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# LCA IMPACT ASSESSMENT OF GHG EMISSION BY NPP

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The purpose of this study is to find functional cause-effect relationships between emission of GHG (Green House Gas) and damages by global warming (climate change) and to explore applicability of NPP to impact assessment on quantitative aspect of ecosystem in LCA. We threw light on changes of biomass production by global warming and adopted NPP (Net Primary Production) as an impact indicator.

NPP is an amount of gross primary production through photosynthesis of ecosystem subtracted by plant respiration. Considering all the creatures in this planet ultimately depend on the solar energy transformed by photosynthesis of ecosystem, the change of NPP is an important indicator as ecosystem. Global warming may influence an amount of NPP in various ways. The influences of global warming are classified into two categories, that is influences by climate change including temperature increase and influences by fertilization effects by increase of $CO_2$ concentration. In addition , loss of land by sea level rise will affect NPP.

As a result of literature survey and GIS analyses, we concluded that NPP would increase by global warming because fertilization effects would be greater than the other influence. In respect of use of NPP as an impact indicator, further examination of estimation method and interpretation of NPP will be necessary.

Key words: climate change, LCA, impact assessment, NPP

## 1. INTRODUCTION

Compared to the inventory data analyses in the process of LCA, the methodology of impact assessments of inventory data is not well developed. Therefore, it is needed to find useful indicators to reflect functional cause-effect relationships between inventory data and their impacts. Among various kind of impacts by emission of pollution substances, impacts on ecosystem is probably the most difficult to measure so that it is difficult to find indicators of impacts on ecosystem.

Meanwhile potential impacts of greenhouse gas are characterized by GWP (global warming potential) in the impact assessments of LCA. GWP is a simple measure of the relative radiative effects of the emissions of various greenhouse gas expressed by CO2 emission units. Although GWP is virtually used as an endpoint-indicator in impact assessments, it can not be applied for comparison of impacts between different impacts categories.

## 2. METHODOLOGY OF IMPACT ASSESSMENT ON ECO SYSYTEM IN LCA

Because a wide spectrum of impacts is expected, we screened the significant impacts based on monetary value of damages derived from literature survey and found that impact on eco-system may be significant as well as impacts by sea level rise and impacts on agricultural production, human health and water resources1). Impacts on ecosystem are classified into categories, qualitative impacts and quantitative impacts. Probably the most recognized qualitative impact is a decrease of biodiversity. However, it is very difficult to measure a change of biodiversity as an impact. On the other hand, indicators as to extinction is well-known. Potentially it can also represent quality of ecosystem. However, it does not represent total amount of ecosystem. We consider NPP is a possibility as an useful indicator to reflect quantitative aspect of ecosystem in LCA.

NPP is defined as the difference between gross primary production through the process of photosynthesis of ecosystem and plant respiration[2]. In other words, NPP is an net amount of carbon fixed by ecosystems' green plants in a year. It also means the amount of solar energy fixed through the process of photosynthesis of ecosystem in a year.

All the creatures in this planet survive using the energy fixed by plants directly or indirectly. Therefore, the amount of NPP is an important indicator telling us the potential of the amount of creatures' activities in an eco-system.

## 3. IMPACTS OF ECOSYSTEM BY GLOBAL WARMING

It has been realized in the world that GHG emission including $CO_2$ may create a wide variety of impacts in human activities and ecosystem in a half century. In this study, we estimated impacts on ecosystem through global warming by NPP to explore applicability of NPP to impact assessment on quantitative aspect of ecosystem in LCA.

Global warming may influence an amount of NPP in various ways. Figure 1 shows the cause-effect chains from emission of GHG to NPP change. The influences of GHG emission are classified into three categories depending on cause-effect chains: the influences by climate change including elevated temperature; the influences by fertilization effects by increase of $CO_2$ concentration; and the influence of loss of land by sea level rise.

We estimates the impacts by climate change and $CO_2$ fertilization based on literature survey and impacts by sea level rise using GIS analyses.

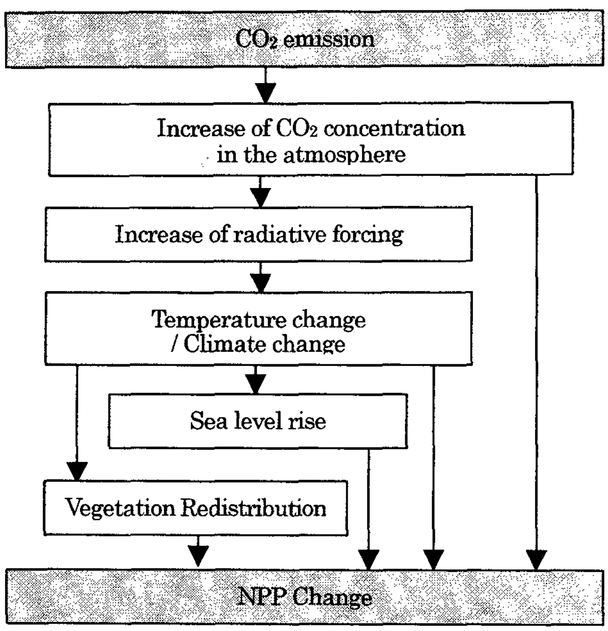


Figure I: Cause-Effect Chain From $CO_2$ emission to NPP Change

As to projection of $CO_2$ emission, we used IS92a scenario. We projected global temperature change from using DICE model developed by Nordhause[3]. In applying the DICE model to the projection, we adjusted several parameters. The result of temperature projection is basically the same as the projection reported by IPCC second report[2].

In the impact assessment of global warming, basically we used benchmark assessment which estimates the impact when $CO_2$ concentration in the atmosphere is doubled compared to pre-industrial era. After obtaining the results of benchmark assessments, we calculate the impact of each year from present to the time of doubled $CO_2$ concentration by interpolation.

## 4. IMPACTS ON NPP BY SEA LEVEL RISE

We started the estimation of area submerged by sea level rise by extracting area with elevation of less than 0.5 m above sea level by GIS. 0.5 m is the sea level rise projected by IPCC at the time of $CO_2$ concentration doubled. The data of elevation is based on ETOPO5 compiled by NGDC. The geographical resolution of the elevation data is one twelfth degree across latitude and longitude. Therefore, the submerged area was calculated by one twelfth degree grid across the world.

One twelfth degree grids with less than 0.5 m elevation which includes a city with population of more than one hundred thousands were excluded from the submerged because they are supposed to be protected by banking. The total of submerged area we estimated was three and half times larger than the area projected through Global Vulnerability Assessment (GVA) by Delft Hydraulics[4]. It was because we did not consider social-economic factor related to protection policy in each country. Therefore, our estimation should be considered as a potential of land loss by global warming.

After projecting the submerged area by sea level rise, we examined the vegetation type of each grid based on geographical vegetation data compiled by Olson[5]. Each vegetation type has a different NPP. In other to estimate NPP of each vegetation we used the equation below called as Chikugo Model[6].

$$NPP=0.29\,[\exp(-0.216RDI^2)]\,Rn \qquad (1)$$

where
RDI ( = Rn / lr) = annual average radiation drying、Rn = annual net radiation (kcal/cm$^2$) ,
r = precipitation (cm) , l = evaporation latent heat of water (kcal/g$H_2O$)

$$Rn = (1-a)\,St-F \qquad (2)$$

where
St = annual flux of insolation (kcal/cm$^2$); a = albedo (0 - 1.0) ; F = low-wave radiation (kcal/cm$^2$)

We used data on RDI and Rn corresponded to vegetation type studied by Uchijima and Seino[6].

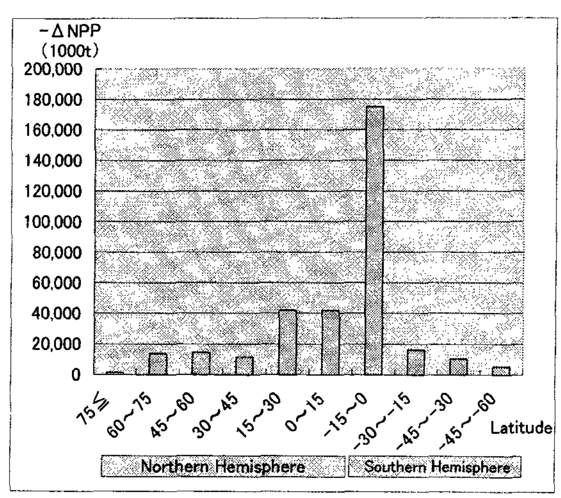


Figure II: NPP loss by sea level rise at the time of doubled $CO_2$ concentration

In order to estimate the impact in each year from present to the time of doubled $CO_2$ concentration, we used the equation below assuming a linear function between amount of loss of NPP and sea level rise.

$$\Delta NPPLL(t) = \Delta NPPLL(CO_2x2) \times (\Delta s(t)/50) \quad (3)$$

where
$\Delta NPPLL(t)$ = NPP loss of submerged land in year t; $\Delta NPPLL(CO_2x2)$ = NPP loss of submerged land at the time when sea level rises by 0.5m ( = benchmark projection); $\Delta s(t)$ =sea level rise in year t

5. IMPACT ON NPP BY $CO_2$ FERTILIZATION AND CLIMATE CHANGE

NPP loss by sea level rise is easily understandable for everybody. There are also expected the impacts via the other pathways, that is impact by fertilization effects by increase of $CO_2$ concentration and impact by climate change including elevated temperature. The impacts via those pathways could be more significant because the area which would be influenced are much larger then the coastal area which sea level rise would influence.

The fertilization effect is that increase of $CO_2$ concentration accelerates photosynthesis of plants resulting in NPP increase. The impacts by climate change are more complicate. Elevated temperature will decrease soil moisture leading to deceleration of photosynthesis of plants. Elevated temperature also promotes respiration of plants leading to reduction of NPP. Meanwhile some types of plants prefer higher temperature and produce more NPP at the temperature.

Higher temperature and change of precipitation induce redistribution of plants toward North in the long term because plants tend to move to more suitable environment. Plants redistribution may create new vegetation in northern area while it may extend dry land. Over all impacts will be different depending on regional climate change.

The fertilization effects, elevated temperature and redistribution of plants may not work independently. They may interact one another on changing NPP. Therefore we adopted a result of model analysis conducted by Melillo et al. [7] which simulated the combined impacts at the time of $CO_2$ concentration doubled. Figure III shows the change in terrestrial carbon storage as the results of the simulation.

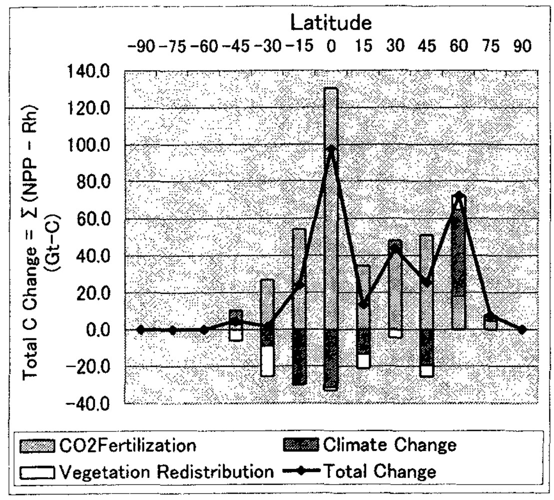


Figure III: Total carbon change stored in terrestrial ecosystem accumulated by the increment between NPP and Rh at the time of doubled $CO_2$ concentration. $CO_2$ fertilization and climate change account for the NPP change. Rh = heterotrophic respiration in a year. Three factors, $CO_2$ fertilization, climate change and vegetation redistribution influence NPP. The original simulations conducted by Melillo et al. did not necessarily independently consider these three factors[7]. In Figure III, the $CO_2$ fertilization effects are referred to the effects simulated without consideration of other factors by Melillo et al. [7] We obtain the climate change effects by subtracting the $CO_2$ fertilization effects from the combined effects of $CO_2$ fertilization and climate change. We obtain the vegetation redistribution effects by subtracting the combined effects of $CO_2$ fertilization and climate change from the total combined effects. These combined effects were simulated by Melillo et al.

We estimated the $CO_2$ fertilization impact and the climate change impact of each year from present to the time of doubled $CO_2$ concentration separately. As for fertilization impacts we used the equation below assuming a linear function between $CO_2$ concentration and the impact on NPP.

$$\Delta NPPCO_2(t) = \Delta NPPCO_2(CO_2x2) \times (\Delta M(t)/\Delta M(CO_2x2)) \quad (4)$$

Where
$\Delta NPPCO_2(t)$ = NPP change by $CO_2$ fertilization in year t; $\Delta NPPCO_2(CO_2x2)$ = NPP change by $CO_2$ fertilization at time of doubled $CO_2$ concentration ( = benchmark projection); $\Delta M(t)$ = $CO_2$ concentration in year t; $\Delta M(CO_2x2)$ = $CO_2$ concentration at the time of doubled $CO_2$ concentration.

As for climate change impacts we used the equation below assuming a linear function between temperature and the impact on NPP.

$$\Delta NPPclimate(t) = \Delta NPPclimate(CO_2x2) \times (\Delta T(t)/\Delta T(CO_2x2)) \quad (6)$$

Where
$\Delta$NPPclimate(t) = NPP change by climate change in year t; $\Delta$ NPPclimate ($CO_2$x2) = NPP change by climate change at the time of doubled $CO_2$ concentration (= benchmark projection); $\Delta$ T(t) = increase of temperature in year t; $\Delta$T($CO_2$x2) $CO_2$ = increase of temperature at the time of doubled $CO_2$ concentration.

## 6. IMPACT ON NPP PER EMISSION

Because DICE model tell us the temperature increase happen in the next year after an emission, we divided NPP change in a year by the amount of GHG emission in the previous year. This would be different from the reality but the results would not be significant in the viewpoint of order estimations because the increase of emission and change of impacts seems relatively constant. We assumed the sea level rise would happen forty years after emission based on benchmark assessment in IPCC report so that we divided NPP impact by sea level rise by the emission of forty years before. Table I shows impacts on NPP per emission.

Table I: Average NPP change per emission ($10^3$t-C/Gt-C)

| year | Sea level rise | $CO_2$ Fertilization | Climate Change |
|---|---|---|---|
| 1995 - 2005 | 400 | -2,100 | 400 |
| 2005 - 2015 | 500 | -2,000 | 400 |

Among three impact pathways, $CO_2$ fertilization is dominant. Considering small impact area by sea level rise compared other pathways, its impact seems significant. However, it should be pointed out that projection of submerged land is a potential. Moreover, the possible redistribution of plants in coastal land was not considered in the impact projection. Those probably produced an overestimation of impact by sea level rise. Compared to other impacts, the impact by climate change seems small. However, it should be reminded that regional impacts might be very significant depending upon the extent of regional climate changes which is expect be very different.

In conclusion the projection means $CO_2$ emission may increase NPP in total, that is, we may be reducing the carbon under the deep ground consuming fossil fuel and be increasing the terrestrial storage as plants.

## 7. APPICALITITY OF NPP AS AN IMPACT INDICATOR

As for the applicability of NPP to the assessment of ecological impacts by global warming, using NPP straightforward will result in a problem because the total projected impacts on NPP indicate that an emission of GHG would produce a positive value. It may be necessary that impacts by three different pathways are interpreted separately.

However, it is considered to be methodologically feasible to use NPP on quantitative aspect of ecosystem in the impact assessment in LCA because of a good availability of data which generate NPP such as climate data and vegetation data. The method used in this study in the assessment of NPP impacts by sea level rise is applicable to other impact category such as land loss by facility location and deforestation by air pollution.

## 8. CONCLUSION

We traced cause effect chain from an emission of GHG to the impacts on ecosystem by global warming (climate change) and assessed the impact using NPP. Simple application of NPP to impact assessment of global warming is questionable because the result indicates positive value of global warming. However, the method used in this study has a possibility applicable to other impact categories.

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