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Impact of agricultural land conversion on climate change

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Abstract

Climate change and land use conversion are two major global environmental issues. A claim is made that climate change has brought new challenges for global land use, while land use conversion is hardly realized as a major driver for climate change. Using mapping techniques, this study aims to investigate the relationship between climate change and agricultural land conversion (ALC), by which land is converted from agricultural to other uses (e.g., urban areas, national and natural parks, roads, industrial areas, and afforestation projects). CO_2 emission is considered as the main impact of climate change, and agricultural land conversion is regarded as the most important global land use. In this study, data are obtained from two databases: the World Bank and the Food and Agriculture Organization (FAO) for the period of 1962–2011. Considering the FAO (2015) classification, the countries are categorized into five different groups (high-income non-OECD, high-income OECD, upper-middle-, lower-middle-, and low-income countries). Economies were divided into several income groups according to 2014 gross national income per capita. The results show that agricultural areas in high-income countries have decreased, while in low- to middle-income countries, they have increased. The highest CO_2 emissions can be observed, especially in high-income countries, whereas the lowest CO_2 emissions happen in the low- and lower-middle-income countries. The results further show that there is a positive relationship between CO_2 emissions and ALC across the world. It can be observed that CO_2 emission is increasing where agricultural area is declining. On the contrary, CO_2 emission is declining where agricultural area is increasing.

Keywords Global warming · CO_2 emissions · Agriculture land conversion · Greenhouse gases · Land use change · Land cover

1 Introduction

Land use change (LUC) makes us face a dilemma. The effect of land use on the world has been demonstrated by several decades of research, ranging from changes in the composition of the atmosphere to extensive changes in Earth's ecosystems (Foley et al. 2015). Changes in land use can affect climate by changing net radiation, dividing energy into

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Extended author information available on the last page of the article sensitive and latent heat, dividing precipitation into water from soil and evapotranspiration, and dividing or sequestrating carbon (Lambin and Meyfroidt 2011; Foley et al. 2015; Pan et al. 2011; Kuklickea and Demerittb 2016). The US National Research Council (Norwegian Refugee Council (NRC) 2005) has already suggested that climate change (CC) expansion should be included as a major climate force in land use and land cover processes. Apart from changing the mean atmospheric composition due to growing greenhouse gases, the NRC report says that landscape variations could have significant local, regional, and global impacts (Paul 2010). LUC is already recognized as a major driver of global climate change (Lambin and Meyfroidt 2011; Foley et al. 2015; Hendrix 2017; Beckman and Thi Nguyen 2017). A climate analysis in the USA shows that a significant proportion of the increases in temperature in the last few decades have resulted from changes in land use (Kalnay and Cai 2003). LUC has also been involved in changing China's regional climate where the daily range of diurnal temperatures has fallen due to urbanization (Zhou et al. 2004; Bastakoti et al. 2016). LUC affects regional climates due to surface energy and water balance changes (Hurtt et al. 2011). Feddema et al. (2001) highlighted the impacts that LUC could have on regional climates in the twenty-first century. LUC has also changed air quality through emissions alteration and changes in air conditions and plays an important role in changing the global carbon cycle (Hurtt et al. 2011; Foley et al. 2015). Since 1850, LUC has accounted for approximately 35% of total anthropogenic carbon dioxide (CO_2) emissions (Foley et al. 2015).

Moreover, CC has brought up new challenges for global land use (Lobell et al. 2008; Gongmei et al. 2009). Climate change is one of the major environmental issues the world is facing today (Apata et al. 2009). There is significant evidence that since the mid-nineteenth century, the earth has become increasingly warm. While the average global temperature increased by 0.8 °C in the 1850s, the average temperature could increase by 1.8–4.0 °C compared with the previous century (Wheeler and von Braun 2013). The level of atmospheric CO_2 contributes significantly to high greenhouse gas (GHG) levels in the atmosphere and global warming and leads to an increase from about 284 ppm in 1832 to 399.6 ppm in 2016 (Ministry of the Environment, Government of Japan (MOEJ) 2016). Several studies have already explored LUC in terms of biophysical circumstances, under current and future climate conditions. These studies have indicated that climate is an important driver of LUC in general (United Nations Environment Program (UNEP) 2014; Huang et al. 2015), and agricultural land conversion (ALC), in particular (Schmidhuber and Tubiello 2007; Lobell and Field 2007; Schlenker and Lobell 2010; Dey et al. 2017). CC, largely caused by increased emissions of GHG, poses more threats to land use compared with previous decades. Human activities are known as the main drivers for GHG emissions (Hurtt et al. 2011; Wheeler and von Braun 2013; Intergovernmental Panel on Climate Change (IPCC) 2014; Amos et al. 2015). Significant CO_2 emission sources include biomass-burning emissions from forest fires, savanna fires, agricultural waste burning, and peatland fires that have a significant impact on ecosystem productivity, global atmospheric chemistry, and CC (Vadrevu et al. 2014). In the context of an increasing population, these effects might even become worse.

Overall, LUC and CC are dependent together. Many studies have indicated that climate is an important factor in land use change (Schmidhuber and Tubiello 2007; Lobell and Field 2007; Schlenker and Lobell 2010), and these studies have been supported by the finding that CC is the main driver for LUC. Moreover, Jetz et al. (2007) projected the overlap between climate change and LUC. In their study, land cover change is expressed by land use change and total CO_2 emissions, and the change in average annual temperature is expressed by climate indicators. Their results show that LUC and CC are strongly interlinked. However, these studies do not specifically mention CO_2 emissions as an outcome of LUC or vice versa. In addition, there are significant differences in the intensity of correlation between climate indicators and LUC in different regions (UNEP 2014). The changes between countries and regions must also be taken into account in the context of world trends and increased trade (UNEP 2014).

Chowdhury et al. (2019a, b) applied energy, exergy, and sustainability analysis and provided suggestions to improve the sustainability of the commercial sector of Bangladesh. Data from 2000 to 2014 were analyzed, and it is found that the estimated energy efficiencies range from 65.42 to 68.5%, while exergy efficiencies range from 10.79 to 11.49%. Mascarenhas et al. (2019) performed a comprehensive analysis on energy performance, exergy efficiency, CO_2 emission, sustainability, and the associated economic implications. The study has demonstrated that exergy and sustainability analysis could be applied to identify inefficient and redundant compressors to assist decision makers in the industrial environment. Chowdhury et al. (2019a, b) analyzed the relationship between exergy and sustainability of industrial sector. Based on the energy consumption data from the year 2000 to 2015, energy, exergy, and sustainability analyses are performed. It is found that the energy efficiency varies from 55.01 to 59.67%, and exergy efficiency varies from 53.11 to 56.97%.

Human-induced LUC has several dimensions such as the conversion of natural forests and grasslands to cropland and pasture, land conversion for urbanization, or forestry practices (Kalnay and Cai 2003). According to Kalnay and Cai (2003), agriculture already occupied roughly 38% of the Earth's land surface and used the most suitable areas available (Ramankutty et al. 2008). It is estimated that the world population will reach 9 billion by 2050 (Kings and Ilbery 2011). At the same time, productivity rises to lower levels compared to past decades, because agriculture today is a major driver for many adverse environmental impacts, including climate change, biodiversity loss, and land and freshwater degradation. This will pose additional pressure on agriculture and might result in further conversion of natural grasslands and forests into cropland and pasture. Deforestation is a severe issue, especially in the tropics where Gibbs et al. (2010) reported that 83% of the establishment of new agricultural areas during the two last decades of the twentieth century has happened at the expense of forests. Despite the huge impact of LUC on CC, Kuemmerlen et al. (2015) believed that the impacts of LUC on CC have rarely been taken into account. According to them, to preserve lives on earth, both changes in global climate and land use must be considered simultaneously. Moreover, it is still unknown to what extent the described dimensions of LUC affect CC, especially the LUC for agricultural activities known as ALC. Given the importance of global agriculture in food security and global climate for agricultural sustainability, this study aims to: (1) estimate changes in ALC and CC at global and regional levels, (2) portray the distribution of these changes throughout the globe, and (3) explore whether and to what extent ALC and CC are intercorrelated in different regions.

2 Methodology

This research is based on secondary data. CO_2 was considered as the main driver of CC, and ALC was regarded as the main driver of LUC. Global datasets for CO_2 emissions and ALC from 1962 to 2011 were elicited from the World Bank (2012) and FAO (2015), respectively. The main reasons why this time interval was considered for the analysis were the availability and possibility of common data for both indicators. In other words, there may be some updated data for either of indicators, but not for both, that make the analysis impossible. Besides, no other reliable dataset was available beyond this range. In total, 190 countries were found with both CO_2 emissions and ALC recorded data. Considering the FAO (2015) classification, the countries were distributed into five different groups: high-income non-OECD (the Organization for Economic Co-operation and Development), high-income OECD, high-middle-income, lower-middle-income, and low-income countries. Economies were divided into several income groups according to 2014 gross national income (GNI) per capita. The groups are low income ($1045 or less), lower middle income ($1046–4125), upper middle income ($4126–12,735), and high income ($12,736 or more) (FAO 2015). Data were analyzed by Statistical Package for the Social Sciences (SPSS) and Geographic Information System (GIS) software.

3 Results and discussion

3.1 Changes in agricultural areas at a global scale

Figure 1 illustrates how the land used for agricultural purposes has changed from 1962 to 2011 at a global scale. This includes, on the one hand, the land that has been converted into agricultural cropland and pastures (e.g., from natural forests and grasslands) and, on the other hand, agricultural land that has been converted into other uses (e.g., urban areas, national and natural parks, roads, industrial areas, and afforestation projects). It can be observed that agricultural areas are rather declining in the northern hemisphere and industrialized countries (e.g., Europe, Canada, and Australia), whereas they are rather increasing in the southern hemisphere, mainly in developing countries, and especially in the tropical belt (e.g., Brazil and Southeast Asia). This is in line with what Lepers et al. (2005) described in their study. According to their research, cropland rather decreases in temperate areas (e.g., Eastern USA) and rather increases in the tropics (e.g., Southeast Asia). Conversion to agriculture is still taking place in some countries, such as the USA, but it is outstripped by conversion from agriculture (e.g., to urban development) (Fisher 2014).

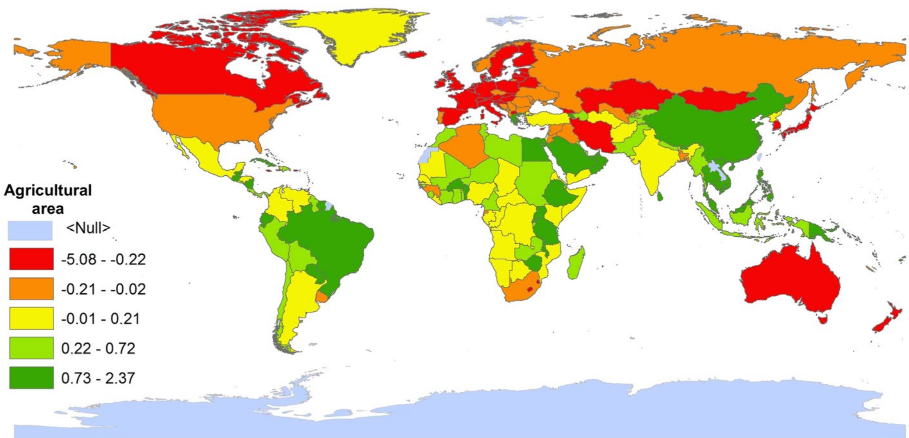

Fig. 1 Average of annual changes in agricultural areas per country (1962–2011); unite (%)

According to UNEP (2014), deforestation and other land degradation problems are causing serious problems in a way that around 23% of global soils are estimated to be degraded. The so-called hot spots are mainly located in the tropics (e.g., the Amazon region), and they are largely urbanized as well.

In recent decades, as noted by Lambin and Meyfroidt (2011), only a few countries have managed a land use transformation in line with their forest cover and agricultural production. The area of agriculture has expanded over the last five decades, at the expense of forests in tropical regions in particular. Over half of new farmlands throughout the tropics came at the expense of intact forests over the 1980–2000 period, and another 28% came from disturbed forests (Lambin and Meyfroidt 2011). There are regional differences (UNEP 2014), with increased forest areas in Europe and North America since 1990, and high losses for forest areas of South America, Africa, and Southeastern Asia.

Table 1 shows the average annual changes in agricultural areas according to income strata between 1962 and 2011. As shown in the table, the agricultural areas have been decreasing in high-income countries showing that agricultural lands are principally being converted to forests. This is in line with what Fisher (2014) shows for the Eastern USA, where significantly more agricultural lands are being converted to forests than vice versa. According to UNEP (2014), forest areas in Europe and North America are increasing.

Table 1 also shows that in low- to upper-middle-income countries, agricultural areas have risen. Moves toward more protein-rich diets in middle-income countries, particularly in developing countries, and the increasing demand for biofuels and biomaterials are increasing the demand for land (Fargione et al. 2008). The global yield growth for cereals and primary cultures, in general, has slowed down since the 1960s (UNEP 2014), and most experts expect a continuing drop compared to past accomplishments. There are quite uncertain future yield projections, and a number of factors will be affected (e.g., climate or soil degradation). Ray et al. (2013) reported that to date, the levels of intensification are not sufficient to meet the predicted food requirement by 2050. Limited yield growth implies the expansion of agricultural lands in developing countries that must be met by future demand. In addition, population prospects predict the world population to increase to around 9.2 billion in 2050 (Kings and Ilbery 2011). Less developed areas will make the most of this increase (UNEP 2014). The supply of food to these people will require a rise in agricultural areas in normal working conditions. Moreover, as explained by Share The World's Resources (STWR) (2012), some capital-rich states have started purchasing or leasing foreign lands to produce food and biofuels. Mostly in Africa, Asia, and Latin America, they have started agricultural externalization (Azadi et al. 2012, 2013). Furthermore, environmental regulations get tighter in capital-rich countries (Fisher 2014), which creates possible incentives for outsourcing agriculture to poorer countries (South Asia,

Table 1 Average of annual changes in agricultural areas according to income strata (1962–2011)

Income group	Mean	*F*	Sig.
ANOVA			
High income, non-OECD	−.4306[a]	10.706**	.000
High income, OECD	−.3387[a]		
Upper middle income	.2523[b]		
Lower middle income	.3811[b]		
Low income	.5051[b]		

**$p < 0.01$

[a,b]Common letters show nonsignificant means

sub-Saharan Africa, Middle East, North Africa, Latin America, and the Caribbean) with fewer restrictions. Another major driver is urban development in many countries, especially in developing countries, where urbanization grows the fastest. Developed countries are managing their urbanization process; therefore, they have the least impact (Sklenicka 2002; Azadi et al. 2011a). Approximately, half of the world's population lived in cities in 2010. By 2050, this share is anticipated to rise to nearly 70%. Between 2010 and 2050, the urban population is estimated to almost double in developing countries (UNEP 2014). A combination of urbanization, increased income, and shifting diets will increase agricultural land requirements significantly (UNEP 2014). In addition, energy and water demand is expected to grow by using the Earth's resources even more (Hurtt et al. 2011).

3.2 Climate change

Figure 2 displays the average of the CO_2 emissions (tons per capita) in the world during 1962–2011. It can be observed that the emissions strongly vary across the globe, ranging from 0.03 up to 56.61 tons per capita. The emissions majorly increased in the northern hemisphere and industrialized countries (e.g., Europe, Canada, Australia, and Russia), moderately in the USA and most of Latin America, and slowly in sub-Saharan Africa and Southeast Asia. This is in line with different studies (Wei et al. 2012; Ward and Mahowald 2014), which state that the northern hemisphere and industrialized countries (e.g., Europe, Canada, and Australia) are known to provide a large source for atmospheric CO_2, whereas the emissions are generally lower in the southern hemisphere and developing countries, especially along the tropical belt in Africa and Asia.

Table 2 shows the average of the CO_2 emissions according to income strata from 1962 to 2011. When divided by income strata, the highest growth in per capita emissions can be observed, especially in high-income countries, whereas the lowest growth happened in the low- and lower-middle-income countries. Similarly, Henriques and Borowiecki (2017) found the high-income countries to be highly related to CO_2 emissions. Wei et al. (2012) showed that in developed countries, historic CO_2 emissions from fossil fuel consumption and cement production contributed to the 62% increase in global mean surface temperature. Nevertheless, Pao and Tsai (2010) estimated that developing countries' CO_2 emissions will

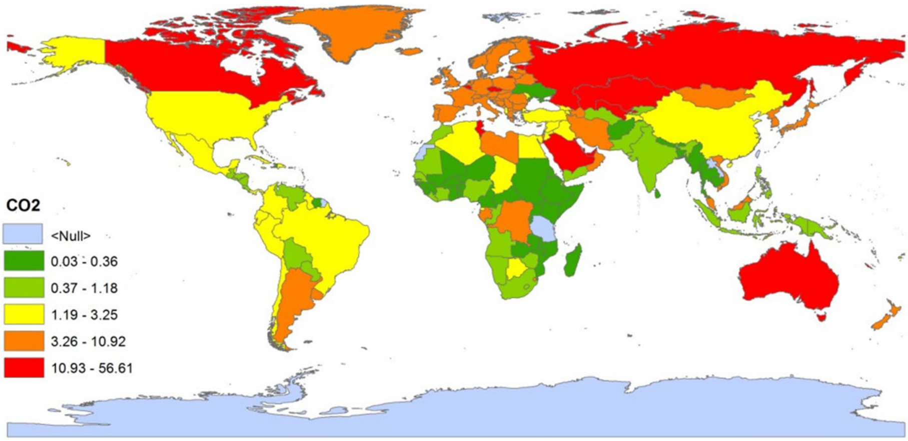

Fig. 2 Average of CO_2 emissions (tn3 per capita) per country (1962–2011)

Table 2 Average of CO_2 emissions (tn3 per capita) according to income strata (1962–2011)

Income group	Mean	F	Sig.
High income, non-OECD	11.1194[a]	26.937**	.000
High income, OECD	9.1966[a]		
Upper middle income	3.2001[b]		
Lower middle income	.9497[b,c]		
Low income	.3689[c]		

**$p < 0.01$

[a,b,c]Common letters show nonsignificant means

be greater than those in developed countries as developing economies continue to expand at a fast pace. High-speed industrialization and development in developing economies require high energy consumption, which leads to increased fuel demand (Nguyen et al. 2011; Zhong et al. 2011). The majority of developing countries are striving for energy and environmental development, which means that development is prioritized over the environment and automation to improve productivity (Azadi et al. 2011b). According to Ward and Mahowald (2014), developing countries' CO_2 emissions (mainly China and India) will exceed around 2030. One of the world's largest greenhouse gas gourmet emitters is China (Azadi et al. 2011b), but since the introduction of its 115 plans in 2006–2010, it has incorporated various climate change and energy efficiency policies. These include activities for economic, social, industrial, and energy conservation, efficiency as well as alternative energy measures (Pao and Tsai 2010).

3.3 CO_2 emissions and ALC overlap

Figure 3 shows the overlap between the increase in CO_2 emissions and changes in agricultural areas between 1962 and 2011. As shown in the figure, agricultural areas have been declining where CO_2 emissions have been increasing. On the contrary, agricultural areas have been increasing where CO_2 emissions have been declining. In this context, our findings are in line with the findings of other scholars such as Schlenker and Roberts (2009) and Tasser et al. (2017) whose emphasis has been on the existence of a negative correlation

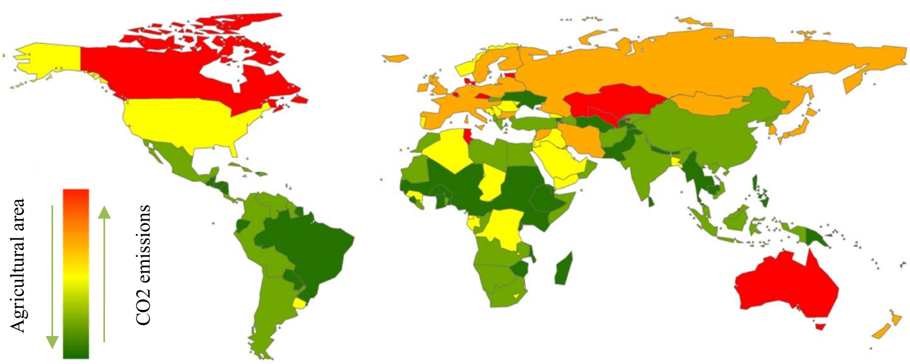

Fig. 3 Pattern of changes in agricultural areas (% annual change) and CO_2 emissions (tn^3 per capita) in 1962–2011

between CO_2 emissions and LUC. However, the severity and the type of influence of land use change on CO_2 emission differ among countries with different income levels. Similarly, Jetz et al. (2007) projected the overlap between climate change and land use change by 2100. Their result shows a change in land cover due to land use and climate change. CO_2 emissions can directly affect ALC in many ways. CO_2 emissions can induce land degradation (Simonneaux et al. 2015). Land degradation refers to degrading the environmental quality and losses of land resource potential and productive capacity, which could lead to the expansion of agriculture into new areas (UNEP 2014). According to Zhang and Cai, climate change will cause reductions in arable lands.

ALC can increase CO_2 emissions by disturbing soils and vegetation, and deforestation is the main driver, in particular when agriculture is taken up (UNEP 2014). Therefore, as many scholars have emphasized (Popp et al. 2012), LUC is a massive source of CO_2 emissions, and these changes contribute significantly to global warming and atmospheric changes. The loss of land cover and other land use changes, as reported by Hurtt et al. (2011), could exacerbate the crisis of extinction and cause further changes in climate conditions. Wheeler and von Braun (2013) have also pointed out that climate change can be caused by human activities, emission of greenhouse gasses such as CO_2 and methane, and changes in land consumption. Additionally, the study confirms the result of previous studies by Bussi et al. (2016) and Tasser et al. (2017), according to which, there is a strong relationship between climate change and land use change.

4 Conclusions

Agricultural areas have strongly changed from 1962 to 2011, showing large regional differences. Results indicate that agricultural activities in high-income countries have decreased, while in low- to middle-income countries, they have increased. In low- to upper-middle-income countries, deforestation, land degradation, and agricultural outsourcing are among the main drivers for the increase in agricultural lands. At the same time, poorly managed agricultural lands and lack of transparent environmental regulations have resulted in a declining availability of lands suitable for food production. Furthermore, population growth, growing demand for food, urbanization, and changing diets are increasing the demand for land resources in low- to upper-middle-income countries which will result in further land use changes in the future. As Fisher (2014) mentioned, it is important to ensure that existing high-quality farmland is being farmed in the future applying sustainable practices instead of changing its use, and this accelerates habitat loss.

The results show that the largest growth of CO_2 emissions will occur in high-income and low-middle-income countries, respectively. Indeed, it should be a priority for all governments around the world to reduce greenhouse gases. High-income countries need upgrades in technology, industrial structures, and rules to manage energy and inflation and gradually reduce energy dependency and carbon emissions. Therefore, environmental protection and emissions regulations need to be robust and stringent. The downside is that the consumption of energy may be a limiting factor in economic growth. These findings suggest for low- and low-middle-income countries that decision makers take environmental aspects into account when planning their development strategies to achieve sustainable development with less growth in greenhouse gas emissions. The results further show that there is a positive relationship between CO_2 emissions and ALC across the world. It can be observed that CO_2 emissions are increasing where agricultural area is declining. On the contrary, CO_2 emissions are declining where agricultural area is increasing. Clarifying the cause of LUC may serve as a policy decision template and alleviate concerns over the potential negative effects of CO_2 and land use changes on agriculture.

As noted by Lambin and Meyfroidt (2011), only a few developing countries such as China, Vietnam, India, Bhutan, Costa Rica, El Salvador, and Chile have managed a land use change over the recent decades. These countries simultaneously increased their forest cover and agricultural production. Then, we need to focus more on nature-based solutions, such as forest landscape restoration. The restoration is key in building and maintaining sustainable and resilient food systems and ecosystem services. It is also recommended that raising public awareness on land use and climate change is crucial.

Land use change as human activities influences the exchange of greenhouse gases and hence has an impact on climate change. Therefore, governments should have sustainable land management systems. Sustainable land management is the road to implement the principle of sustainability and effective climate protection in the political and administrative practice of dealing with a country. It covers the protection, conservation, and restoration of land, soil, water, and other related natural resources. Sustainable land management can also protect and enhance biodiversity in the interests of the conservation of life on earth.

The issues of land use and climate change are critical for human well-being. Given the fact that the sources of CO_2 emission change over a long period of time, further studies should be conducted with added variables and longer time intervals. This study relied on World Bank datasets for CO_2 emissions, but in the future, other variables such as changes in the sea level and urbanization should be added to the land use variables for longer time intervals. Human life index and income sources could be added to the economic variable and greenhouse gas emissions excluding CO_2, which should be added to climate change variables. Generally, from the perspective of land management, the actual land use, utilization, ownership, and political/administrative priorities are the decisive factors. Such factors can address the global land use problems, the land management counterpart, and the conflict between use and protection. Arable lands, irrigated lands, forest areas, and economic needs are the essential points to be considered for proper land management. It is recommended that raising public awareness on land use and climate change is important. The change in land use has many faces as cornfields are forcing meadows and pastures, tropical rainforests are cleared for oil palm trees or hedgehogs, and steppes are broken down into arable land. The reasons are complex, and the effects are often fatal like the change in animal and plant communities, the disappearance of ecosystem functions, and the contribution of carbon emissions to climate change. What happens on a regional scale has a worldwide impact in a way that clearing a forest in one village can have a global impact on CC.

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