Sustainability Science (2019) 14:1657–1672
https://doi.org/10.1007/s11625-018-0650-6

ORIGINAL ARTICLE

Synergy potential between climate change mitigation and forest conservation policies in the Indonesian forest sector: implications for achieving multiple sustainable development objectives

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Received: 1 July 2018 / Accepted: 6 December 2018 / Published online: 15 December 2018

Abstract

There has been growing interest in achieving multiple Sustainable Development Goals (SDGs) by identifying effective interactions or synergy potential among measures/policies on sustainable development. The simultaneous implementation of climate change mitigation (SDG 13) and forest protection (SDG 15) is an example of an interaction where the measures/policies that contribute to both goals can be identified and the overlaps eliminated. However, there are limited studies that quantitatively evaluate the synergy potential in the forest sector. This study is the first attempt to examine the synergy potential in the forest sector in Indonesia focusing on climate change mitigation and forest protection. We evaluated four scenarios that differentiated climate and forest policy options and assessed the effectiveness of implementing these two policies simultaneously by 2030, using a computable general equilibrium model and a land-use model. We found that the additional efforts needed for emission reduction were larger for the scenario not considering forest protection than for that considering forest protection. This caused differences in the mitigation measures introduced and the resulting land use that depended on the scenario. Consequently, mitigation costs would be reduced by implementing mitigation and forest protection policies simultaneously, suggesting that the synergy effect in the forest sector in Indonesia does exist. This also implies simultaneous contributions to SDGs 13 and 15 (Targets 13.2 and 15.2). To realize such synergies, which have not yet been considered, it is necessary for policymakers to fill the institutional gaps between the policies/strategies of mitigation and forest conservation and enforce the policies for SDGs.

Keywords Climate change mitigation · Forest conservation · Synergy · Indonesia · AFOLU model · Computable general equilibrium model

Introduction

Seventeen Sustainable Development Goals (SDGs) in the 2030 Agenda for Sustainable Development were adopted at the United Nations (UN) Sustainable Development Summit in 2015 (UN General Assembly Resolution A/RES/70/1). The SDGs include goals for climate action (SDG 13) and life of land (SDG 15), which call for a halt to deforestation. There has been growing interest in achieving multiple SDGs by identifying effective interactions among SDGs, including goals for climate action and life of land (Nilsson et al. 2016; Stafford-Smith et al. 2017). Such information is necessary for policymakers to formulate coherent policies and strategies for achieving SDGs, which minimize negative effects from trade-offs and avoid duplication among SDGs-related measures.

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Forest conservation, which is an important agenda for both developed and developing countries, has been addressed under various platforms including climate change mitigation and halting deforestation. However, because gaps exist between discussions on climate change mitigation and on halting deforestation, it is important to bridge these gaps, using forest conservation to effectively and efficiently tackle both climate change and deforestation. This study aimed to bridge the gaps at the national level applying quantitative approaches for the country of Indonesia, which urgently requires forest conservation.

International situation

Because there is no international convention on forest issues, forest conservation has been addressed under different international environmental regimes,[1] such as the UN Framework Conventions on Climate Change (UNFCCC) (United Nations Framework Convention on Climate Change 2018a), Convention on Biological Diversity (Convention on Biological Diversity 2018a, b), UN Convention to Combat Desertification (United Nations Convention to Combat Desertification 2015, 2018), and UN Forum on Forests (United Nations Forum on Forests 2018). As mentioned above, SDGs 13 and 15, which are international aspirational goals, are also important to enhance forest conservation measures.

Among these international environmental regimes, UNFCCC (related to SDG 13) and halting deforestation (related to SDG 15) are currently the primary platforms for discussing forest conservation. Under the UNFCCC, main discussions in the forest sector are on the effects of greenhouse gas (GHG) emission reduction and sinks under agendas related to "reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries (REDD+)" and "land use, land-use change and forestry (LULUCF)" (Pistorius et al. 2017). The Paris Agreement, adopted in 2015 under the UNFCCC, shows the importance of taking action to conserve and enhance sinks and reservoirs of GHGs, including forests, and the importance of REDD+ (Article 5). Furthermore, the Paris Agreement requires each party to prepare, communicate, and maintain the successive Nationally Determined Contributions (NDCs) that it intends to achieve (Article 4). In the first NDCs, developed and developing countries which have the potential to enhance and protect sinks and reservoirs of GHGs through the LULUCF sector, such as Japan, New Zealand, Indonesia, and Brazil, clearly described the importance of mitigation measures in the LULUCF sector (United Nations Framework Convention on Climate Change 2018b).

Another important element for forest conservation is the goal to halt deforestation under the SDGs and the UN Secretary-General's Climate Summit. As mentioned above, SDG 15 calls for halting deforestation by stating the following: "by 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests, and substantially increase afforestation and reforestation globally" (United Nations 2018). Before that, the New York Declaration on Forests, which is a non-legally binding political declaration pledging to at least halve the rate of loss of natural forests globally by 2020 and strive to end natural forest loss by 2030, was launched in 2014 at the UN Secretary-General's Climate Summit (New York Declaration on Forests Global Platform 2014). Currently, companies set voluntary deforestation targets, and there are memberships such as the Consumer Goods Forum that have agreed to achieve zero net deforestation by 2020 through responsible sourcing of key commodities, such as soy, palm oil, paper and pulp, and cattle (Consumer Goods Forum 2018). After the Consumer Goods Forum committed to zero net deforestation, the forum partnered with the US government in 2013 to create the public–private Tropical Forest Alliance 2020, with the mission of mobilizing all actors to collaborate in reducing commodity-driven tropical deforestation (Tropical Forest Alliance 2020 2018). In the same year, the Banking Environment Initiative and Consumer Goods Forum's Soft Commodities Compact was adopted, which is a unique client-led initiative that aims to mobilize the banking industry as a whole to contribute to transforming soft commodity supply chains, thereby helping corporate clients to achieve zero net deforestation by 2020 (Cambridge Institute for Sustainability Leadership 2015). Zero-deforestation movements are present in countries such as Indonesia (Pirard et al. 2015) and Brazil (Instituto de Pesquisa Ambiental da Amazônia 2017), and also in multinational companies, such as Unilever (2018) and Danone (2016).

Policies and strategies for forest conservation in Indonesia

In Indonesia, CO_2 emissions from the land-use sector are largest in the world (Food and Agriculture Organization 2018) and the land-use sector also dominates its GHG emissions (Wijaya et al. 2017). Furthermore, Indonesia had the highest rate of increasing forest cover loss from 2000 to 2012 and primary forest loss was 6.02 million ha in total over that period (Margono et al. 2014). Therefore, Indonesia is a good example of a country that requires effective and efficient implementation of forest conservation in terms of climate change mitigation and halting deforestation. Indonesia

[1] International regimes are defined as sets of implicit or explicit principles, norms, rules, and decision-making procedures around which actors' expectations converge in a given area of international relations (Krasner 1982).

promotes the implementation of REDD + and emphasizes the importance of LULUCF in the NDCs (Republic of Indonesia 2016). In addition to tackling climate change, Indonesia is fully committed to achieving all SDGs including SDG 15 (Ministry of Environment and Forestry 2018), and various measures have been implemented to address deforestation. Zero-deforestation commitments are rapidly emerging in this country (Pirard et al. 2015), including the commitments of the Indonesian palm oil sector to zero deforestation such as "No Deforestation, No Peat, No Exploitation" (Pacheco and Komarudin 2017). Other measures for reducing deforestation have also been implemented such as prevention of forest fires and restoration of the peat ecosystem (Ministry of Environment and Forestry 2018). In Indonesia, both climate change measures and halting deforestation are addressed by one ministry, the Ministry of Environment and Forestry, established by merging the Ministry of Environment and the Ministry of Forestry in 2014.

With regard to climate change mitigation, Indonesia accounts for one of the highest levels of GHG emissions, a large portion of which is from land-use change (Ministry of Environment 2010). In 2010, the Government of Indonesia pledged to reduce emissions by 26% (conditional target of 41% reduction with international support) against a business-as-usual scenario by 2020 (Republic of Indonesia 2016). Indonesia aims to achieve 87% of this goal by reducing emissions from deforestation and peatland conversion (Austin et al. 2014). In Indonesia, relevant legal and policy instruments have been promulgated, including a national action plan on GHG emission reduction (Presidential Regulation No. 61/2011), and on GHG inventory (Presidential Regulation No. 71/2011) (Republic of Indonesia 2016). According to Indonesia's Third National Communication of 2018, its total GHG emissions for the three primary GHGs (CO_2, CH_4, and N_2O), with the inclusion of LULUCF and peat fires, were 1,844,329 Gg CO_2e in 2014 (Ministry of Environment and Forestry 2017). Indonesia has taken significant steps to reduce emissions in the land-use sector by instituting a moratorium on the clearing of primary forests and by prohibiting conversion of its remaining forests through deforestation and forest degradation reduction, ecosystem function restoration, and sustainable forest management (Republic of Indonesia 2016). REDD + will be an important component of the NDC target from the land-use sector in Indonesia (Republic of Indonesia 2016), and the government has developed REDD + -related policy interventions, regulations, and actions (Ministry of Environment and Forestry 2017). REDD + activities in Indonesia have a potential to reduce emissions by up to 70% of the total planned emission reduction in the land-based sector (Ministry of Environment and Forestry 2017). However, reducing emissions to meet Indonesia's conditional target of a 41% reduction below business-as-usual levels would require even stronger efforts, including extending the country's forest moratorium, restoration of degraded peatland, implementation of energy conservation programs, and mitigation measures for other sectors and non-CO_2 GHGs (Wijaya et al. 2017).

In terms of SDGs, Indonesia has established an SDG Transition Secretariat in the Ministry of National Development Planning (Bappenas) and has sorted the goals, targets, and indicators of SDGs into the following four pillars: social, economic, environment, and law and governance (Bastos Lima et al. 2017). Bappenas conducted a mapping exercise for assessing SDGs against the goals and targets of the medium-term development plan (RPJMN) and has identified 108 of 169 matches (Bastos Lima et al. 2017). Technical guidelines for the SDG Action Plan have been completed. Although it was expected that Indonesia would complete a National SDG Roadmap and define national and sub-national SDG actions in 2017 (Bastos Lima et al. 2017), these will likely be completed in 2018.

Indonesia's major programs and approaches for achieving SDGs in the forestry sector are REDD +, social or community forestry that addresses social problems and contributes to improving communities' welfare, the Indonesian Timber Legality Assurance System that promotes the legal timber trade, the Ecosystem Restoration of Production Forest that is a new paradigm of forest production management that tries to restore degraded areas of production forests, and the Forest Management Unit that is a legally established permanent entity with clearly demarcated forest boundaries and clear economic, social, and ecological management objectives stipulated by long-term management plans (Rovani 2018). Furthermore, as mentioned above, zero-deforestation commitments are rapidly emerging in Indonesia, and they cover a large portion of crude palm oil production and almost the entire pulp and paper sector (Pirard et al. 2015). The values of the "No Deforestation, No Peat, No Exploitation" policies are reflected in the commitments (Pirard et al. 2015). Although the Indonesian palm oil sector has committed to zero deforestation, recent oil palm expansion is already occurring more often in non-forest areas even in the absence of zero-deforestation commitments (Austin et al. 2017). In addition, there is a large area of potentially suitable land for oil palm that is not forested in Sumatra and Kalimantan, suggesting that zero-deforestation pledges may not constrain future plantation expansion in these regions.

In addition, in May 2011, Indonesia brought into effect a 2-year moratorium on new concessions to convert primary natural forests and peatlands into oil palm and timber plantations and selective logging areas (Austin et al. 2014). This 2-year moratorium has been extended three times and is still ongoing. The moratorium was introduced to ensure that agriculture growth goals (increasing the agricultural production of 15 major crops, including palm oil production, by 2020 from 2009 levels) will not be achieved at the expense of climate change goals (Austin et al. 2014). Indonesia's forest moratorium not only contributes to reducing deforestation, but it is the single policy with the largest mitigation potential, and if the policy is renewed through 2030 in its current form it could reduce emissions by approximately 188 $MtCO_2$ by 2030 (Wijaya et al. 2017).

As mentioned above, other measures for reducing deforestation have been implemented such as prevention of forest fires and restoration of the peat ecosystem (Ministry of Environment and Forestry 2018). Forest and land fires in Indonesia have attracted global attention since 1982, and significant forest and land fires occurred in 2007, 2012 and 2015 (Ministry of Environment and Forestry 2018). To prevent the haze pollution caused by forest and land fires, Indonesia ratified the ASEAN Agreement on Transboundary Haze Pollution (Ministry of Environment and Forestry 2018). In accordance with the agreement, specific targets related to forest and land fire control activities were set for the period from 2015 to 2019 (Ministry of Environment and Forestry 2018). The specific targets are intended to achieve goals such as ensuring the effective management of peatland areas which are particularly prone to forest and land fires, mainstreaming forest and land fire control programs, and eliminating and prohibiting the practice of burning to clear land in high-risk areas, particularly peatlands. Effective fire prevention efforts include prioritizing no-burn and zero-deforestation commitments in provinces with chronic fires, where the clearing of forests and peatlands for agricultural expansion needs to be contained (Chamorro et al. 2017).

Although there are various activities to prevent deforestation, there are continuing discussions on the real effects of existing zero-deforestation-related policies, such as concerns over a lack of significant improvements of the moratorium on logging (Coca 2018) and limited progress on the zero-deforestation commitments (Jong 2018). To enhance the effects of forest conservation in Indonesia, holistic policies and approaches to address climate change mitigation in the forest sector and deforestation are necessary.

Literature review on the relationship between climate change and forest, and purpose

Many studies have evaluated the impact of climate change mitigation, including in the land-use and forestry sectors (e.g., van Vuuren et al. 2011; Hasegawa et al. 2016a; Fujimori et al. 2016; Riahi et al. 2017; Matsumoto et al. 2018). However, only a limited number of studies (shown below) have addressed the links between climate change actions in the forest sector and forest conservation or protection policies. Here, we focused on studies which examine the relationship between climate change mitigation and forest conservation or protection.

The most important set of studies evaluated the carbon stocks of forests from various perspectives, such as strategies, international cooperation, and uncertainties. For example, Xu et al. (2018) examined the climate change mitigation potential of five individual strategies and their combinations in the forest sector in British Columbia. They showed a wide range of mitigation potential and found that both the magnitude and timing of mitigation varied across strategies with regionally different implementations of change. Bhan et al. (2017) evaluated the climate action commitments under the Paris Agreement of the BRICS countries (Brazil, Russia, India, China, and South Africa) and critically analyzed forestry sector-specific climate mitigation actions. They found a demonstrable focus on this sector, indicating its leading role in climate mitigation. Furthermore, south–south cooperation and knowledge sharing can bring about additional gains toward innovations in increasing carbon sinks, reducing emissions from forests, building tools for robust Safeguards Information Systems, and accessing climate finance instruments. Vauhkonen and Packalen (2018) assessed the magnitude of potential uncertainties due to changing climate and forest management on projections of carbon stocks in forest biomass in Finland until 2050, using an area-based matrix model. They found that climate- or management-induced growth improvements could increase carbon stocks by up to one-third at the end of the simulated period. Therefore, projections solely based on business-as-usual transitions and harvests could lead to inefficient decisions regarding future carbon stocks and harvesting possibilities.

Other studies focused more on the aspects of policy. Van Kooten (2018) developed a forest management model of the southern interior of British Columbia and examined forest conservation that prevents CO_2 emissions, and even-flow and commercial harvesting where timber is processed into long-lived wood products that store carbon and residuals for energy. The author found that the decision on which and how many forestry activities generated carbon offset credits was essentially a political decision rather than a scientific one. Hoberg et al. (2016) applied policy gap analysis to policies for GHGs and forest management in British Columbia, focusing on challenges posed by existing policies and opportunities for policy innovation to more effectively promote forest carbon mitigation. They showed that because the province had few policies explicitly targeting forests or the use of harvested wood products for carbon mitigation, forest carbon mitigation was an underexploited opportunity in the province. Although forest management policies had evolved in response to changing social values, it was time for jurisdictions to renew their forest policies to more effectively incorporate opportunities for carbon mitigation.

These studies quantitatively or qualitatively analyzed the relationship between climate change mitigation and forest conservation or protection, particularly the carbon stocks and sinks. However, none have approached the synergies between the mitigation and forest conservation.

In addition to the above studies on climate change mitigation and the forest sector, studies were also conducted on the relationship between land use (including agriculture, forestry, and other land use or the so-called AFOLU) and climate change actions, which are very relevant to the model we applied in this study (Ravindranath 2007; Hoa et al. 2014; Sayer et al. 2015, 2017; Hasegawa and Matsuoka 2015; Hasegawa et al. 2016b).

Focusing on related topics in Indonesia, Hasegawa et al. (2016a) investigated key mitigation options for achieving the midterm target of carbon emission reduction in Indonesia using a computable general equilibrium (CGE) model coupled with a land-based mitigation technology model. One of their findings suggests that to reduce carbon emissions for meeting the target, approximately 58% of total reductions should come from the AFOLU sector by implementing forest protection, afforestation, and plantation efforts. Graham et al. (2017) analyzed the cost-effectiveness of the four types of REDD + strategies in Indonesia using spatially explicit information. They found that when spatial variation in costs and benefits was considered, low-cost options emerged even for expensive strategies. In addition, funding strategies for emission reduction depended on the emission reduction target. Suwarno et al. (2018) explored possible effects of the forest moratorium policy in Indonesia, a significant component of the NDC, on land-use decisions of private companies and communities using an agent-based model. They found that the current implementation of the forest moratorium policy was not effective in reducing forest conversion and carbon emissions, because companies continued to invest in converting secondary forest on mineral soils and the moratorium did not affect community decision-making. Instead, a policy combining a forest moratorium with livelihood support and increasing farm-gate prices of forest and agroforestry products could increase the local communities' benefits from conservation. Schebek et al. (2018) simulated land-use changes and their effect on CO_2 emissions in Indonesia under three policy scenarios and different projections of palm oil production by 2020. They showed a large increase in deforestation and large CO_2 emissions in the case of no improvements in policy enforcement. Better and enhanced policy enforcement could bring significant mitigation effects in terms of land-use change because it could reduce deforestation. This implies that the current policies have a substantial potential to protect land resources against the growing pressure on land conversion in Indonesia.

As described above, there are studies on climate change mitigation and forest conservation or protection from various approaches and perspectives. However, no study has quantitatively evaluated the link or synergy between climate change mitigation in the forest sector and forest protection, which contributes to multiple SDGs, although an effective policy for tackling both climate change and forest issues is essential (Hoberg et al. 2016). A quantitative evaluation is indispensable for this study to explicitly compare and discuss if such a synergy occurs in the forest sector. Evaluation of the synergy potential in the forest sector will provide important information for policymaking, particularly for combating climate change, because land-use emissions are considerable throughout the world. Because land-use emissions are large and forest protection is also a significant issue in Indonesia, Indonesia is a highly suitable target on this kind of analysis. Morita and Matsumoto (2018a, b) have addressed potential synergies in climate change mitigation and biodiversity in the forest sector. However, the focus in their studies was institutional aspects with qualitative approaches. In this study, we aimed to quantitatively show one of the sustainable development policy instruments that can achieve multiple objectives simultaneously using economic and land-use models with future scenarios. Here, we have considered Indonesian climate change mitigation (SDG 13) and forest conservation (SDG 15) as a case study.

Methods

In this study, we first analyzed multiple scenarios that differentiate policy options and assessed the effectiveness of implementing the two policies simultaneously (i.e., the synergy potential) using economic and land-use models. We then discussed how synergies of these two areas were envisioned and described a policy framework for enhancing their synergies. It should be noted that this study does not conduct predictions or forecasts, rather we conducted scenario analyses. This means that we compared the results of multiple scenarios to evaluate the effect of policy considered in each scenario.

Study design

To assess the synergy potential of emission reduction in the forest sector and forest protection,[2] aiming to achieve multiple objectives for sustainable development in Indonesia under scenarios with different policies, here we adopted a modeling scheme combining the CGE model (Fujimori et al. 2012) and the AFOLU model (Hasegawa and Matsuoka 2015) that was previously employed by Hasegawa et al. (2016a, b) for Indonesian studies. Various CGE models have

[2] Forest conservation is the practice of planting and maintaining forested areas for the benefit and sustainability of future generations (Pawar and Rothkar 2015); therefore, this phrase was used in the previous section. However, because this study focuses on no deforestation, we use the phrase "forest protection" to explain our analysis.

been used for climate mitigation analyses (Fujimori et al. 2014a, b; Sands et al. 2014; Matsumoto 2015; Matsumoto and Andriosopoulos 2016; Matsumoto et al. 2016, 2018; Babatunde et al. 2017; Ren et al. 2018), but coupling these two types of model and conducting detailed analysis of emission reductions in the forest sector are still rare (Hasegawa et al. 2016a, b). Furthermore, this study is the first attempt to assess the synergy potential of climate change mitigation and forest protection quantitatively using such models. Using these two models, we evaluated four scenarios, which will be explained in "Scenarios." The CGE model is an economic model, which can evaluate the changes in the entire economic activities of the nation when implementing climate change mitigation. Because the model handles the economic activities in an aggregated manner, it cannot evaluate the AFOLU emissions in detail. The AFOLU model can evaluate GHG emission reductions and abatement costs in the AFOLU sectors by using detailed information on mitigation measures. However, the model cannot analyze economic conditions. To exploit the characteristics and compensate for the shortcomings, we applied these two models in this study. First, we used the CGE model, known as AIM/CGE, to provide future national-level land-use change and carbon prices under the four scenarios and input them into the AFOLU model. We then used the AFOLU model to evaluate the abatement cost, mitigation effects, and area used for mitigation measures under the given land-use scenario and carbon prices. Socioeconomic assumptions for the future, such as population, gross domestic product (GDP), consumer preference, and crop yields, were based on those by Hasegawa et al. (2016a, b). Figure 1 shows the scheme of our model analysis. Figure 2a shows the total GHG emissions in Indonesia for each scenario, which are used as inputs in the CGE model. Figure 2b shows the carbon prices under two climate policy scenarios, which are outputs from the CGE model and the inputs into the AFOLU model.

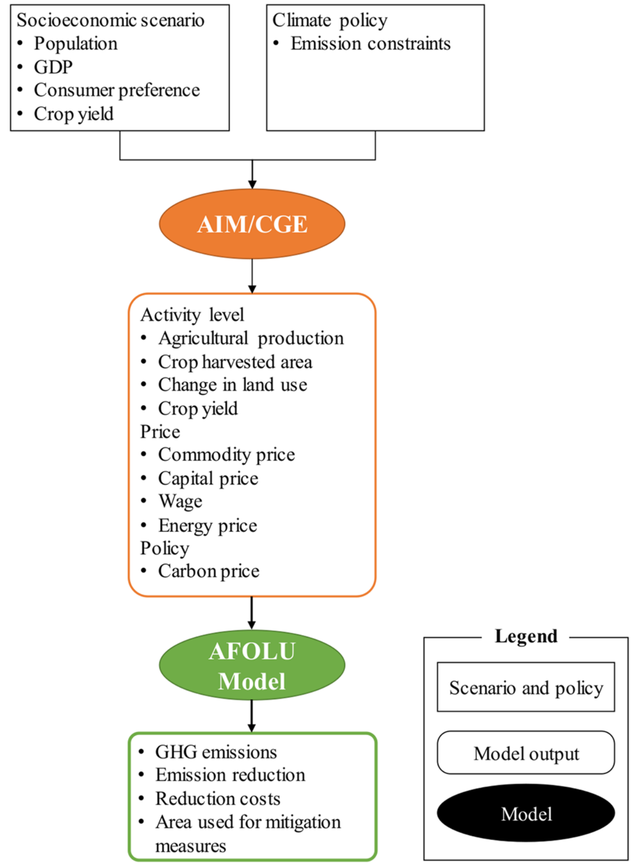

Fig. 1 Model framework coupling the AIM/CGE and AFOLU models. This figure is based on Hasegawa et al. (2016b)

The AIM/CGE model

Global and national AIM/CGE models have been built for the work in earlier studies (Fujimori et al. 2012, 2014a, b). In this study, the national model for Indonesia was used because we focused on a single country (Siagian et al. 2017). In the model, supply, demand, investment, and trade are described as individual behavioral functions that respond to changes in the price of production factors and commodities as well as changes in technology and preference parameters on the basis of assumed population, GDP, and consumer preferences.

The model contains 42 industrial classifications. Production functions were formulated as multi-nested constant elasticity of substitution functions, and household demand was formulated as a linear expenditure system function. Household behavior was described as utility maximization. To maximize a household's utility, food demand was changed in response to prices and income. Parameters of the formulas were calibrated using income elasticity of demand. Income elasticity of a commodity was derived from a marginal expenditure share parameter divided by an expenditure share of the commodity, which was defined as monetary consumption of the commodity divided by total expenditure (De Boer and Paap 2009). Consumer preference was described by the income elasticity of food demand. The income elasticity of demand for each commodity and adjustment parameters were calculated from per-capita food consumption and income projected by Bruinsma et al. (2006). The income elasticity for livestock products was changed according to the future income increase, whereas the value of crops was fixed. Future elasticity of livestock products was calculated using a function of the relationship between meat calorie intake and income estimated from time-series cross-country data (Hasegawa et al. 2015). Parameters were recursively updated to realize the assumed income elasticity.

Allocation of land across sectors was formulated as a multinomial logit function for reflecting differences in

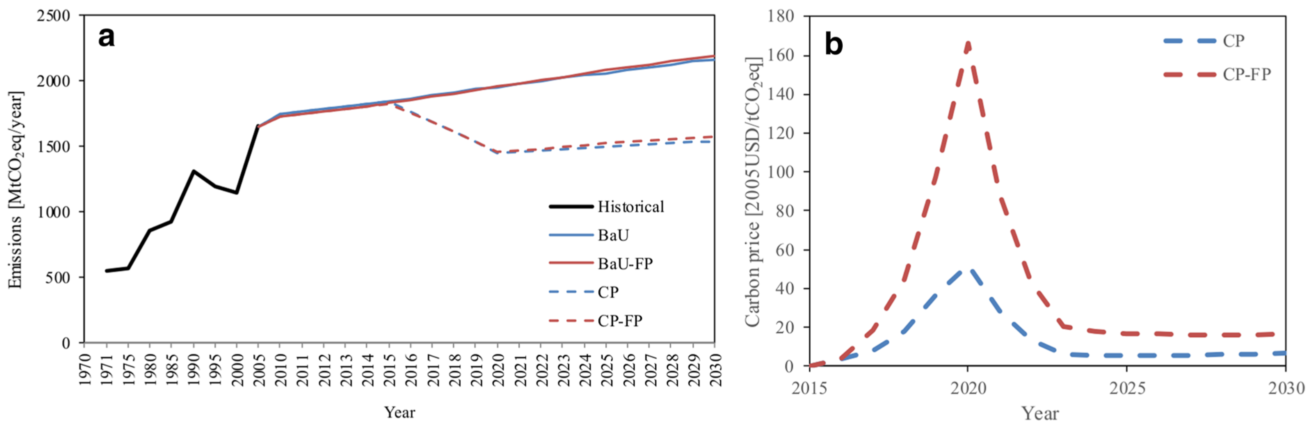

Fig. 2 **a** Pathways of total emissions (including fossil fuels, industry, and land use) for four scenarios and **b** resulting future carbon prices for climate policy scenarios in Indonesia. *BaU* business-as-usual, *BaU–FP* business-as-usual with forest protection, *CP* climate policy, and *CP–FP* climate policy with forest protection. Details of the scenarios are explained in "Scenarios"

substitutability across land categories with land rent. This function assumes that land owners in each agroecological zone decide on land sharing among the options, with land rent depending on the production on each land (i.e., crops, livestock, and wood products). The land rent of forest includes revenue from wood products and the price of the carbon stock. Carbon contents per unit forest area were assumed as a single value because Indonesia is in a single agroecological zone. Therefore, the forest area expands and the carbon stock in the forest increases under high carbon price in the climate change mitigation scenario. In the AIM/CGE model, carbon price is described as tax imposed on GHG emissions and placed on carbon stock in the forest (i.e., shadow price of GHG). Revenue from tax was received per household, although other approaches for dealing with the tax revenue can also be considered (e.g., subsidies for energy-saving devices and investment on research and development). GHG emissions from non-energy sectors were assumed to linearly increase along with the activity level. The GHG emission reduction ratio was assumed to increase along with increasing carbon price. The parameters of the function were based on those used by Lucas et al. (2007). See the study by Fujimori et al. (2012) for more details on the AIM/CGE model.

AFOLU model

The AFOLU model has been developed for assessing abatement costs and emission reduction in the AFOLU sectors at a country level (Hasegawa and Matsuoka 2015) and has been applied to some national analyses, including Indonesia (Hoa et al. 2014; Hasegawa and Matsuoka 2015; Jilani et al. 2015; Pradhan et al. 2017). This model evaluates GHG emission reductions and abatement costs of individual mitigation measures at cost minimization under a given carbon price and assumed future agricultural production and land-use changes. The model incorporates detailed information on mitigation measures using the following inputs: (1) future assumptions of production in agricultural commodities and area of land-use change in a baseline case, where emission reduction is not strongly addressed; (2) information on mitigation measures (e.g., cost, reduction effects, and lifetime; Table 1); and (3) policy scenarios on carbon tax. Cropland area and yields were calculated to meet given agricultural production levels. The model also considers forest fires, which are an important issue in Indonesia (Ministry of Environment and Forestry 2018). In the model, forest fires occur when forests are converted to agricultural land, and prevention of forest fires is incorporated as a measure against forest fire. Mitigation technology options are based on a previous study (Hasegawa et al. 2016b) (Table 1). See the study by Hasegawa and Matsuoka (2015) for more details on the AFOLU model.

Scenarios

To analyze the effects of forest protection on climate change mitigation efforts and costs in Indonesia, we considered the following four scenarios with two dimensions, which are climate change mitigation policy and forest protection (no-deforestation) policy, by 2030 (Table 2): (1) "BaU" is a baseline case representing business-as-usual with no climate change mitigation policy and no forest protection policy; (2) "BaU-Forest protection (FP)" targets no-deforestation as a forest protection policy by 2030 but has no climate policy; (3) "Climate policy (CP)" targets the national emission reduction targets by 2020 and 2030 but has no forest protection target; and (4) "CP–FP" includes both climate change mitigation and forest protection targets. The future socioeconomic scenario is based

Table 1 Mitigation measures in land-use sectors assumed in the AFOLU model. This table is created based on the study by Hasegawa et al. (2016b)

	Cost [USD/ha/year]	Mitigation effect [tCO_2/ha/year]			Maximum annual available area [1000 ha/year]	Technical potential area [1000 ha]
		CO_2	CH_4	N_2O		
Plantation—short rotation (PSR)	118[a]	13.6[b]	–	–	205[c]	12805[c]
Plantation—long rotation (PLR)	147[a]	18.9[b]	–	–	5.3[c]	1862[c]
Reforestation—fast growing species (RFS)	100[a]	30.9[b]	–	–	31[c]	1011[c]
Reforestation—slow-growing species (RSS)	132[a]	30.8[b]	–	–	93[c]	2908[c]
Forest protection (FP)	13[j]	405[d]	–	–	34[c]	14993[c]
Reduced impact logging (RIL)	78[a]	5.1[b]	–	–	100[c]	40062[c]
Enhanced natural regeneration (ENR)	27[a]	7.3[b]	–	–	133[c]	29130[c]
Prevention of forest fires (PFF)	13[j]	316[d]	28.6[d]	12.4[d]	30[c]	900[c]
Water management in peatland (WM)	18[i]	16.6[e]	–	–	150[g]	8823[h]
Peatland rehabilitation (PR)	17[k]	2.6[e]	–	–	100[g]	3000[g]
Agroforestry (AGF)	20[f]	43.5[f]	–	–	67[c]	2000[c]

All costs were calculated based on 10% discount rate

[a]Calculated from the cost for mitigation measures shown in the study by Boer (2001)

[b]Calculated from the mitigation potential of measures shown in the study by Boer (2001), Fig. 3, and lifetime of effect

[c]Based on land area used for mitigation measures in 2000–2030 and technically available areas shown in the study by Boer (2001), Tables V/VII, mitigation scenario

[d]Based on emission factor of fire or deforestation in Intergovernmental Panel on Climate Change (2006)

[e]Assumed such that the unit cost is similar to assumptions presented in Dewan Nasional Perubahan Iklim (2010)

[f]Based on the mitigation potential and cost of oil palm in the study by Boer et al. (2007)

[g]Assumed

[h]Total area of forest and cropland on peatland, calculated from the land transition matrix

[i]Based on Indonesia National Council on Climate Change (2012). Peat water management technology peat re-mapping

[j]Based on the mitigation cost of protection or conservation as described in the study by Sathaye et al. (2001), Table II

[k]Based on labor demand and wage assumed

Table 2 Scenario settings in this study

	Forest protection policy[b]	
	No forest protection	Forest protection
Climate policy[a]		
No climate policy	BaU	BaU–FP
Climate policy	CP	CP–FP

[a]Climate policy is emission reduction targets based on the Copenhagen Accord and the Paris Agreement

[b]The forest protection policy is a no-deforestation target

on the scenario described by Hasegawa et al. (2016a, b). As climate policy (mitigation targets), we assumed the Indonesian national target of total GHG emission reduction by 26% by 2020 and by 29% by 2030 from BaU levels unilaterally (Fig. 2a). The Indonesian government pledged the 2020 target at the Copenhagen Accord, which was noted in the UNFCCC conference of the parties in 2009, whereas the 2030 target is the emission reduction targets in the Indonesian first NDC aligned with the Paris Agreement, adopted in 2015. The effects of the forest protection policy can be assessed by comparing the scenarios with and without the forest protection policy, whereas the

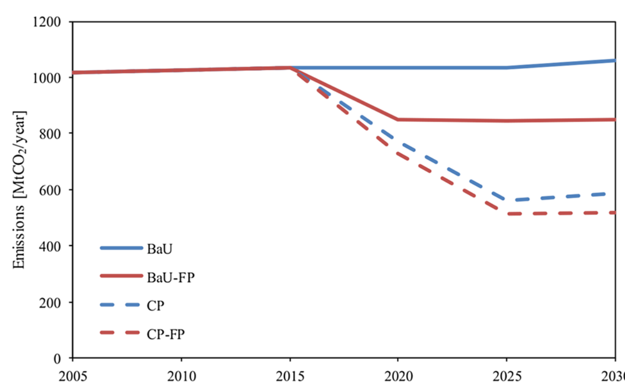

Fig. 3 Pathways of CO_2 emissions from land-use change for the four scenarios

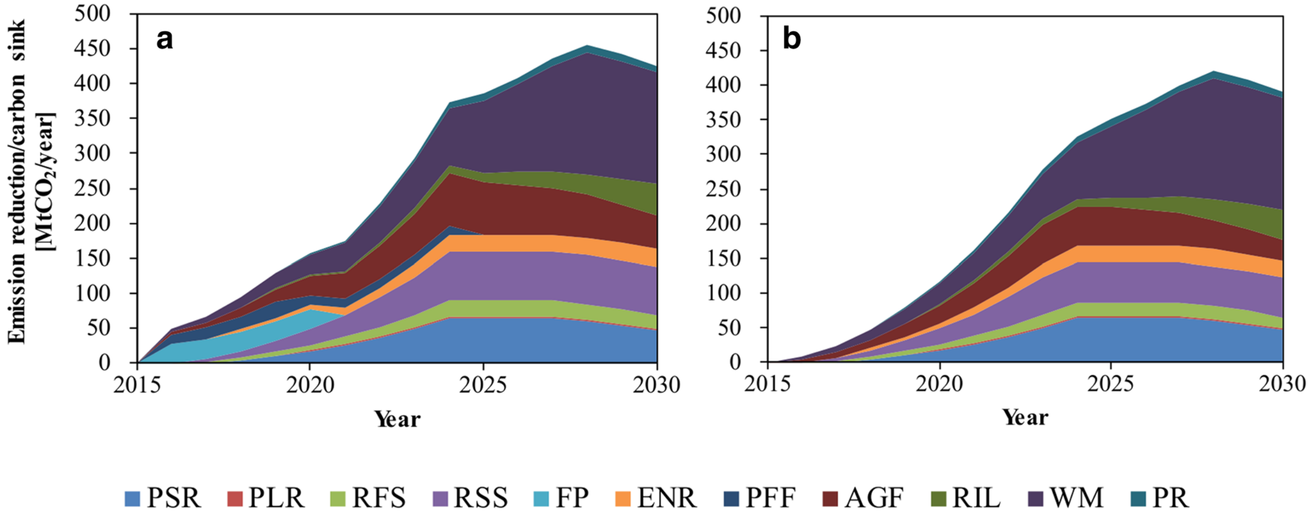

Fig. 4 Emission reduction in the forest sector by mitigation measures. **a** CP scenario and **b** CP–FP scenario. Emission reduction in the CP scenario is that from the BaU scenario, whereas emission reduction in the CP–FP scenario is that from the BaU–FP scenario

effects of climate policy are extracted by comparing those with and without climate policy. In addition, declines in forest area due to illegal logging, shifting cultivation, and transmigration were exogenously assumed by adding to a baseline land-use change. In no-deforestation scenarios, declines in forest area were assumed to be zero.

Figure 3 shows emissions from land-use change for the four scenarios. To achieve the Indonesian emission reduction targets, more emission reductions from land-use change are needed for the CP–FP scenario than for the CP scenario.

Results and discussion

To achieve the emission reduction target in the forest sector in Indonesia, which has been described in "Scenarios," 11 types of mitigation measures were considered in the model, as shown in Table 1. Figure 4 shows the contribution of each mitigation measure to emission reduction in the forest sector.[3] Overall, similarities in the choice of mitigation measures were seen between the CP and CP–FP scenarios, although there were some different trends in the early years. In both scenarios, water management in peatland was the major mitigation measure for emission reduction, particularly in the middle to the later years (161 $MtCO_2$ in 2030 in both scenarios). This is because water management in peatland is one of the lowest-cost measures, and its annual available and technical potential areas are larger than those areas of lower-cost measures (Table 1). In the early years, however, forest protection was the major mitigation measure in the CP scenario (Fig. 4a). This was not applicable to the CP–FP scenario because deforestation was halted in this scenario. Among the other measures, reforestation (slow-growing species) and agroforestry had large contributions to emission reduction in the accumulated amount during the study period and emission reduction in 2030 (70 $MtCO_2$ and 48 $MtCO_2$, respectively, for CP, and 58 $MtCO_2$ and 29 $MtCO_2$, respectively, for CP–FP) for both CP and CP–FP scenarios, particularly for CP, because of their relatively low costs for mitigation (agroforestry is one of the cheapest options) and the potential to be introduced. Prevention of forest fires was also introduced as a mitigation measure, but its contribution was small because forest fires are assumed to occur during conversion of forest to agricultural land and such conversion does not occur largely due to efficiency improvements in the agricultural sectors and forest protection as a mitigation measure.

Figure 5 shows the land area where the mitigation measures were applied (annual and accumulated area), corresponding to the mitigation measures shown in Fig. 4. Although the amount of emission reduction differed by scenario (Fig. 4), the difference in the land area where the mitigation measures were applied was slight between the two scenarios, except around the year 2024. The area where any mitigation measure was applied increased by 2024; however, such areas tended to decrease after that (Fig. 5a, b). This is because emission reductions from the earlier years were required to achieve the emission reduction target and only moderate amounts of newly introduced mitigation measures

[3] Emission reduction in the CP scenario is that from the BaU scenario, whereas emission reduction in the CP–FP scenario is that from the BaU–FP scenario.

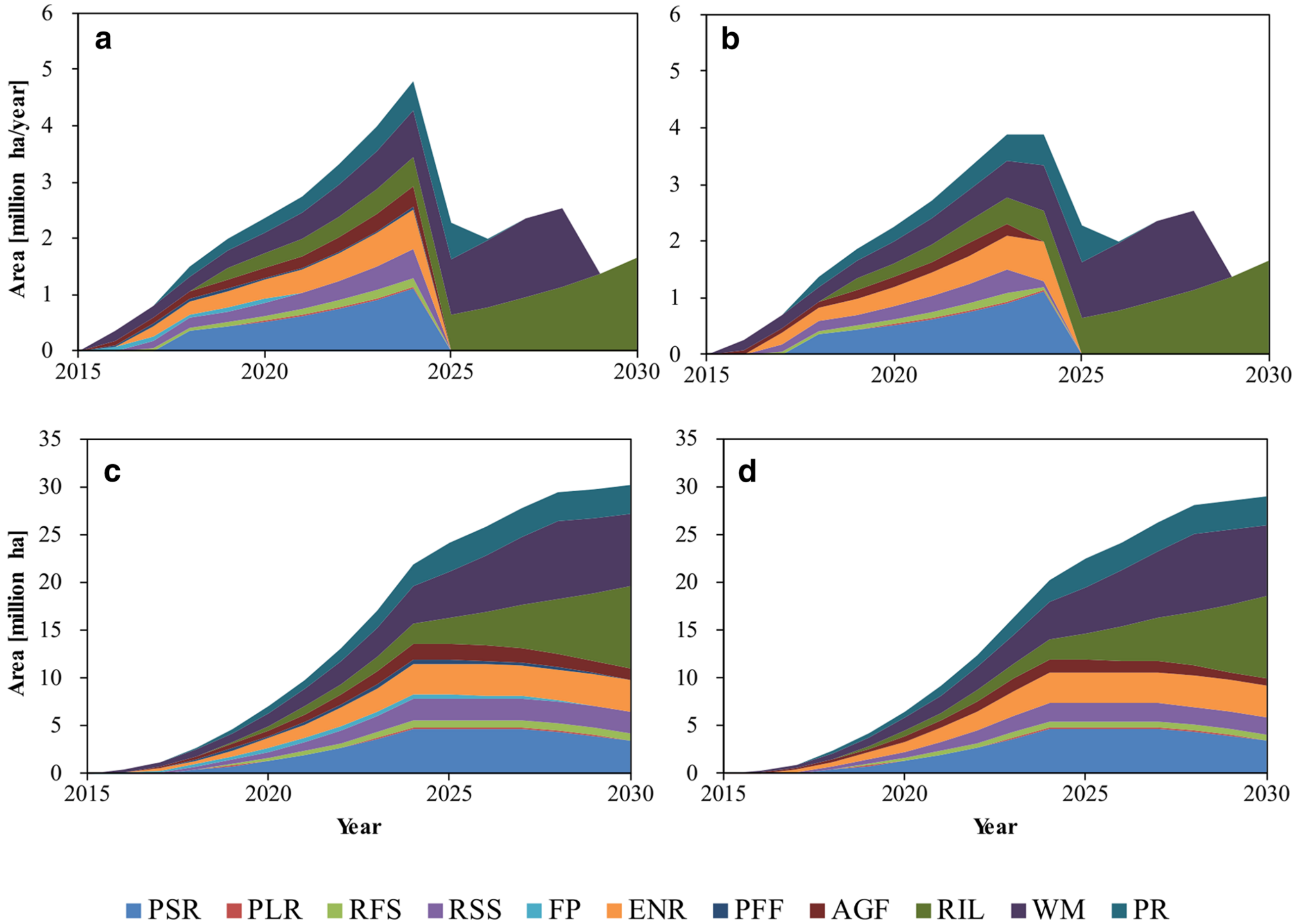

Fig. 5 Annual and cumulative land area mitigation measures were applied. **a** Annual land area for the CP scenario, **b** annual land area for the CP–FP scenario, **c** cumulative land area for the CP scenario, and **d** cumulative land area for the CP–FP scenario

were needed after 2024. The peaks for most of the individual measures were also observed at approximately 2023–2024. However, the land area for reduced impact logging and water management in peatland expanded after 2024, which is consistent with Fig. 4.

Although forest protection was a significant mitigation measure for emission reduction in the forest sector, particularly in the earlier years, the land area where it was applied was very small (the maximum cumulative area: 350,000 ha). This is because forest protection is an efficient method for emission reduction (i.e., the amount of emission reduction per hectare is large; Table 1). The largest area where mitigation measures were applied was reduced impact logging and water management in peatland (the maximum cumulative area: 6,694,000 ha and 8,161,000 ha, respectively), which has large annual available and potential area to be introduced for emission reduction.

Emission reduction in the land-use sector resulted in land-use change (Fig. 6). In the BaU scenario, the forest and grassland decreased (6.5% and 17.6%, respectively), whereas the cropland increased (2.0%) in 2030 from that in the base year. This is due to an increase in the agricultural demand in the country.[4] Other land use[5] also increased for the BaU scenario. For the other three scenarios, cropland also expanded by a similar degree as that for the BaU scenario, and the trend for grassland was also similar because there was little difference in demand for agricultural and livestock products among the scenarios. A large difference was observed for forests, including afforestation and reforestation, and other areas. Afforestation and reforestation, which is defined as forest area expanded from the BaU scenario, was assumed to be introduced in the FP scenario because of

[4] For example, the demand for rice and wheat increased by 1.24 and 1.30 times, respectively, in 2030 from that at 2005. The demand for livestock products increased by 2.1 times in the same period.

[5] "Other land use" includes other vegetated (primary or secondary non-forest and non-agricultural vegetation, including savannah, natural grassland, scrubland, and tundra) and non-vegetated (bare land, deserts, ice, and water) areas.

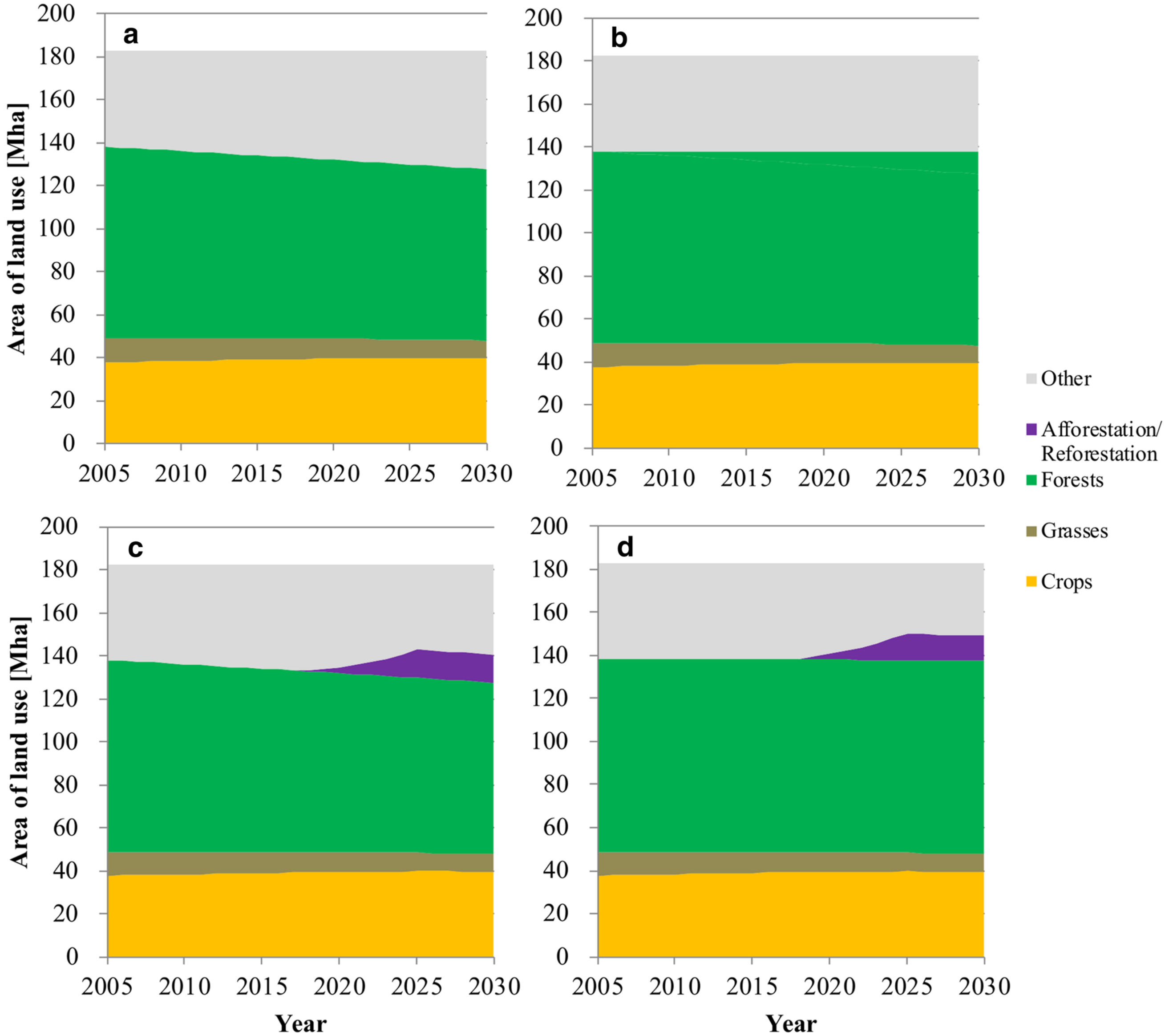

Fig. 6 Land-use change by scenario. **a** BaU scenario, **b** FP scenario, **c** CP scenario, and **d** CP–FP scenario

the no-deforestation policy. Therefore, the sum of forest and afforestation and reforestation areas was constant during the study period for that scenario. For the two climate change mitigation scenarios (i.e., CP and CP–FP), afforestation and reforestation started to expand from 2017 and became constant (i.e., peaked) after 2024, which is consistent with Fig. 5. This increase in afforestation and reforestation was compensated by a decrease in other areas (10.3% and 25.8% reduction for the CP and CP–FP scenarios, respectively, in 2030 from that in the base year).

Finally, Fig. 7 shows the mitigation cost for achieving the above-mentioned emission reduction and resulting land-use change; thus, the figure depicts data only for the two mitigation scenarios. As shown in Fig. 7a, the unit cost of mitigation, calculated by the total costs divided by the total mitigation amount, was lower for the CP scenario than for the CP–FP scenario because of larger increases in afforestation and deforestation as a mitigation measure for the CP scenario from the BaU scenario. However, it should be noted that the mitigation amount for the CP–FP scenario was calculated from the emissions in the BaU–FP scenario; thus, the unit costs will be lower for the CP–FP scenario if emission reduction for this scenario is accounted for in comparison with the BaU scenario. Nevertheless, the total mitigation cost, also shown in Fig. 7a, was lower for the CP–FP scenario than for the CP scenario. This is because the amount of emission reduction required for achieving the target was larger for the CP scenario because the

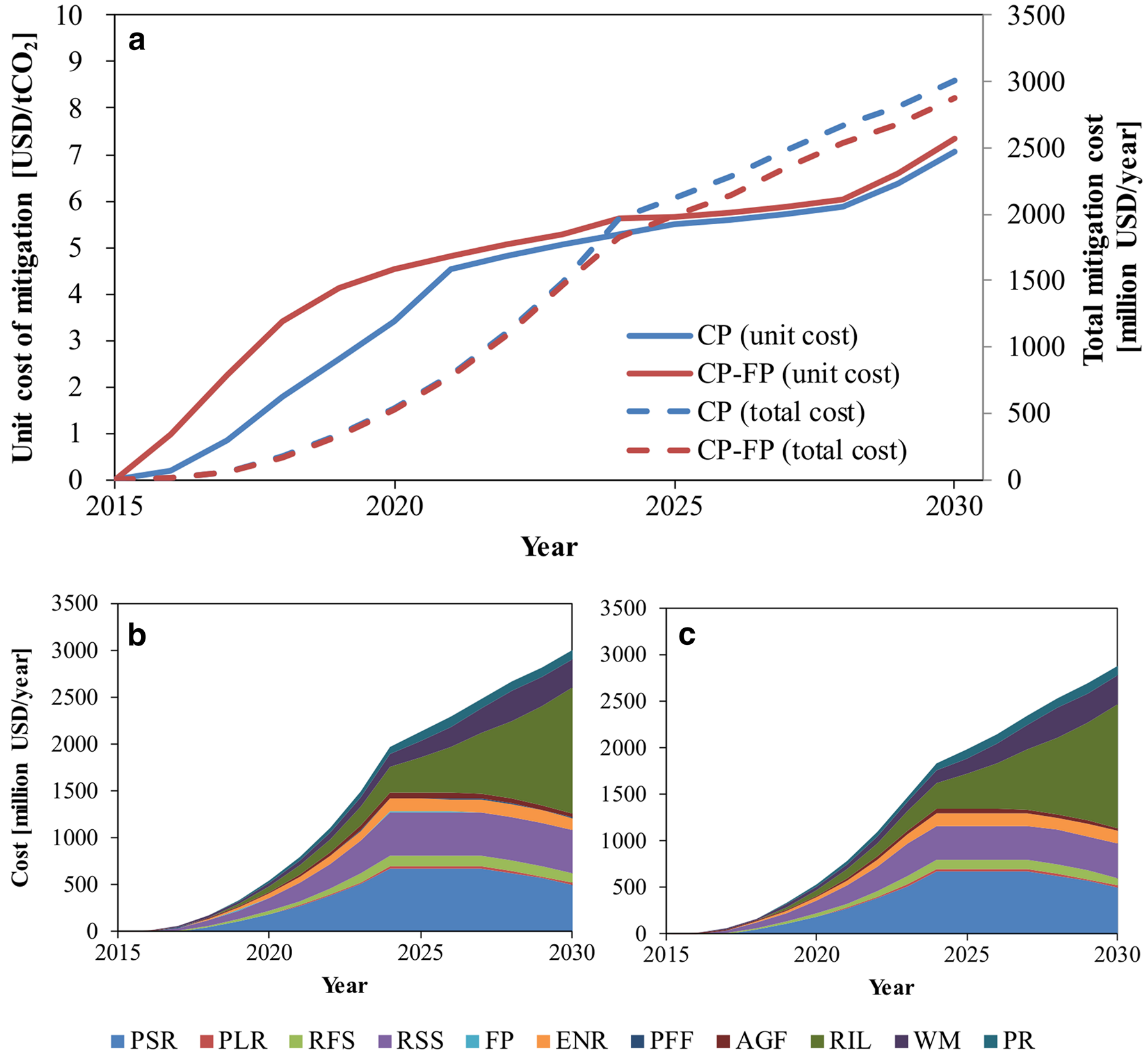

Fig. 7 Mitigation cost for achieving emission reduction targets. **a** Unit cost and total cost of mitigation for the CP and CP–FP scenarios (solid lines depict unit cost and dashed lines depict total cost), **b** mitigation cost by mitigation measure for the CP scenario, and **c** mitigation cost by mitigation measure for the CP–FP scenario

"no-deforestation" policy was not introduced. The difference in annual costs between the two scenarios differed by year and was 1.2–22.2%. The annual costs were 3,003 and 2,875 million USD for the CP and CP–FP scenarios, respectively, in 2030, and the cumulative costs during the study period (discount rate = 10%) were 21,846 and 20,817 million USD, respectively.

Figure 7b, c shows the breakdown of the total mitigation costs. These structures are similar. The major differences between the two scenarios were observed for mitigation measures such as reforestation (first- and slow-growing), forest protection, prevention of forest fires, and agroforestry, which are due to existence of no-deforestation policy. Because of the policy, the cost was lower for the CP–FP scenario for these measures. In both scenarios, the cost for reduced impact logging was the highest, because it is the highest-cost mitigation measure assumed in this study.

We elucidated that the mitigation costs to achieve a target will be lower if climate change mitigation and forest protection are implemented simultaneously than if only climate change mitigation is implemented. This is primarily because of the role of forest as a carbon sink, thus contributing to additional emission reduction. CO_2 emissions from the forest sector are large worldwide; thus, it will be one of the most influential sectors in future climate change mitigation, including the Paris Agreement. Furthermore, forests have various other benefits, such as wood supply, biodiversity preservation, and appropriate land management, although these are out of the scope of this study. Therefore, simultaneous implementation of climate change mitigation and forest protection can generate a "synergy" for climate change mitigation in the forest sector as well as have various benefits from protection. Because Indonesia is a country with a large forest area and its deforestation is the third largest in the world (Hansen et al. 2013), it is particularly effective and efficient for the country to promote sustainable forest management, including climate change mitigation in the forest sector, by linking different policy measures, such as those analyzed in this study.

Indonesia has so far implemented measures that contribute to climate change mitigation in the forest sector and halting deforestation by developing national policies and strategies aligned with the discussion under the UNFCCC and SDGs. In the NDC of Indonesia, emissions from LULUCF have also been emphasized (see "Policies and strategies for forest conservation in Indonesia"). Because Indonesia has introduced multiple policies and strategies, and programs and projects that contribute to implementing climate change mitigation in the forest sector as well as promoting forest conservation, existing policies and strategies in Indonesia cover both UNFCCC- and SDG-related objectives in the forest sector. However, each policy, strategy, program, and project has its own priorities. Furthermore, it is difficult to deliver coordinated actions in the land-use sector under the Indonesian bureaucracy (Di Gregorio et al. 2017). One possible issue will be institutional gaps between the policies and strategies that primarily aim for climate change mitigation in the forest sector and forest conservation. For example, REDD+ aims for mitigation in the forest sector, and zero-deforestation commitments aim for forest conservation. Although both initiatives aim to achieve deforestation, REDD+ has been implemented through government-led discussions (Moeliono et al. 2014), while the latter commitments are more private sector-led processes. Another possible issue is that the policies for SDGs in Indonesia are at the early stage of development. Therefore, filling institutional gaps between the policies and strategies of mitigation and forest conservation, and enforcing the policies to achieve multiple SDGs are indispensable for realizing the synergy. The recently published "The State of Indonesia's Forests 2018" (Ministry of Environment and Forestry 2018) showed a major shift has taken place in Indonesia through a new perspective of sustainability through integration of two portfolios, forestry, and environment. The report describes the new forest governance in Indonesia, which is a new paradigm in managing, governing, and administering forest resources, and highlights the linkage among policy instruments of land reform and social forestry, peatland management, and SDGs. Therefore, the new forest governance outlined in the report is a first step to filling institutional gaps between the policies and strategies of mitigation and forest conservation, and enforcing the policies for achieving multiple SDGs by addressing the various forest-related problems through the coordination of policies for land reform, social forestry, and peatland management (which include climate change mitigation in the forest sector and forest conservation), and of SDGs. However, compared with climate change mitigation in the forest sector such as REDD+ where the outcomes are measured using the indicators of GHG emissions under the REDD+ related institutions, forest conservation such as zero-deforestation commitments are fragmented, and lack the institutions to measure their real effects. Because of the fragmentation and lack of forest governance for voluntary-based forest conservation initiatives in Indonesia, holistic forest-related policies and strategies which contain climate change mitigation such as REDD+ and forest conservation based on initiatives such as zero-deforestation commitments, and cover multiple actors including private sectors, are necessary to fill the institutional gaps further.

This study evaluated emission reduction scenarios to achieve the Indonesian NDC using simulation models, which are optimum solutions (minimizing the costs) under certain constraints. In reality, such optimum consequences are not necessarily achievable and the cost-effectiveness demonstrated in this study may not be realized, although this method of calculations is used in similar studies. However, because the method was applied for all the scenarios in this study to calculate the optimum solutions, the consequences of this study are not affected qualitatively. This implies that synergy is created between climate change mitigation and forest protection. With this effect, meaning that a climate change mitigation target can be achieved with lower costs, (1) more CO_2 emission reduction is achievable with the same costs when climate change mitigation is implemented independently or (2) the excess finance can be used for other purposes. The former implies that if the government spends the excess finance on additional climate change mitigation, the country can achieve a higher target or achieve the target earlier; thus, further progress of climate change mitigation is expected. For the latter, if the government decides to use the excess finance on other climate measures, the finance can be used for, e.g., climate change adaptation. The finance can, of course, be used for other environmental issues or policies in general, including economic policies. Therefore, such synergy effects have various benefits to the country and the world.

Concluding remarks

In this study, we analyzed a synergy potential in terms of CO_2 emission reduction between climate change mitigation in the forest sector and forest conservation policy in Indonesia as a case study for achieving multiple sustainable development objectives. Using a modeling approach and the NDC scenario, we elucidated that mitigation costs will be reduced by implementing climate change mitigation and forest protection simultaneously. This suggests that a synergy effect in the forest sector exists and addresses the contributions to SDGs 13 and 15 (particularly, Targets 13.2 and 15.2) at the same time.

Although this study used Indonesia as an example, effects of synergy between mitigation in the forest sector and forest conservation may be seen in other developing countries, particularly those with a large forest area and severe deforestation, such as Brazil. Although this study focused on the synergy between mitigation and forest conservation, further studies are necessary to quantitatively understand other possible synergy effects, such as those with climate change mitigation and adaptation as well as climate policies and biodiversity or ecosystem conservation (Morita and Matsumoto 2018a). In the forest sector, mitigation, adaptation, and biodiversity or ecosystem conservation measures can be implemented in a more integrated manner. Future tasks include evaluating potentials of synergy effects among the three measures to more effectively and efficiently implement forest-related policies.

Acknowledgements This research was supported by the Environment Research and Technology Development Fund (S-14) of the Ministry of the Environment, JSPS KAKENHI Grant number 18K11754 and 18K11800, and the Integrated Research Program for Advancing Climate Models (TOUGOU program) of the Ministry of Education, Culture, Sports, Science and Technology. We thank Leonie Seabrook, PhD, from Edanz Group (http://www.edanzediting.com/ac) for editing a draft of this manuscript.

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