may affect yields, to interruptions in lead times during processing and distribution of biofuels. For example, sensitive biofuel feedstocks quickly perish and lose their economic value, and transport interruption and capacity constraints of oil palm distilleries have in some cases resulted in the harvested crops perishing before being distilled, causing subsequent income loss to small scale farmers for example in parts of Africa (FAO, 2002). Due to the difficulty to quantify and monetise such *indirect* effect, their detailed analysis is excluded from our analysis. This contributes to further providing a low bound rather than the precise effects of the passage of a tropical cyclone.

However, in order to illustrate the extent of downtime, additional to simulating feedstock damage the time lost due to typhoons was also simulated. A Monte Carlo simulation was used to obtain the Expected Duration that each region is affected by winds of various strengths in a given future year. The Expected Duration $\hat{\vartheta}(s)$ for a wind of strength s can be defined as the sum of each of the values of time affected by a certain wind due to storms for one year $\vartheta(s)$ for all the simulation runs divided by the number of simulated runs N, or,

$$\hat{\vartheta}(s) = \frac{\sum_1^N \vartheta(s)}{N} \quad (2)$$

3. Results

3.1. *Direct effects: lower feedstock yield*

Firstly, at the national level the climate change induced increase in wind damage will cause the average loss ratio to increase from the 2014 (i.e. control scenario) levels to the ‘2050’ scenario, for all feedstocks (Table 3). Camote has the highest loss ratio (3.5%), followed by coconut, cassava and sugarcane (2.0, 1.2 and 0.7%, respectively). These numbers correspond to strong *increases* in loss ratio for all feedstock, strongest for sugarcane (43%) followed by cassava, camote and coconut (corresponding to 48, 3, 20 and 39 k tonnes of biofuel feedstock, respectively).

A more detailed analysis at the province level was done in order to account for differences in wind loss across different provinces. Figs. 3–6 show the location specific consequences of wind damage across the Philippine’s 80 provinces. Notably, the principal production centres for coconut, camote, cassava and to some extent sugarcane are located in areas which can be significantly affected by strong winds, such as the Negros region: its sugarcane biofuel feedstock production is projected to reach 3097 k tonnes in 2014 (as illustrated in Fig. 3, by the lower of the two largest circles). Without an increase in typhoon intensity (control scenario) the losses due to typhoons would be 11 k tonnes. This amounts to a 0.3% loss to production volume ratio. However, accounting for the projected future increase in typhoon intensity in 2050 and calculated on the same production volume, the losses would reach 17 k tonnes, or a 0.6% loss ratio (i.e. a 65% increase in losses). In Batangas, another major production centre of sugarcane (illustrated by the higher of the two largest circles), the loss ratio will increase by 98% from an initially already high loss ratio of 1.3%.

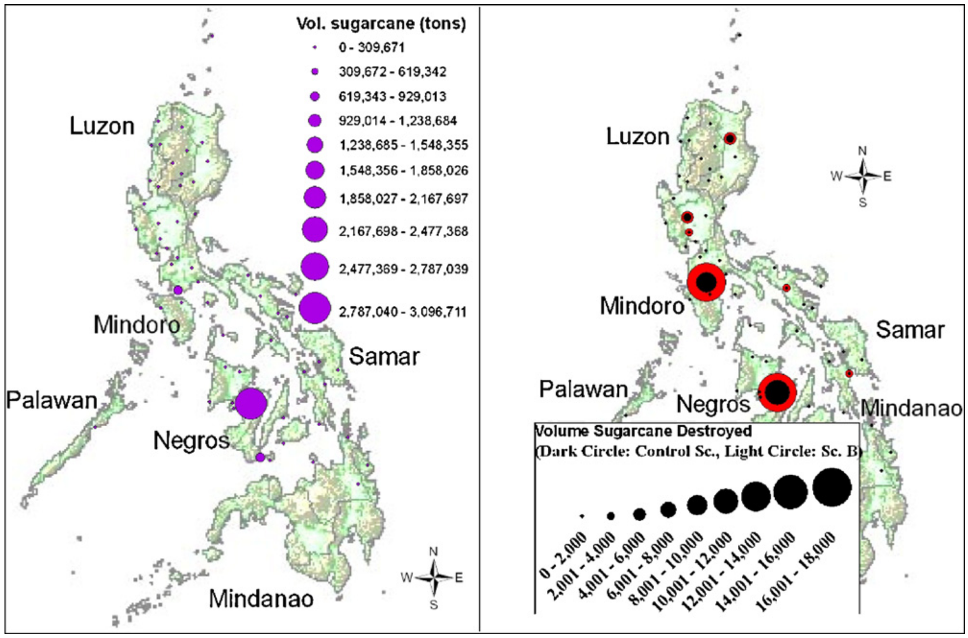

Fig. 3 – Biofuel feedstock production of sugarcane, in 2014. Right: tonnage of that feedstock lost due to typhoon winds, in 2050 (dark circle represents control scenario only, light outer circle adds the medium strong climate change scenario).

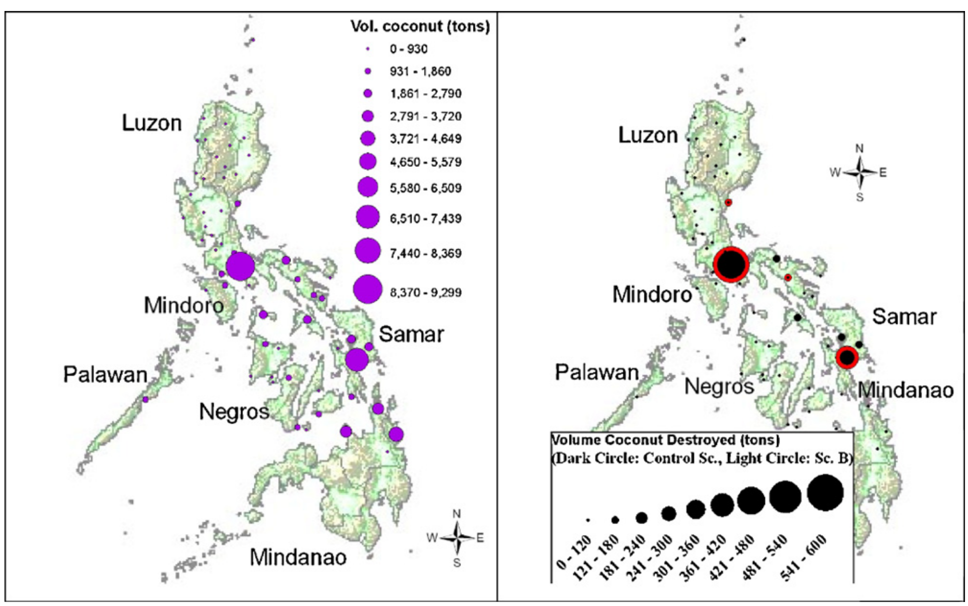

Fig. 4 – Biofuel feedstock production of coconut, in 2014. Right: tonnage of that feedstock lost due to typhoon winds, in 2050 (dark circle represents control scenario only, light outer circle adds the medium strong climate change scenario).

3.2. *Indirect effects: downtime*

As for indirect losses due to downtime, the expected number of hours that each area of the Philippines is affected by winds of 30 knots or greater strength per year is given in Fig. 7. It can also be seen that the strongest winds are expected in the north east parts of the country, and their frequency will have increased drastically by 2050.

4. Discussion

The effect of climate change induced wind damage on biofuel feedstock production in the medium term may be modest for the Philippines aggregate energy security, i.e. the Philippine biofuel plan's first aim. Such modest medium term national level impact has been noted elsewhere, in the case of climate

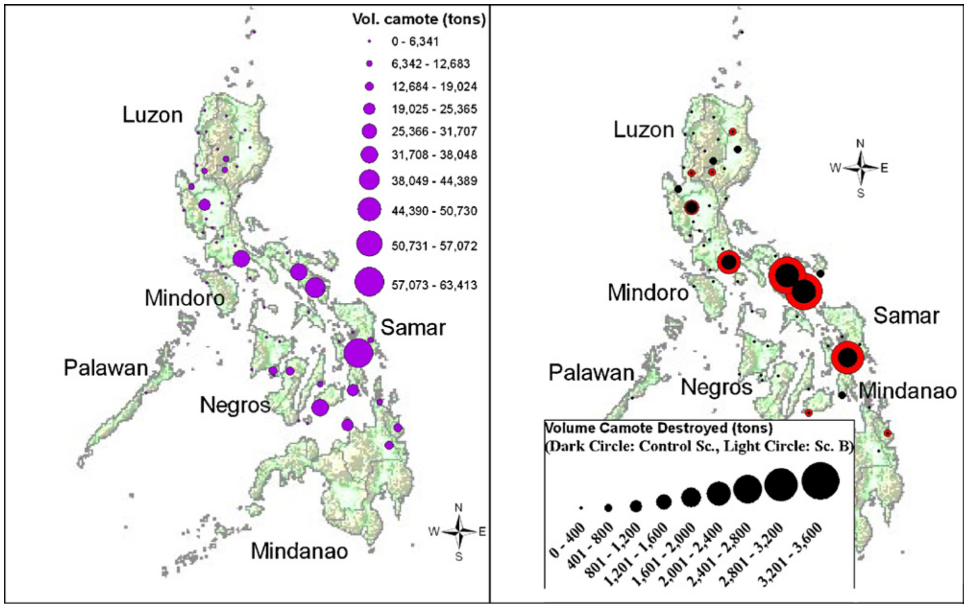

Fig. 5 – biofuel feedstock production of camote, in 2014. Right: tonnage of that feedstock lost due to typhoon winds, in 2050 (dark circle represents control scenario only, light outer circle adds the medium strong climate change scenario).

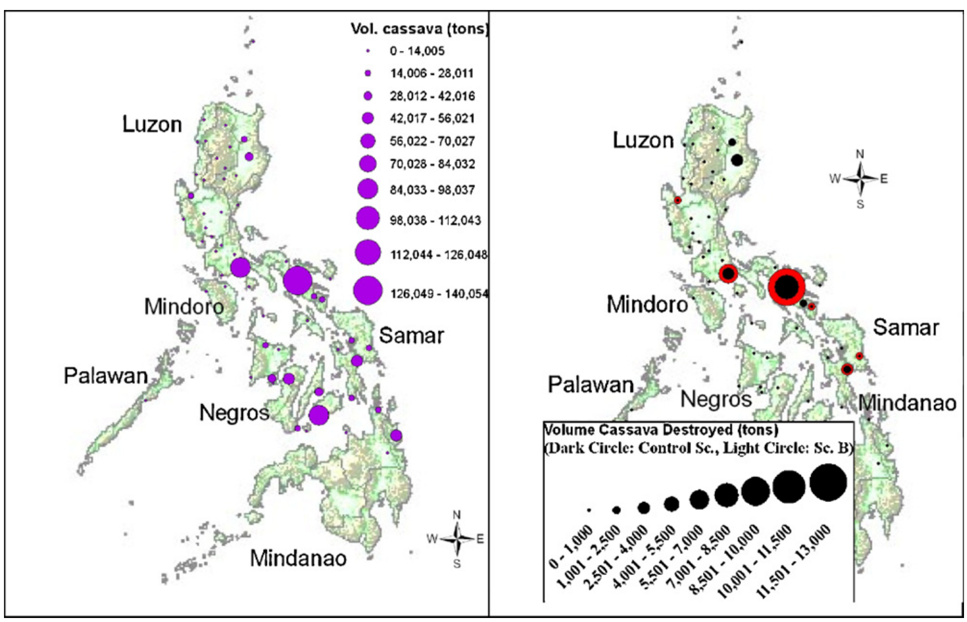

Fig. 6 – Left: biofuel feedstock production of cassava, in 2014. Right: tonnage of that feedstock lost due to typhoon winds, in 2050 (dark circle represents control scenario only, light outer circle adds the medium strong climate change scenario).

change induced temperature and precipitation effects, for example in Brazil (Féres et al., 2008). Our results show that in 2014 the energy content of the bioethanol and the biodiesel that could have been produced with the four feedstocks but was lost due to typhoon winds will be in the order of 2.69E+14J.[14] This amount is expected to be equal to approximately 0.9% of the whole biofuel feedstock yield.

[14] We collected the conversion factors for each feedstock from a number of studies (e.g. Johnston et al., 2009; Nguyen et al., 2007; Dai et al., 2006) and personal communication with Jane Romero.

Policy makers may consider putting the emphasis on either an outgrower or plantation approach (henceforth 'outgrower scenario' and 'plantation scenario', respectively). It has been shown elsewhere (for example in Mozambique, Arndt et al., 2010) that the overall contribution to GDP and for rural development and income distribution is higher with an outgrower than a plantation approach. In particular, the outgrower approach may be financially more vulnerable to wind damage than a plantation approach, which may be able to better absorb short term fluctuations in profit for example thanks to better access to formal insurance or technology to

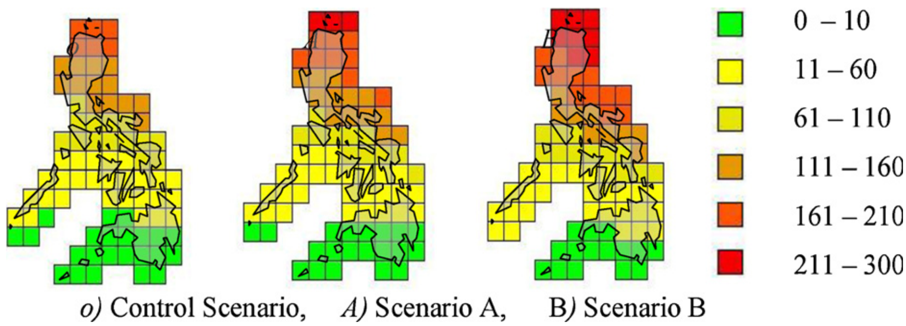

Fig. 7 – Expected number of hours of hours lost due to winds of at least 30 knot winds.

reduce their vulnerability (e.g. Acosta-Michlik and Espaldon, 2008; Mendelsohn et al., 2000; Robles et al., 2009; Woods, 2006). Arguably the plantation approach is also more flexible to use the location-feedstock choice as a way to ameliorate climate change vulnerability. Further down the biofuel production chain the profit gets increasingly influenced by inputs of for example skilled labour and advanced technology (OECD, 2008).

These figures hides significant variability between different localities, feedstocks and production systems, which are of relevance for rural development: as shown by the examples for Negros and Batangas (Section 3), some production centres will face more significant losses than others. In particular Fig. 7 highlights that the north eastern areas will be strongly affected, i.e. where several of the smaller production units are located such as for the outgrower feedstocks cassava and camote. Moreover, as the wind strength increases over time, its volatility will have a more marked effect on feedstock production. Unpredictable timing and strength of winds in different localities adds an uncertainty element to feedstock production, with an expected negative effect on investment incentives in both a plantation and outgrower approach, as showed elsewhere (e.g. Chambwera and Stage, 2010).

It is difficult to hypothesise about future feedstock prices and thus the monetary impact of wind damage. However, the implications of wind damage can potentially be high in the medium term. There is considerable wind damage for example for camote in eastern Philippines (Fig. 5). The wind damage will affect both plantation crops (sugarcane and coconut) and outgrower crops (cassava and camote). The highest tonnage loss will affect sugarcane, and cassava will also be significantly affected (Table 3). Coconut and camote face the highest loss ratios, and sugarcane followed by camote and cassava face the highest increase in loss ratio.

Sugar cane production in the Philippines is already operating with excess capacity in many regions meaning that profit margins can be expected to be zero (Javier, 2008). Hence productivity loss may have significant economic consequences especially for small scale production units: in the '2050' scenario the lost yield corresponds to an annual national income loss of more than USD 2 million counted in farm gate prices. This number is modest in comparison to the total income from these biofuel feedstocks at the farm gate of USD 679 million (Table 4).[15]

[15] USD conversion from Philippine pesos, exchange rate as of December 19 2009.

In the case a plantation approach is adopted, sourcing all feedstock from sugar cane and coco (with unchanged aggregate net energy content), the income loss will be USD 2.9 million. With an outgrower approach the income loss will be USD 17.6 million. However, while this is a notable amount, the percentage increase compared with the control scenario is modest. Indeed, in the plantation policy scenario, the average percentage loss in income ('2050' scenario compared with control scenario) would decrease from 1.4% to 0.7%. In contrast, in the outgrower policy scenario the corresponding average loss would be higher, 1.7%. However while the losses in the plantation crops sugarcane and coconut are the smallest, the larger losses in camote and cassava may have dire effects at the house hold level. Moreover, we recall from (Section 3.1) the increase in loss ratio for these crops (27% for camote, 30% for cassava) is high. This increase would of course hit a larger number of households if the outgrower policy scenario is chosen. However, Table 4 shows that even for these crops the average effect on changed income is likely to be modest at the household level, in scenario 'a' (0.7% for camote, 0.3% for cassava). In sum, the results indicate that the effect of climate change may not alter the viability of feedstock production as such, but may affect economies at the household level with potential negative implications for rural development.

Apart from direct economic damage (including loss of crop, interruptions in supply chains, volatility in yield that decrease the net present value of future yields and hence disincentives investment, and cost of downtime) there are other negative effects from typhoons not directly measurable in economics terms. Livelihoods are built upon crop production, both for outgrowers and plantation workers. These people cannot easily be moved to areas with less exposure to typhoons without a considerable social cost.

As for the third policy goal, climate change mitigation, for those feedstock-location combinations suffering heavy losses from typhoon winds, one response option is to relocate (existing or planned) plantations to less wind exposed areas. One apparent such area is Mindanao, with 97,530 square km., since it is not exposed to typhoons and yet is the least exploited region in the country regarding agricultural activity. However, while it offers potential gains from the point of view of energy security and rural development, this is one of the few remaining large tracts of relatively untouched forest and with some tracts of peatland with significant carbon stocks. Hence this location means a likely tradeoff with the biofuel plan's

Table 4 – Costing the yield lost due to wind damage in 2050.

Biofuel feedstock	Biofuel production 2014 (k tonnes)	Loss 2050: control scenario (k tonnes)	Loss 2050: middle scenario (k tonnes)	Price per tonne at farm gate (USD)	Income control scenario (k USD)	Income loss 2014 (control scenario, k USD)	Income loss 2050 (middle scenario, k USD)	Change in income loss 2014–2050 (middle scenario, k USD)	Income loss in 2050 as % of income in 2014
Policy scenario a: current feedstock mix and locations									
Sugarcane	6848	34	48	24.94	170,802	839	1196	358	0.7%
Coconut	140	2	3	92.45	12,945	226	260	34	2.0%
Camote	557	15	19	190.705	106,390	2929	3719	789	3.5%
Cassava	3315	30	39	117.39	389,232	3510	4554	1043	1.2%
Total	10,862				679,370	7504	9729	2225	1.4%
Policy scenario b: plantation approach									
Sugarcane	15,021	73	105	24.94	374,639	1839	2624	785	0.7%
Coconut	154	2	3	92.45	14,259	249	287	37	2.0%
Total	15,175	76	108		388,898	2089	2911	822	0.7%
Policy scenario c: outgrower approach									
Camote	1297	35	45	190.705	247,416	6812	8648	1836	3.5%
Cassava	6566	59	76	117.39	770,816	6951	9018	2066	1.2%
Total	7863	94	122		1,018,233	13,763	17,665	3902	1.7%

Source: Own climate data and farm gate prices from Bureau of Agricultural Statistics (http://www.bas.gov.ph).

third goal, i.e. climate change mitigation through decreased green house gases.

Feedstock cost represents more than half of the total production costs of ethanol and biodiesel (other costs include physical capital for processing, labour, chemical and energy inputs). For example, feedstock costs represented 58–65% of ethanol production costs in Brazilian ethanol in 2005, at the time when Brazil had the world's lowest cost of production (Kojima et al., 2007). Consequently changes in feedstock productivity may critically affect the economic viability of biofuels if farmers producing feedstock in wind affected areas cannot compete with alternative energy sources unaffected by climate change. This in turn may affect the speed and rate of replacing fossil fuel for biofuel, with possible negative or positive effects on net greenhouse gas emissions (e.g. Gasparatos et al., 2011). While this study has focused on the domestic impacts in producer countries, by the mitigation–adaptation link can certainly be an issue for countries that import biofuel feedstock too.

It is important to remember that the model used in the present paper has a number of limitations, and that a lot of factors that can contribute to or alleviate damage have been excluded. Precipitation, the condition of the crops before the typhoon, the local relief or the effect of windbreakers, have not been included in the present work. Particularly the precipitation during a typhoon is thought to be particularly important to the amount of crop damage, and while it is not included in the present simulation, somehow a stronger typhoon will also result in more precipitation. Hence wind speed can act as a proxy of this factor. Nevertheless, it must be understood that considerable variation exists between the damage caused by one typhoon and the next, even if they have similar wind fields, due to all these other factors that can affect damage. By carrying out a Monte Carlo simulation, however, these difficulties can be partly overcome as what is finally presented is the average of thousands of simulation runs, representing an expected average outcome, rather than a prediction of the damage that will happen in one particular year.

5. Conclusions

The objective of this paper was to explore a so far little described link between mitigation and adaptation strategies to climate change. We analysed wind damage on biofuel feedstock production, and assessed the implications for energy security, rural development and climate change mitigation. The Philippines was chosen for the simulation, since it is highly exposed to typhoons, and has recently initiated an ambitious national biofuel production strategy. The paper uses as its basis the results of Knutson and Tuleya (2004), and assumes that although tropical cyclones will increase in intensity according to the results of these authors, their paths and frequencies will not change in the future.

At the national level the damage caused by typhoon winds on biofuel feedstock is modest. However, we find that even without monetising the *indirect* damage, the effects of certain combinations of feedstock and production system as well as location choice are vulnerable to climate change in the Philippines. This climate vulnerability may affect the regional compliance with the policy goals of enhanced energy security, rural development and climate change. These findings illustrate that there may be climate change adaptation and mitigation implications for the biofuel strategies in other feedstock producing countries such as China and Central American countries and other storm exposed regions, which either are implementing or planning biofuel feedstock production. This is an area that deserves further research, however the present study highlights that in order to make financially, socially and environmentally sound investment decisions in biofuel, the combination of locality–feedstock–production system is of outmost importance, and requires to be placed in the context of future climate change.

The research highlights that energy and rural development planning must address middle term effects in order to provide policies that are economically sustainable and which rest on sound assumptions about the future payoffs from production. For example, land use decisions can have irreversible effects or entail large sunk costs, i.e. such investments that once incurred cannot be reversed. One example is the foregone and irreplaceable ecosystem value of cleared forest. Forest clearance releases greenhouse gases, can cause soil erosion and loss of water regulatory services. Hence sound economic analysis hinges on factoring in production risks from tropical cyclones into the biofuel production decision in order to choose the land use which is socially desirable and environmentally sustainable not only in the short but also long term.

The results of the present simulation can be seen as an attempt to move from the general approach followed by the Stern Report (Stern, 2006) into a more detailed individual economic assessment of the direct impacts in this case the agricultural sector on the Philippines. A nationwide large scale biofuel policy also entails high sunk costs in technology and energy infrastructure. Given such potential financial thresholds it may be justified to account for a high climate change scenario instead of the modest one deployed in this paper. In such case the wind impact on yield is much higher, with a corresponding increase in the opportunity cost of opting for any locality–feedstock combination in areas exposed to wind damage.

Acknowledgements

The authors would like to thank the Japanese Society for the Promotion of Science (JSPS) for the post doctoral scholarships without which this research would not have been possible. One of the images used was produced by Nilfanion on the Wikipedia Website, and released into the public domain. Jane Romero provided very helpful comments about the Philippine biofuel program.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.envsci.2011.06.004.

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