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Does oil palm agriculture help alleviate poverty? A multidimensional counterfactual assessment of oil palm development in Indonesia

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Abstract

Palm oil producing countries regularly promote the positive impact of palm oil agriculture on poverty alleviation, despite limited evidence about the contribution of this crop on village well-being. Past evaluations that quantify the social impact of oil palm are dominated by localized studies, which complicate the detection of generalizable findings. Moreover, only a few of these evaluations are based on rigorous case-control studies, which limits the robustness of the conclusions. Here we examined the association between the development of oil palm plantations and change in objective or material well-being between 2000 and 2014 across villages in Kalimantan, Indonesian Borneo. We applied a matching method to evaluate the impacts of oil palm plantations across different aspects of well-being, accounting for varying time delays in the accrual and realization of benefits after plantation development. Our study reveals that the social impacts of oil-palm plantations are not uniformly positive, nor negative, and have varied systematically with biophysical locations and baseline socioeconomic conditions of nearby communities prior to oil palm development. Plantations developed in villages with low to moderate forest cover, in which the majority of communities already relied on market-oriented livelihoods, were associated with improved socioeconomic well-being compared to villages without oil palm development. However, we found the opposite for plantations developed in remote villages with higher forest cover, in which the majority of communities previously relied on subsistence-based livelihoods. Overall, oil palm growing villages were more associated with reduced rate of improvement of social and environmental well-being compared to villages without oil palm development, regardless of location and baseline community livelihoods. Our findings highlight an urgent need for careful evaluation and planning in the development of oil palm agriculture in remote forested areas. For oil palm regions that have been developed, our study shows that unsustainable livelihoods, increased socioeconomic disparity, and environmental issues remain major challenges.

Keywords: human well-being; impact evaluation; Indonesia; landscape analysis; multidimensional poverty; oil palm

1. Introduction

In recent decades there has been an enormous increase in the demand for oils and fats worldwide due to growing populations and wealth: the global consumption rose from 80 million to 213 million tonnes between 1990 and 2015 (FAO 2016). Palm oil production has boomed in response to this demand, with the global production increasing from 14 million to 63 million tonnes over the same period (FAO 2016). Globally, oil palm plantations have expanded from 6 to 18 million hectares over the last two decades, and now account for 0.4% of the world's permanent cropland (FAO 2016). Indonesia and Malaysia is currently the world's leading palm oil producer, supplying approximately more than 80% of the commodity globally (FAO 2016). In Indonesia, plantations have predominantly been developed in Sumatra and Kalimantan (Indonesian Borneo), with rapid expansion in recent decades (Fig. A1 and A2 in Appendix A; Directorate General of Estate Crops Indonesia 2015). Prior to 2000, oil palm plantations were developed mainly on barren land (e.g. burnt-over areas) or on established farmland, but conversion of forest to plantations has become increasingly common in recent years due to increasingly scarce non-forest land for agriculture (Fig. A3a; Santika *et al.* 2015; Gaveau *et al.* 2016b). Agricultural expansion into forested areas could have profound impacts on local and traditional communities who depend highly on forest produce and income (Sheil *et al.* 2009).

In 2017, the Indonesian oil palm industry was estimated to employ 3.8 million people (Directorate General of Estate Crops 2017), ca. 2.4% of the total Indonesian work force (Allen 2016), and the Indonesian government increasingly promotes oil palm cultivation as a way to alleviate poverty and advance development in remote forested landscapes (Cooke 2012; Potter 2012; Li 2016). Other developing and emerging countries, such as Brazil, Peru, Colombia, Nigeria, Gabon, Ghana, and Rwanda, are following similar steps (Villela *et al.* 2014; Byerlee *et al.* 2017; Meijaard *et al.* 2018). However, despite driving macro-level economic growth in many tropical countries, there are mixed reports about the social impact of oil palm agriculture on the life of communities in production areas. While positive impacts on household income and consumption, as well as local development and employment have been observed, numerous social and environmental costs of oil palm have also been reported (reviewed in Table B1 in Appendix B). For example, in some areas the promised benefits and compensation of oil palm cultivation has not reached all smallholders (Sheil *et al.* 2009; Rist *et al.* 2010), and consultation with indigenous peoples has not always occurred (Colchester *et al.* 2006), leading to escalating conflicts with local people (Abram *et al.* 2017; Wakker *et al.* 2004). Expansion of the oil palm industry in some areas has increased income benefits mainly among wealthy farmers and skilled migrants while marginalising others, leading to social disparities (Obidzinski *et al*. 2012, 2014; Zen *et al.* 2016). In addition, depletion of land and water resources, and deterioration of air and water quality due to unsustainable oil palm practices have further burdened communities in some locations (Phalan 2009; Sheil *et al*. 2009; Wells *et al.* 2016).

Past evaluations of the social impact of industrial-scale oil palm plantations in developing countries have typically been appraised in localized studies, either within district, province or state (Table B1). A few exceptions are Obidzinski and colleagues (2012) who studied the perceptions of the social impact of oil palm plantations among three indigenous communities in the province of West Kalimantan, Papua, and West Papua, and Castiblanco, Etter and Ramirez (2015) who studied the social impact of oil palm across municipalities in Colombia. Furthermore, only a few of these past evaluations were based on rigorous case-control studies (Table B1). In complex social and environmental settings, there are many factors other than the intervention that may cause or moderate change, so quantifying the impact of an intervention is impossible without identifying an appropriate comparator or counterfactual of what would have happened in the absence of that intervention (Ferraro 2009). Additionally, studies that apply a counterfactual analysis approach for evaluating the social impact of oil palm are mostly based on data from Sumatra, and geographically biased around transmigration areas in the province of Riau and Jambi (e.g. Alwarritzi *et al.* 2015; Euler *et al.* 2017; Gatto *et al.* 2017; Krishna *et al*. 2017) (Table B1). These provinces are not only recognized as the hotspots of Indonesia's recent oil palm boom, but also the hotspots of transmigration programs during the New Order regime in 1965-1998 (the period from *Pra-Pelita* to *Pelita IV*), when at least 680,000 transmigrants from Java relocated in both provinces combined

(Junaidi 2012; Palupi *et al.* 2017). Thus, the baseline socioeconomic context and socio-political history of the oil palm growing areas associated with these studies likely have limited transferability of the resulting conclusions to other oil palm areas where recent migration was considered to be less prevalent prior to oil palm developments, such as in many parts of Kalimantan and Papua.

Our literature review (Table B1) highlights substantial variability of the social impact of oil palm among locations with different biophysical characteristics and baseline socioeconomic conditions of communities. There is therefore a clear need for greater synthesis to detect generalizable findings, which can come from landscape-based assessment over broad areas. Understanding variation in how social benefits accrue from oil palm developments is critical to help identify opportunities to improve policy implementation and ultimately improve outcomes for village communities (Hodbod & Tomei 2013; Blaber-Wegg *et al.* 2015). Therefore, a robust evaluation of the impact of the oil palm industry requires analyses of (1) changes in indicators of well-being due to the oil palm development compared to the counterfactual condition without oil palm, (2) trends over time to account for potential delays in the accrual and realization of benefits, and (3) multiple sites over broad areas to detect variations in the impacts of oil palm across different baseline biophysical and community socioeconomic conditions.

Here we assessed the impact of oil palm plantation developments on changes in objective or material aspects of well-being between 2000 and 2014 across villages in Kalimantan, Indonesian Borneo. Oil palm plantations mainly include industrial scale plantations developed within concession boundaries (including smallholder plantings operated as part of the nucleus estate system, i.e. cooperation between company plantations and smallholders in terms of capital and labour supply) and to a smaller extent independent smallholders (see Fig. A1a). We note that industrial scale plantations often spatially coincide with independent smallholder plantations (Euler *et al.* 2016; Jelsma *et al.* 2017), and that our results should be interpreted as an overall effect of oil palm development, across different production scales, on village well-being. As plantations require some time to mature, be harvested, and provide economic benefits (Rist *et al.* 2010), we investigated the change of well-being following 2-3, 6-8, and 11-14 years after initial plantation development within the village administrative unit. We defined well-being across five dimensions: (1) basic (i.e. living conditions), (2) physical (i.e. infrastructure), (3) financial (i.e. income support), (4) social (i.e. security and social equity), and (5) environmental (i.e. prevention of natural hazards). We used 17 indicators from the village level dataset *Potensi Desa* (PODES) as proxies for these aspects of well-being (Table 1). PODES data were collected by the Bureau of Statistics Indonesia (BPS) roughly every three years between 2000 and 2014 (BPS 2015), providing the best data option for this broad-scale analysis. We recognise that more subjective, non-material, indicators exist to measure human well-being (Costanza *et al*. 2007; Daniel *et al.* 2012). However, these are difficult to aggregate at the village-level and are not available within the PODES dataset.

The effect of oil palm plantations on village well-being was assessed based on a counterfactual analysis: comparing what actually happened and what would have happened in the absence of the oil palm plantations. For this counterfactual, we employed a matching method (Dehejia & Wahba 2002) to select a set of control villages outside oil palm growing areas that exhibited the same baseline characteristics as villages within the oil palm areas. By doing so, we controlled for variables that could confound the analysis, such as socio-political factors, accessibility, agricultural productivity, and recent climate, as well as baseline village well-being and primary livelihoods (Table 2). We explored how the effect of oil palm plantations varied across different village primary livelihoods prior to plantation development, which includes (1) subsistence-based livelihoods, i.e. swidden farming of dryland rice (inter-cropped with banana, maize, and cassava, and typically supplemented by market exchange for forest and/or agroforest products) and inland fishing (Budiharta *et al.* 2016), and (2) market-oriented livelihoods, including polyculture plantations (e.g. coffee, rubber, oil palm, coconut), horticulture, aquaculture, agricultural services, and non-agricultural sectors.

Table 1. PODES indicators used as proxies for five dimensions of well-being: basic, physical, financial, social, and environmental. Variable w_k denotes the directional effect of the change in indicator *k* that defines improvement in well-being. If w_k=1, then positive change (i.e. an increase) in indicator *k* represents improvement in well-being. If w_k=-1, then negative change (i.e. a reduction) in indicator *k* represents improvement in well-being.

Dimension of well-being	PODES indicator (*k*)	Description	w_k	Response
Basic (Living conditions)	POOR	Proportions of households with poor housing conditions *	-1	Continuous
	ELCT	Proportions of households with electricity *	1	Continuous
	COOK	Cooking fuel for majority of households	-1	Categorical (1=electricity or liquefied petroleum gas (LPG), 2=kerosene, 3=wood/others)
	TOLT	Toilet facilities for majority of households	-1	Categorical (1=own toilet, 2=joint toilet, 3=public toilet, 4=non-toilet)
	MLNT	Child malnutrition incidence in the last year †	-1	Continuous
Physical (Infrastructure)	HEAL	Distance to nearest healthcare facility	-1	Continuous
	PSCH	Distance to nearest primary school	-1	Continuous
	SSCH	Distance to nearest secondary school	-1	Continuous
Financial (Income support)	COOP	Number of active village cooperative schemes or other schemes ‡	1	Continuous
	CRDT	Number of credit facilities for farmers or communities ‡	1	Continuous
	SIND	Number of small industries (<20 employees) ‡	1	Continuous
Social (Security and social equity)	CNFL	Frequency of conflicts among communities in the last year	-1	Continuous
	AGLB	Proportion of families with agricultural wage labourers **	-1	Continuous
	SUIC	Suicidal rates in the last year †	1	Continuous
Environmental (Natural hazard prevention)	WPOL	Water pollution over the last 3 years	-1	Categorical (1=none, 2=mild, 3=severe)
	APOL	Air pollution over the last 3 years	-1	Categorical (1=none, 2=mild, 3=severe)
	FLOD	Frequency of floods and landslides over the last 3 years	-1	Continuous

† per 1000 people, ‡ per 100 households, * of total households, ** of total agricultural families

Table 2. Variables used to assess oil-palm efficacy in improving village well-being.

Variable	Description (Static/Dynamic [§])	Type (Scale)	Data source
SOCIO-POLITICAL			
KABU	Regency (*kabupaten*) boundaries (Dynamic)	Categorical	Indonesia Population Census 2010 (BPS 2010)
LZON	Majority of legalized land use zone (Static)	Categorical (HP=Production Forest; APL=Non Forest Estate)	Forest Zone Map (MEF 2010)
ACCESSIBILITY			
ELEV	Mean elevation (Static)	Continuous (m a.s.l)	SRTM 90m Digital Elevation Database v4.1 (Jarvis *et al.* 2008)
SLOP	Mean slope (Static)	Continuous (degree)	SRTM 90m Digital Elevation Database v4.1 (Jarvis *et al.* 2008)
CITY	Mean distance to large cities or arterial roads (Static)	Continuous (log(km))	Provincial map from Geospatial Information Agency Indonesia (BIG 2016)
POPB	Mean human population density per km^2 prior to of oil palm development (Dynamic)	Continuous (log(people))	*Potensi Desa* (PODES) (BPS 2015)
FORB	% natural forest cover a year prior to oil-palm development (Dynamic)	Categorical (1=0-25%; 2=25-50%; 3=50-75%; 4=75-100%)	Global Forest Change dataset (Hansen *et al.* 2013) and Indonesia's primary and secondary forest map (Margono *et al.* 2014)
AGRICULTURAL PRODUCTIVITY			
SDRY	Mean long-term monthly rainfall during dry season (Static)	Continuous (mm)	WorldClim (Fick & Hijmans 2017)
SWET	Mean long-term monthly rainfall during wet season (Static)	Continuous (mm)	WorldClim (Fick & Hijmans 2017)
SOIL	Presence of peat soil (Static)	Categorical (1=Peat; 0=Mineral)	Peat Hydrological Area Map (MEF 2017)
TRNS	Mean distance to transmigration areas prior to oil palm development (Dynamic)	Continuous (log(km))	Land Cover Map (MEF 2016)
BASELINE VILLAGE SOCIOECONOMIC CONDITION			
LVHD	Village primary livelihood at initial stage of oil palm development (Dynamic)	Categorical (SL=Subsistence livelihoods; ML=Market-oriented livelihoods)	*Potensi Desa* (PODES) (BPS 2015)
$WLBN_k$	Baseline well-being indicator *k* (Table 1) at initial stage of oil palm development (Dynamic)	Either continuous or categorical	*Potensi Desa* (PODES) (BPS 2015)
VILA	Extent of village (Static)	Continuous (km^2)	*Potensi Desa* (PODES) (BPS 2015)
RECENT CLIMATE			
TDRY	Mean monthly rainfall during the dry season over the time frame assessed (Dynamic)	Continuous (mm)	TRMM Multi-Satellite Precipitation Analysis (TMPA) v. 7 (Huffman *et al.* 2007)
TWET	Mean monthly rainfall during the wet season over the time frame assessed (Dynamic)	Continuous (mm)	TRMM Multi-Satellite Precipitation Analysis (TMPA) v. 7 (Huffman *et al.* 2007)

§ Static: vary spatially but are fixed through time, and Dynamic: vary both spatially and temporally.

2. Materials and Methods

2.1. Study area

Our study covered Kalimantan (540,000 km^2), the Indonesian portion of the island of Borneo, comprising five provinces and 6,600 villages in 2010 (BPS 2010). Kalimantan's interior is largely hilly and mountainous, but extensive lowlands and swamps occur along the coasts. A large part of the region is drained by navigable rivers. In 2015, the population of Kalimantan was estimated as 15 million (BPS 2015), with many mainly residing along the coastline (Fig. 1A). Communities are comprised of three broad ethnic groups: the indigenous Dayak predominantly residing in the interior regions, the indigenous Melayu (of which the majority are Muslim) occupying mainly the coastal regions, and recent migrants from the neighbouring islands of Java, Madura and Bali (arriving mainly as part of the government-supported transmigration programs since the 1960s) (Fig. 1B). Village economies in Kalimantan have traditionally been based on subsistence agriculture (i.e. swidden farming and seasonal inland fishing) and forestry, but plantation agriculture (both polyculture and monoculture) has become an increasingly vital sector in recent decades (Fig. 1C).

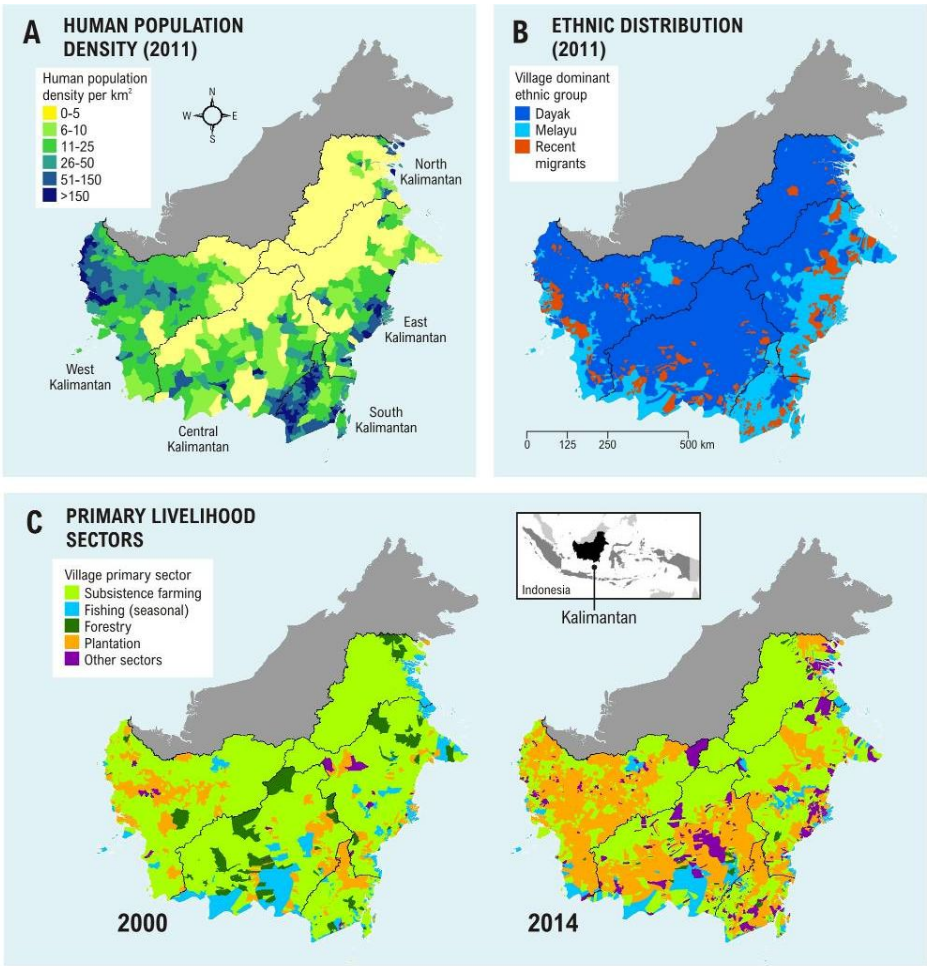

Fig. 1. (A) Human population density (per km^2), and (B) village dominant ethnic group, in Kalimantan based on PODES 2011 (data closely reflect the results of 2010 national census). (C) Change in village primary livelihood sectors between 2000 and 2014, which includes subsistence farming, seasonal inland fishing, forestry, plantation (polyculture or monoculture), and other sectors (including horticulture, aquaculture, agricultural services, and non-agricultural sectors). Black lines in the maps indicate provincial boundaries.

2.2. Oil palm plantations

We used spatial data on the boundaries of planted oil palm plantations every five years between 1995 and 2015 provided by Gaveau et al. (2016a). These data comprise estates located within the boundaries of oil palm concessions, including large-scale industrial plantations, smallholders under the *Perkebunan Inti Rakyat* (PIR) or Nucleus Estate Smallholder schemes in transmigration areas (McCarthy *et al*. 2012), and a smaller extent of independent smallholders (outside oil palm concessions) (Fig. A1a). It is worth noting that the proportion of industrial plantation estates in Kalimantan is much higher than in neighbouring Sumatra (64% of all plantations in Kalimantan, 33% in Sumatra, in 2015, Fig. A1). Oil palm developments at different spatial scales (smallholder to large industrial scale) usually coincide spatially due to their reliance on access to palm oil mills and related services (Klasen *at al.* 2016), hence our analysis reflects more broadly the effects of all oil palm developments. In addition, the proportion of oil palm plantations that have been certified through internationally recognized certification bodies, such as the Roundtable on Sustainable Palm Oil (RSPO), between 2000 and 2015 is relatively small (around 12% by 2015) (Fig. A1). Kalimantan's oil palm plantations have expanded rapidly over the last decades, covering a total area of 13,000 km^2 (in 1073 villages) in 2000, tripling to 40,000 km^2 (in 1980 villages) in 2015 (Fig. A2).

2.3. Indicators of well-being

Village-level data, *Potensi Desa* (PODES), collected by the Indonesian Bureau of Statistics (BPS) roughly every three years between 2000 and 2014 (BPS 2015), were used as proxy indicators of five dimensions of village well-being (Table 1, with associated questionnaires provided in Table B2). The data are the most comprehensive information on land use, population demographics, and village infrastructure available in Indonesia, and have been used extensively to inform government policy, as well as socioeconomic studies (Table B3). The choice of indicators and directionality of the effects on well-being listed in Table 1 correspond to existing methodologies used to assess poverty and livelihoods, such as the Multidimensional Poverty Index (MPI, Alkire *et al*. 2014), the Sustainable Livelihood Approach (SLA, Scoones 1998), and the Nested Spheres of Poverty (NESP, Gönner *et al.* 2007) (Fig. A4).

PODES data represent the overall socioeconomic conditions in a village, and thus do not capture the variation and disparity in socioeconomic indicators among different sub-villages (*dusun*) nor households. Rather, the data provide a useful way to compare village administrative units over large spatial extents. PODES data are collected from the village head offices by BPS representatives, thus the reliability of data may vary across different villages and there is potential for bias, e.g. under-or over-reporting. However, should this random bias propagate sufficiently, we expect that the error would be inflated and override the true oil palm effect, and thus the estimated effect of oil palm would appear negligible, as opposed to changing the directionality of the effect.

2.3. Analysis methodology

2.3.1. Unit of analysis

We used the village administrative unit as the spatial unit of analysis, which was defined according to the Bureau of Statistics Indonesia in 2010 census (BPS 2010). We assessed the impact of oil palm on the change in village well-being following 2-3, 6-8, and 11-14 years of plantation age, which allows understanding of the complex temporal dynamics of oil palm impacts across different indicators of well-being in different contexts. To do so, we compared the change in well-being indicators between paired PODES censuses (Table B4).

Oil palm usually takes 3-4 years to mature to produce commercially viable yields (Basiron 2007; Lee *et al.* 2014), hence profits from plantations are usually realized after at least 3 years. Smallholders under the Nucleus Estate Smallholder schemes (who are normally tied to transmigration areas) typically use these initial profits to gradually pay back investment from their nucleus company, and are only able to pay off their debt around 6 years after planting (Feintrenie *et al.* 2010). For independent smallholders the realization of socioeconomic benefits would depend on land ownership and starting capital (Lee *et al.* 204; Euler *et al.* 2016). Regardless of the types of oil palm plantation holders, we expect the economic benefits to be realized after the first harvesting cycle between 3 and 8 years.

Changes in indicators of social well-being, such as the frequency of conflicts, may occur either during the oil palm development stage or several years after planting. Land grabbing disputes are expected to manifest early in the oil palm development stage, whereas conflicts due to unfulfilled promised benefits and compensation are expected to occur several years later (Wakker *et al.* 2004; Colchester *et al*. 2006; Rist *et al.* 2010). The prevalence of agricultural wage labourers is expected to increase dramatically during the oil palm development stage, especially when a plantation reaches its full production level (Potter 2012). Changes in indicators of environmental well-being, such as water pollution, are likely to occur after the oil palm infrastructure, including mills, are established and palm oil production begins in earnest, although these impacts could take some years before they are noted (Comte *et al*. 2012; Obidzinski *et al.* 2012).

As the unit receiving treatment, we used villages where oil palm plantations were detected as the primary land use over the full analysis periods, but not within the prior five years. As the unit for control, we used villages where oil palm plantations were not detected as the primary land use over the range of analysis period, nor in the prior five years. For example, to assess the effect of oil palm on the change in village well-being between the 2003 and 2011 PODES censuses (eight years of plantation age), the unit receiving treatment were villages where oil palm plantations were detected within the village boundaries in 2005 and 2010, but not in 2000, and the control unit were villages where oil palm plantations were not detected within the village boundaries in 2000, 2005 and 2010. Therefore, the number of villages in the treated and control unit vary depending on the time frame of analysis, as shown in Table B4.

2.3.2. Confounding variables

We controlled for potentially confounding variables in the assessment of oil palm impact in terms of both selection of villages for treatment and the outcome being measured (Table 2). To achieve this we included variables representing: (a) socio-political factors, (b) accessibility, (c) agricultural productivity, (d) baseline village socioeconomic conditions, and (e) recent climate.

We used the regency administration boundaries (*kabupaten*) (variable *KABU* in Table 2) and land use regulation (*LZON*) as proxies for socio-political factors. Decentralization of government functions to regency levels has been identified as a key driver of deforestation, land degradation and conversion of forest to agriculture in Indonesia (Resosudarmo 2004; Moeliono & Limberg 2012). Oil palm plantations in Kalimantan are typically developed either outside the Forest Estate Zone, *Area Penggunaan Lain* (APL), or inside the Forest Estate Zone in Production Forest, *Hutan Produksi* (HP).

Average elevation (*ELEV*) and slope (*SLOP*), proximity to large cities or arterial roads (*CITY*), human population density (*POPB*), and forest cover (*FORB*) were used as proxies for accessibility. Oil palm is typically developed in villages with particular topographical characteristics, e.g. flat or lightly undulating land with good access to water. Villages located within proximity to major roads and towns tend to be converted first to agriculture because the land is more accessible (Kinnaird *et al.* 2003; Linkie *et al.* 2004). Villages within proximity to major roads and towns, higher human population density, and relatively low forest cover are also recognized to be associated with communities with higher baseline cash income and economic welfare (Belcher *et al.* 2015).

We used long-term seasonal rainfall patterns (*SDRY* and *SWET*), presence of peat soil (*PEAT*), and distance to transmigration areas (*TRNS*) as proxies for agricultural productivity. The amount of rainfall during the dry and wet seasons is the most important factor affecting agricultural productivity in Indonesia (Oldeman & Frere 1982; Santika *et al.* 2017a). Soil type, i.e. mineral or peat soil, is also an important factor driving forest conversion to agriculture (Carlson *et al*. 2013). The increase in agriculture area in Indonesia had been partly attributed to an increase in transmigration sites and expansion of oil palm plantations (Dennis & Colfer 2006).

Village primary livelihoods (*LVHD*) and well-being conditions (*WLBN*) at the initial stage of oil palm developments, and the extent of village (*VILA*) were used as proxies for baseline village socioeconomic conditions. These variables provided a baseline to control for conditions that may have biased impact estimates. We used the monthly average of rainfall during the dry and wet seasons over a given time frame of analysis (*TDRY* and *TWET*) as proxies for recent climate conditions (Santika *et al.* 2017b). These variables are important for assessing the association between oil palm and natural hazards, such as water and air pollution, and floods and landslides (Tosca *et al.* 2011; Merz *et al.* 2014).

2.3.3. Matching method

We employed a matching method (Dehejia & Wahba 2002) to select a set of control villages in which oil palm plantations had not been developed and that exhibited the same baseline characteristics as villages where plantations had been established. The matching method was performed based on nearest-neighbour matching of propensity scores based on all variables described in Table 2 and exact matching of the categorical baseline variables (i.e. *KABU*, *LZON*, *SOIL*, *FORB*, *LVHD*, and *WLBN*). We used matching algorithms implemented in the R-package Matching (Sekhon 2015). We used a non-parametric generalized boosted regression model (Friedman 2001) for binary outcomes implemented in the R-package gbm (Ridgeway *et al.* 2015) to generate the propensity scores. The model allows flexibility in fitting non-linear surfaces for predicting treatment assignment and can incorporate a large number of covariates without negatively affecting model prediction. In various applications, this modelling approach has been shown to outperform other methods that require model selection, specification of model functional form, and are lacking flexibility, such as the commonly used generalized linear model (Lee *et al*. 2010). We used a 0.25 calliper width of the propensity scores' standard deviations in the nearest neighbour approach, as this width was previously shown to be optimal (Austin 2011). The matching method was applied separately for each of the 17 indicators of well-being and for each time period analysis. We observed substantial improvement in the extent of overlapping areas of all continuous variables between villages with and without plantation development in the matched dataset compared to the original (unmatched) dataset (Fig. A5).

2.3.4. Assessing impact of oil palm plantations

The impact of oil palm on human-well-being was estimated by comparing the change in well-being indicator in villages with oil palm plantations with the change in control villages without plantations. A village *i* within an oil palm plantation is considered to be effective at alleviating a single indicator of well-being *k* over time period *t* if the difference between the change in the value of the indicator in the treated village ($O_{i,t,k}$) and the rate in the control village ($C_{i,t,k}$), i.e. $A_{i,t,k}$, where $A_{i,t,k} = w_k \times (O_{i,t,k} — C_{i,t,k})$, is positive. The value of w_k represents the directional effect of the change in indicator *k* that defines improvement in well-being (Table 1), i.e. w_k=1 if positive change (or an increase) in indicator *k* represents improvement in well-being (e.g. proportion of household with electricity) and w_k=–1 if negative change (or a reduction) in indicator *k* represents improvement in well-being (e.g. malnutrition prevalence, conflict frequencies). The estimated impact of oil palm based on indicator *k* over time period *t*, i.e. $\bar{A}_{t,k}$, was then obtained by fitting an ordinary linear regression model with $A_{i,t,k}$ as a response and a binary variable representing the treated and the control villages and all variables described in Table 2 as predictors. We then normalized the estimated treatment effects for each indicator of well-being. To obtain the overall efficacy of oil palm in improving each aspect of well-being *m* for plantation age *h*, i.e. $\breve{A}_{m,h}$, we averaged $\bar{A}_{t,k}$ across all indicators *k* belonging to the same group of well-being aspect *m* (Table 1) and across time period *t* belonging to the same group of plantation age *h* (Table B4).

While the value of $\breve{A}_{m,h}$ is an informative measure of the overall impact of oil palm in improving each aspect of well-being for a given plantation age, it is also of interest to understand how efficacy varies spatially. We conducted a systematic review on past, local-level evaluations of oil palm impacts (Table B1), and based on this review we stipulated that baseline community livelihoods in the earliest stage of oil palm development, particularly between subsistence-based livelihoods and market-oriented livelihoods, play an important role in altering the direction and relative magnitude of oil palm impact on well-being. An overall positive association between oil palm plantations and socioeconomic well-being was found in villages where the majority of communities rely on market oriented livelihoods (92% of the studies we reviewed indicate a positive association). In contrast, an overall negative association was found in villages where the majority of communities rely on subsistence livelihoods (60% of the studies we reviewed indicate a negative association). For social and environmental well-being, none of the studies we evaluated reported positive impacts of oil palm.

To assess the robustness of the matching method against the possible presence of an unobserved confounder, we applied a sensitivity analysis based on the principle of randomization inference (Rosenbaum 2005) implemented in R-package rbounds (Keele 2014). This approach relies on the sensitivity parameter Γ that measures the degree of departure from random assignment of the treatment, in this case, oil palm plantation villages. A threshold value of Γ, namely Γ_C, was calculated at the point at which hidden bias would eliminate the effect of oil palm plantations. A study is considered sensitive to hidden bias, i.e. the effect of oil palm plantation development likely can be explained by an unobserved covariate, if $\Gamma_C<1$, and a study is considered robust if the value of Γ_C is large. The sensitivity analysis indicated that our estimate on the impact of oil palm plantation on all the well-being indicators for each time period based on matching was robust to the possible presence of an unobserved confounder, as indicated by relatively large values of the sensitivity parameter threshold Γ_C ($\Gamma_C \geq 1.72$) (Table B5).

3. Results

3.1. Market economy characteristics of the baseline livelihoods

Living conditions (electricity, adequate sanitation, non-wood cooking fuel), access to infrastructure (schools and healthcare facilities), and various credit schemes were better in villages where market-oriented livelihoods dominated than in villages where most communities depended on subsistence livelihoods (Fig. A6a-c). The biophysical features of these villages, i.e. proximity to major cities and roads, may have contributed to creating such conditions (Fig. A7). In villages where subsistence-based livelihoods dominated, basic infrastructure was generally lacking due to isolation, and households with poor living conditions were common (Fig. A6a). Despite lacking material wealth, however, malnutrition rates among infants were lower in subsistence-based livelihood villages (Fig. A6a), which could reflect access to a greater variety of food sources (fruits, vegetables, and medicinal plants) due to high levels of food self-sufficiency through farming and forest product collection (Budiharta *et al.* 2016; Ickowitz *et al.* 2016). Moreover, the occurrence of cooperative schemes and micro enterprises (<20 employees, mainly in forestry related products, such as rattan) were higher overall (Fig. A6c). Nearly 60% of the new oil palm plantations developed between 2000 and 2015 in Kalimantan were situated in villages where the majority of communities had relied on subsistence-based livelihoods (Fig. A3b).

3.2. Overall effect of oil palm on village well-being

We found an overall increase in basic, physical and financial indicators of well-being between 2000 and 2014, both in villages with oil palm plantation developments and those without such developments across Kalimantan between 2000 and 2014 (Fig. 2A-C). Conversely, there was an overall decline in social and environmental measures of well-being (Fig. 2D-E). On average the improvements in basic, physical and financial well-being occurred more slowly in villages with oil palm plantations compared to those without, for villages of similar biophysical features and baseline community socioeconomic conditions (Fig. 2F-H). Moreover, the decline in social and environmental well-being had occurred significantly faster overall in villages with oil palm plantations compared to villages without plantations (Fig. 2I-J).

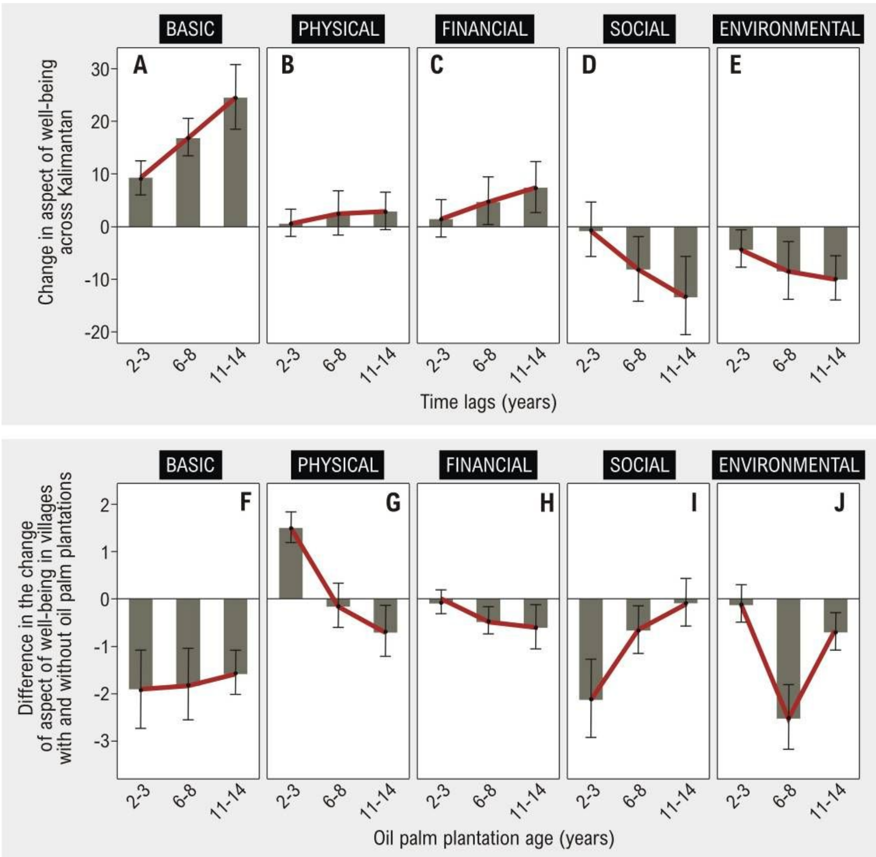

Fig. 2. (A-E) Mean rate of change in human-well-being across Kalimantan villages for varying time lags, which correspond to plantation ages since establishment. (F-J) Difference in the mean rate of change of well-being over the same time lags in villages with and without oil palm. Large negative values indicate higher reduction of well-being relative to the counterfactual. Aspects of well-being assessed include: (A,F) basic well-being (living condition), (B,G) physical well-being (infrastructure), (C,H) financial well-being (income support), (D,I) social well-being (security and social equity), and (E,J) environmental well-being (natural hazard prevention). Error bars represent 95% confidence intervals.

3.3. Benefits vary with baseline conditions

Despite the overall negative association between of oil palm and all aspects of human-well-being (Fig. 2F-J), these associations varied across different baseline community livelihoods at the initial stage of plantation development (Fig. 3). While the association between oil palm development and basic, physical, and financial well-being appeared to be negative overall in villages where communities had relied formerly on subsistence-based livelihoods, the association was positive overall in villages where communities had relied on market-oriented livelihoods (Fig. 3A-C). However, the negative association between the industry and social and environmental well-being appeared to be more severe in villages that formerly relied on market-oriented livelihoods compared to villages with livelihoods that were formerly subsistence-based (Fig. 3D-E).

In villages that formerly relied on market-oriented livelihoods water and air pollution were reported to be more severe compared to villages that were mostly subsistence-based (Fig. 4E). This could reflect substantially higher agriculture intensification and the occurrence of more oil palm mills in the former (Fig. A7f). An increase in frequency of floods and landslides was reported to be greater in oil palm villages where communities formerly depended on subsistence-based livelihoods (Fig. 4E). The rate of forest conversion(>60% forest cover) within five years prior to oil palm plantation developments was comparatively similar to villages that formerly relied on market-oriented livelihoods (Fig. A8). However, most of the near-intact forest being cleared for plantations in former subsistence-based livelihoods villages was located at relatively high altitude and had received considerable amount of rain during the wet season over the last decades (Fig. A7a-b).

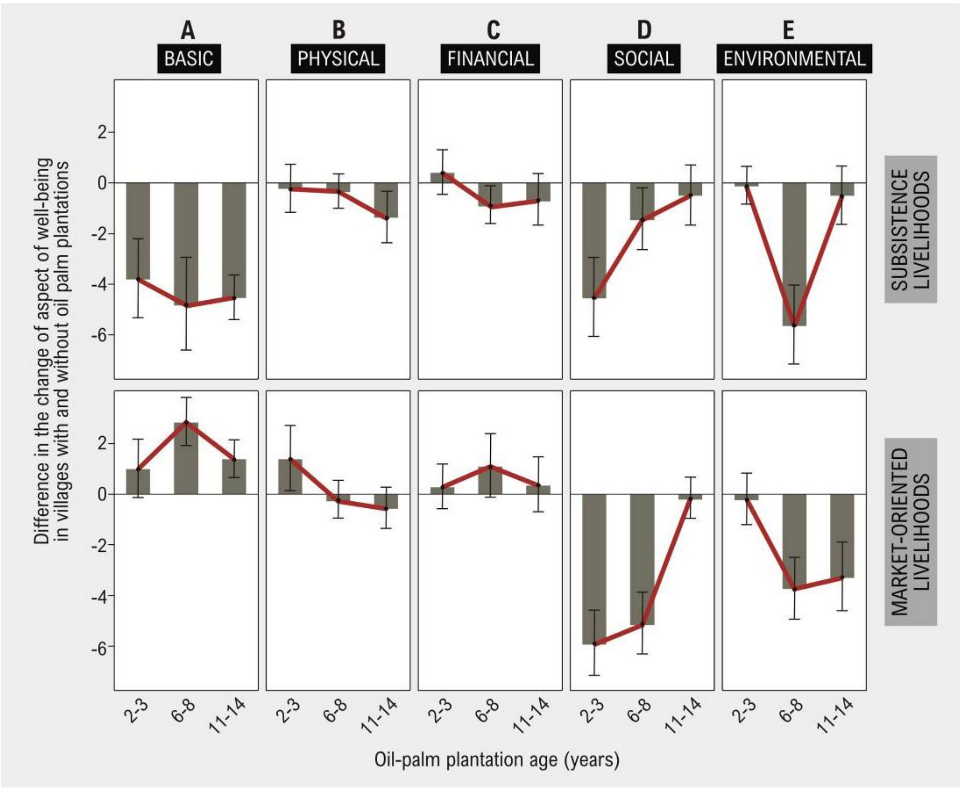

Fig. 3. Difference in the mean rate of change of aspects of well-being over varying oil palm plantation ages in years, in villages with and without oil palm, where most communities formerly depended on: subsistence-based livelihoods or market-oriented livelihoods. Large negative values indicate a greater decline in well-being relative to the counterfactual. Aspects of well-being include: (A) basic well-being (living condition), (B) physical well-being (infrastructure), (C) financial well-being (income support), (D) social well-being (security and social equity), and (E) environmental well-being (natural hazard prevention). Error bars represent 95% confidence intervals.

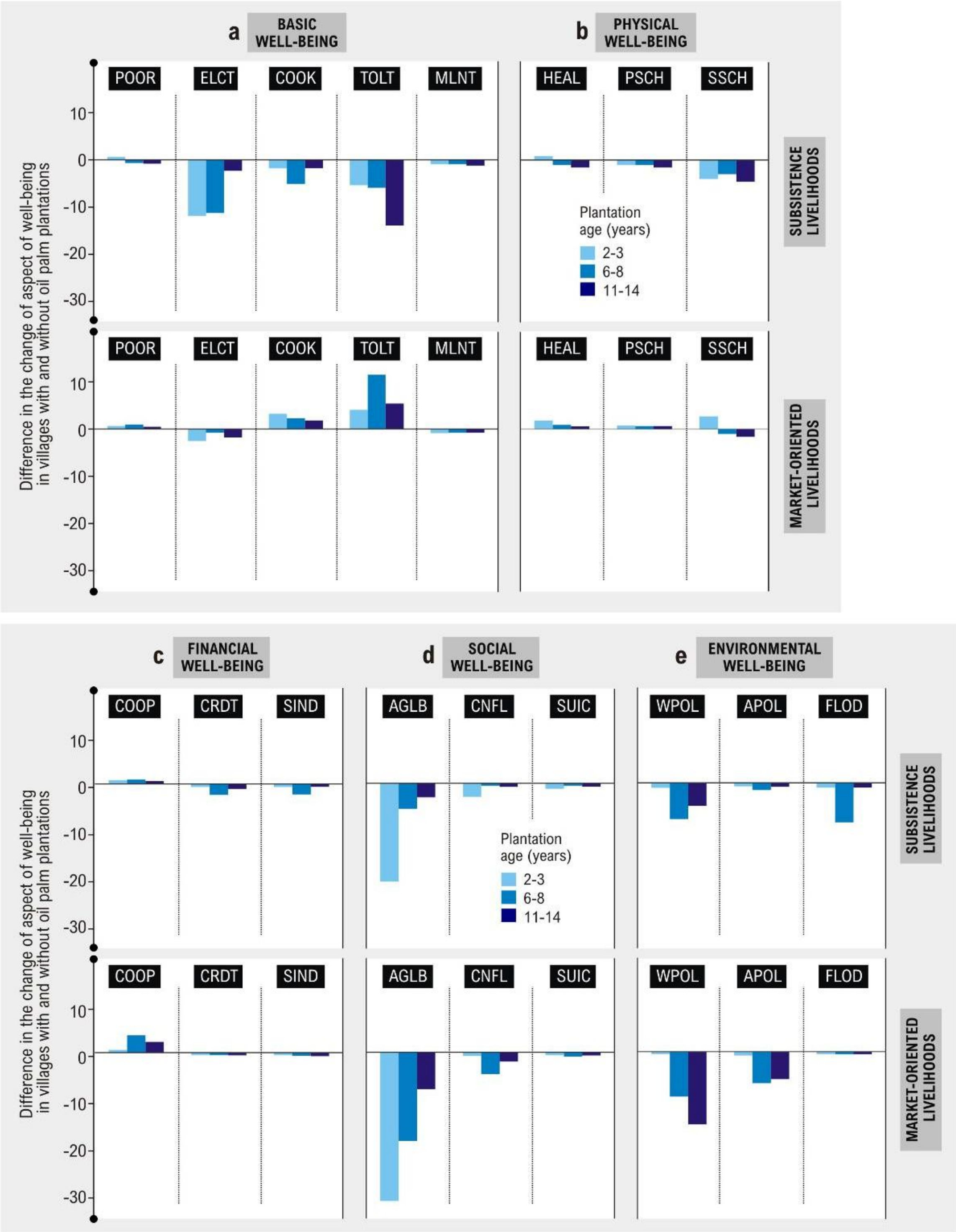

Fig. 4. Difference in the mean rate of change of aspects of well-being over varying oil palm plantation ages (in years) between villages with and without oil palm, where most communities formerly depended on subsistence-based livelihoods or market-oriented livelihoods. Large negative value indicates higher reduction of aspect of well-being relative to the counterfactual. Aspects of well-being include: (A) basic well-being (living condition), (B) physical well-being (infrastructure), (C) financial well-being (income support), (D) social well-being (security and social equity), and (E) environmental well-being (natural hazard prevention). Detail explanation for each variable is provided in Table 1.

3.4. Benefits vary through time

3.4.1. Socioeconomic effect

In villages that had an existing market economy we observed that basic well-being indicators, such as adequate sanitation and energy for cooking, improved 6-8 years after a plantation had been established (Fig. 4A). Physical well-being indicators such as access to healthcare facilities and secondary schools primarily improved in the early stages (i.e. 2-3 years) of oil palm plantation development (Fig. 4B). Financial well-being improved mainly through increased access to credit schemes after 6-8 years (Fig. 4C).

On the other hand, for oil palm established in villages where most communities had relied on subsistence-based livelihoods, we observed the opposite trends on socioeconomic aspects of well-being. Basic well-being indicators such as access to electricity, adequate sanitation and energy for cooking were markedly reduced since the early stages (i.e. 2-3 years) until 11-14 years of oil palm plantation development compared to the control villages (Fig. 4A). Physical well-being indicators, in particular access to secondary schools, were also reduced (Fig. 4B). Reduced basic and physical well-being relative to the controls likely occurred due to a combination of the remoteness of villages (Fig. A7c) and the influx of workers from outside the region. An increase in wage labourers in these villages was substantially higher compared to the controls in the first 2-3 years of plantation development (Fig. 4D), and the ethnic diversity of communities also increased after plantations were established (Fig. A9b). Labour influx in some villages may be related to the existing low population density of these villages (Fig. A7d).

In villages where most communities had relied on subsistence-based livelihoods, financial well-being indicators (e.g. access to cooperative schemes, number of small enterprises) reduced relative to the controls after 6-8 years of plantation development (Fig. 4C). This could reflect the impact of increased specialisation towards cash cropping (Cramb *et al.* 2009; Kremen *et al.* 2012) and increased scarcity of forest products, such as rattan (Meijaard *et al.* 2014).

3.4.2. Environmental impacts

Water and air pollution in oil palm landscapes is sometime associated with the production of palm oil mill effluent (POME) in the oil extraction process after harvesting (Singh *et al.* 2010). This could explain why water and air pollution was often reported in the 6-8 years after plantation establishment (Fig. 4E), around the period when fruit yields have become substantial (Carter *et al*. 2007). Excessive applications of pesticides and fertiliser could also contribute to water pollution (Meijerink *et al.* 2008; Comte *et al.* 2012). It has been estimated that for every tonne of crude palm oil produced, about 2.5 tonnes of liquid waste is generated (Ahmad *et al*. 2003), although companies vary on how this waste is treated.

3.5. Interacting and possible spillover effects

The influx of workers in remote villages that lack infrastructure facilities (Fig. A6a-b) could be associated with the reported reduction in electricity provision, clean sanitation, energy for cooking, and secondary schools, which were all substantially greater in these villages compared to the counterfactual (Fig. 4A-B). This does not necessarily mean that such facilities are reduced in villages with oil palm development, but it is rather caused by reduced proportion on the provision of such facilities relative to village population as the population increased. An increase in waged labourers from outside the region not only occurs in remote villages where most communities had relied on subsistence-based livelihoods, but also in semirural villages where communities were formerly dependent on market-oriented livelihoods. In the latter, the increase in waged labourers was substantially higher relative to the controls up to 6-8 years of plantation being established (Fig. 4D). This could reflect higher pressure to intensify agricultural production and labour requirements, both for plantations and oil palm mills that largely occur in semirural villages (Fig. A7f).

Conflicts have occurred more frequently in villages where communities formerly relied on market-oriented livelihoods, particularly after 6-8 years of plantation age (Fig. 4D). In these villages it is possible that these conflicts are triggered by communities' discontent over insufficient company benefit sharing to local communities (Sheil *et al.* 2009; Abram *et al.* 2017) after initiation of harvesting at around four years (Carter *et al.* 2007), as well as a signal of rising social inequalities and disparities (Euler *et al*. 2017). On the other hand, in villages formerly relying on subsistence-based livelihoods, conflicts mostly occurred at the start-up phase of plantations (i.e. 2-3 years). In former subsistence-based villages, indigenous communities dominate (Fig. A9a). In these villages, the conflicts could be a result of the loss of indigenous land and perceived lack of land compensation at the beginning of plantation development (2-3 years), due to a weak land tenure system (Colchester *et al.* 2006).

4. Discussion

There is a widespread belief that oil palm development results in increased socioeconomic well-being. Yet, in Kalimantan, we found that the socioeconomic effects of the industry were not always equal across villages, and depended on the biophysical characteristics and baseline socioeconomic conditions of communities prior to oil palm development. In villages where communities had mostly relied on market-oriented livelihoods, oil palm development was associated with increased basic, physical and financial well-being. However, in remote forested villages where communities had often relied on subsistence-based livelihoods, a substantial reduction in basic, physical and financial well-being was observed, along with reduced social and environmental well-being. This could reflect harmful implications of rushed development in remote areas where the government's regulatory powers and monitoring capacity are limited (Zoomers *et al.* 2017). Two-thirds of the new oil palm plantations developed between 2000 and 2015 in Kalimantan were situated in villages where the majority of communities had relied on subsistence-based livelihoods. Further expansion of oil palm in remote forested landscapes, such as in Kalimantan and Papua, should therefore be considered more carefully. While poverty can be caused by isolation, abrupt contact with a market economy can lead to exacerbation of poverty and displacement of communities who are not well integrated in the market system. Alternative policies that could facilitate local communities in remote areas to thrive and prosper given the right skills, strengths, and social context should be sought (Ruiz-Pérez *et al*. 2004; Shackleton *et al.* 2011).

For oil palm industries that have been developed, regardless of baseline village livelihood sector, our findings show that unsustainable livelihoods, increased socioeconomic disparity, and environmental issues remain major challenges. Local communities are burdened with the socioeconomic and environmental costs of poorly planned and implemented development, while a small number of rural and urban elites may take the largest share of economic benefits (Sheil *et al.* 2009). Taxation of oil palm with direct production bonuses accruing at regency and district levels could ensure that the economic benefits of industrial oil palm directly compensate local development costs (McCarthy *et al.* 2012; Falconer *et al.* 2015). However, to achieve this would require several vital adjustments in terms of (a) fiscal policy on collection and redistribution of revenues, (b) monitoring and regulation of tax compliance, and (c) data sharing and transparencies among different key government ministries involved in the oil palm sector (i.e. Ministry of Environment and Forestry; Ministry of Agriculture; Ministry of Villages, Disadvantaged Regions and Transmigration; Ministry of Finance; and Ministry of Agrarian Affairs and Spatial Planning). These issues are inextricably and causally intertwined, and they ought to be addressed in concert.

The current fiscal policy in Indonesia highlights relatively low levels of tax collection from the oil palm industry and redistribution of revenues to local governments, with only an estimated 14 % of palm oil tax revenues being redistributed to local governments (Falconer *et al.* 2015). Corruption and lack of tax compliance are recognized as key reasons for low levels of tax collection, and are considered to be the biggest issues tainting the reputations of many oil palm companies in Indonesia (Falconer *et al.* 2015; CNN Indonesia 2017; Mongabay 2018a). In the provinces of West Kalimantan and Riau alone, only 10% and

30% oil palm plantation companies have complied with their tax obligations, respectively (Tempo 2016; Times Indonesia 2018). Indonesia's Corruption Eradication Commission, known as KPK, has recently been called upon to intervene in the country's palm oil sector with the hope of rectifying this problem (Tempo 2017c; Mongabay 2018a). However, the work of the KPK also faces tremendous challenges given uncertainty in land ownership and permits, and lack of data sharing and transparencies among different government ministries, as reflected by the slow progress in the implementation of One Map Policy or *Kebijakan Satu Peta* (KSP) that attempts to bring together data from different government departments in a single spatial platform (Kompas 2018). The KSP data portal was eventually launched by the Indonesian President in December 2018, and this is a substantial achievement. However, the accessibility of the data is currently restricted only to the President and Vice President, government ministries, and local government heads, i.e. Governors and *Bupati* (Head of Regency) (Presidential Instruction No. 20/2018). Excluding non-governmental organizations and the general public from accessing these data fundamentally limits the utility and the main goal of the KSP in providing transparency and inclusiveness (Mongabay 2018b). It is also recognizable that analysing multifaceted geospatial data would require adequate skills in data processing, modelling, and analysis, and importantly collaborative efforts across different disciplines and levels of society to provide accurate interpretation in different contexts, in which the public could greatly assist (Mongabay 2018b). Mechanisms for including public participation in analysing the data are required for the effectiveness of the KSP, not only to resolve conflicts related to overlapping land permits, but also to provide foundations for good governance and planning for healthy and sustainable developments that ultimately benefit rural people in the long run.

While our study provides an understanding of the impact of oil palm development in general across different types of plantations, it is worth mentioning that there are currently a few mechanisms that attempt to improve the performance of oil palm plantations to deliver socioeconomic benefits to villages. Certification schemes, such as the Roundtable on Sustainable Palm Oil (RSPO), could help considerably, although by 2015, only 12% of the oil palm plantations in Kalimantan that had been certified (Fig. 1A). Although many of the earlier plantations in Kalimantan and Sumatra contained little forest when they were RSPO certified, Carlson et al. (2018) demonstrated that most of these plantations reduced deforestation rates. On the other hand, the impact of this scheme in reducing fire occurrences (Cattau *et al.* 2016; Noojipady *et al.* 2017; Carlson *et al.* 2018) and delivering socioeconomic benefits to village communities are questionable (Morgans *et al.* 2018). Further scrutiny of the RSPO-certified plantation estate using our analytical framework could help address this knowledge gap.

While the premise regarding variation in the impact of large-scale agriculture, land reform, and development in general in different locations has been reported in numerous studies (e.g. Mertz *et al.* 2009; Shete & Rutten 2015), evidence for the heterogeneity of the impact on well-being was lacking for the oil palm. Lack of understanding and evidence about the conspicuous difference between the impact of oil palm on market-oriented livelihoods and the impact on subsistence-based livelihoods is (and is used as) a basis of constant debate in the Indonesian politics on development objectives, particularly between the Ministry of Environment and Forestry (who effectively has jurisdiction in the majority of forest area and is responsible for the welfare of nearby communities who largely depend on subsistence-based agriculture, including farming, fishing and gathering of non-timber forest products), the Ministry of Agriculture (who is responsible for commercialized agriculture sector and welfare of the peasants), and the Ministry of Villages, Disadvantaged Regions and Transmigration (who is responsible for advancing developments in the outer islands of Java and transmigration programs) (Mongabay 2016; Tempo 2017a, b). For the local government at *Kabupaten* or Regency level, direction towards supporting versus resisting oil palm is likely to be informed by the vision of most communities: either to pursue socioeconomic growth or to maintain socioecological capital. Regencies where the majority of communities depend highly on forest environmental income (which tend to be of indigenous background with stronger ties to ancestral land) may place higher importance on maintaining socioecological values (Potter 2009; Sirait 2009). Acknowledging that the impacts of oil palm developments can be fundamentally different across different baseline village livelihood systems should inform fruitful multi-level and cross-sectoral government discussions on the long-term risks and benefits of oil palm plantation on the well-being of local communities.

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Appendix A. Supplementary Figures

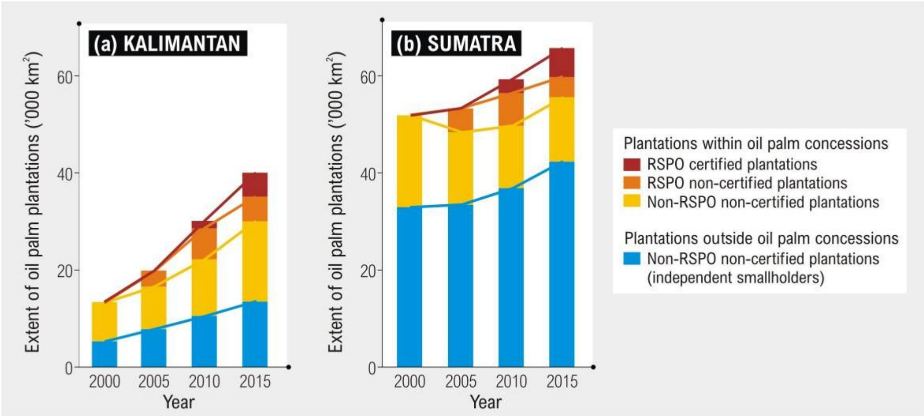

Fig. A1. The change in the extent of oil palm plantations in (a) Kalimantan, and (b) Sumatra, every 5 years between 2000 and 2015, by type of plantation holder: Roundtable on Sustainable Palm Oil (RSPO) certified plantations, RSPO non-certified plantations, Non-RSPO non-certified plantations within oil palm concessions, and Non-RSPO non-certified outside oil palm concessions (independent smallholders).

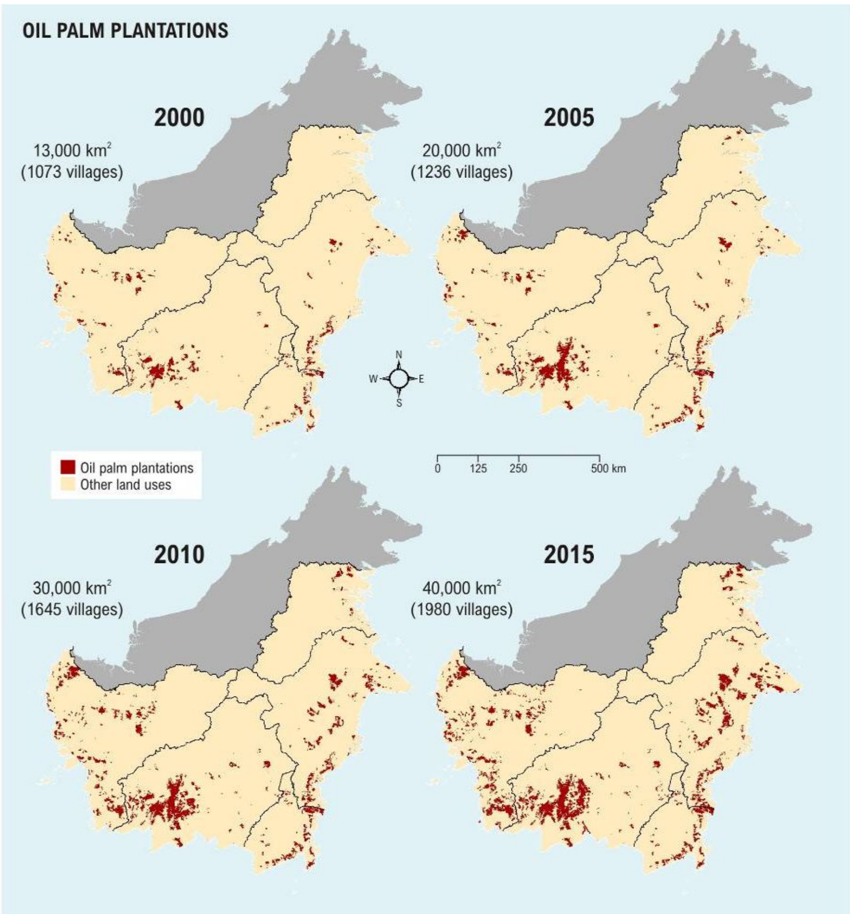

Fig. A2. Change in the distribution of oil palm plantations in Kalimantan every five years between 2000 and 2015.

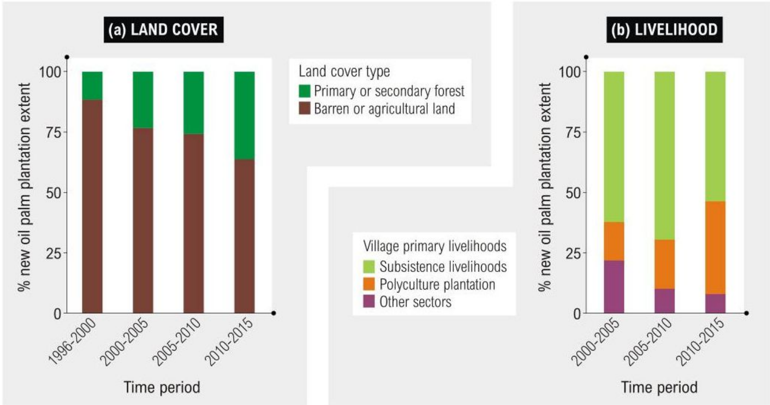

Fig. A3. (a) Land cover types, including primary or secondary forest, barren or agricultural land, and (b) primary livelihood of communities, including subsistence-based livelihoods, plantation (polyculture), and other sectors (horticulture, aquaculture, agricultural services, and non-agricultural sectors), where new oil palm plantations have been developed in Kalimantan in 1996-2000, 2000-2005, 2005-2010, and 2010-2015.

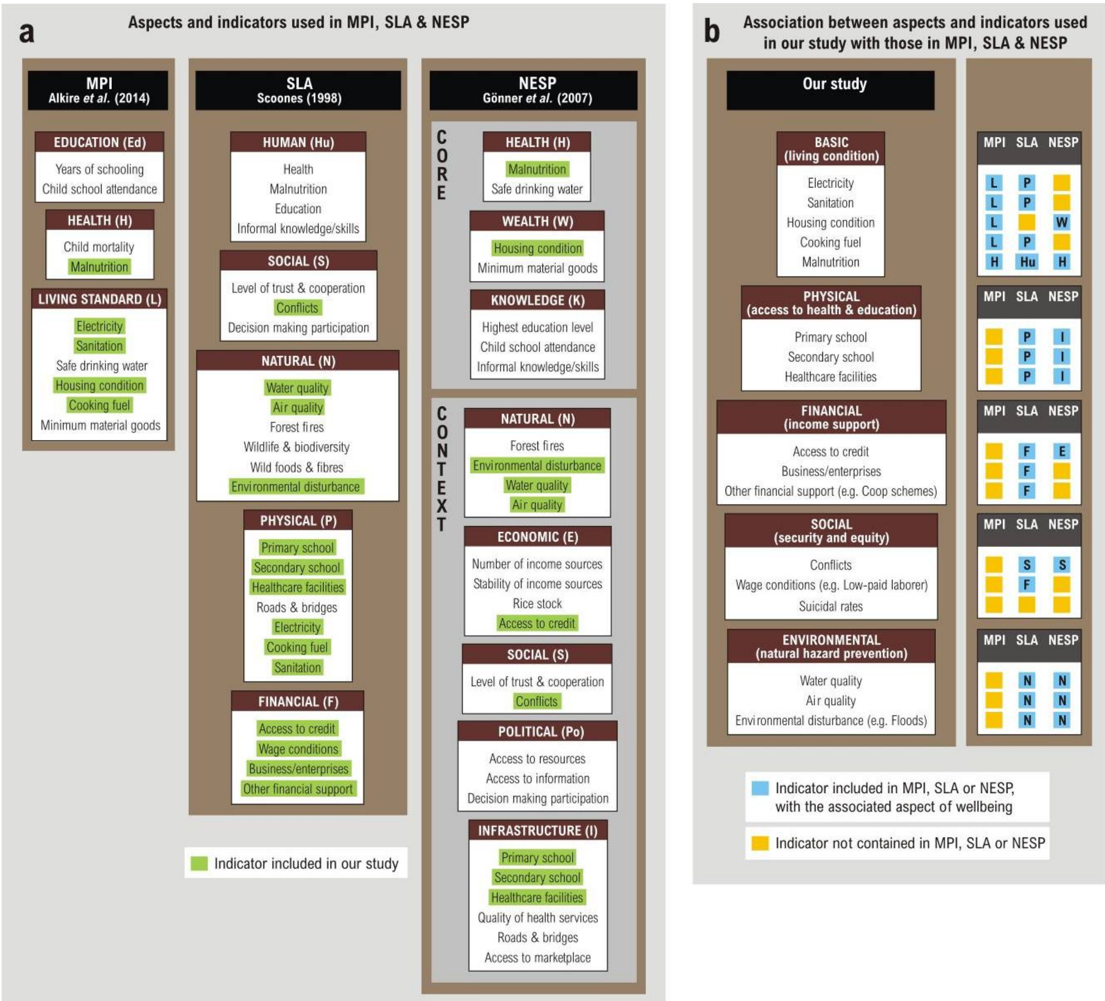

Fig. A4. (a) Aspects (dimensions) and indicators of well-being used in the Multidimensional Poverty Index (MPI, Alkire *et al.* 2014), the Sustainable Livelihood Approach (SLA, Scoones 1998), and the Nested Spheres of Poverty (NESP, Gonner *et al*. 2007). (b) Association between aspects and indicators used in our study with those encapsulated in MPI, SLA and NESP, with the associated aspect represented by the capital letter in the second column. For MPI, the aspects include: Education (Ed), Health (H), and Living standards (L). For SLA, the aspects include: Human (Hu), Social (S), Natural (N), Physical (P) and Financial (F). For NESP, the Core includes: Health (H), Wealth (W), and Knowledge (K); and the Context includes: Natural (N), Economic (E), Social (S), Political (Po), and Infrastructure (I).

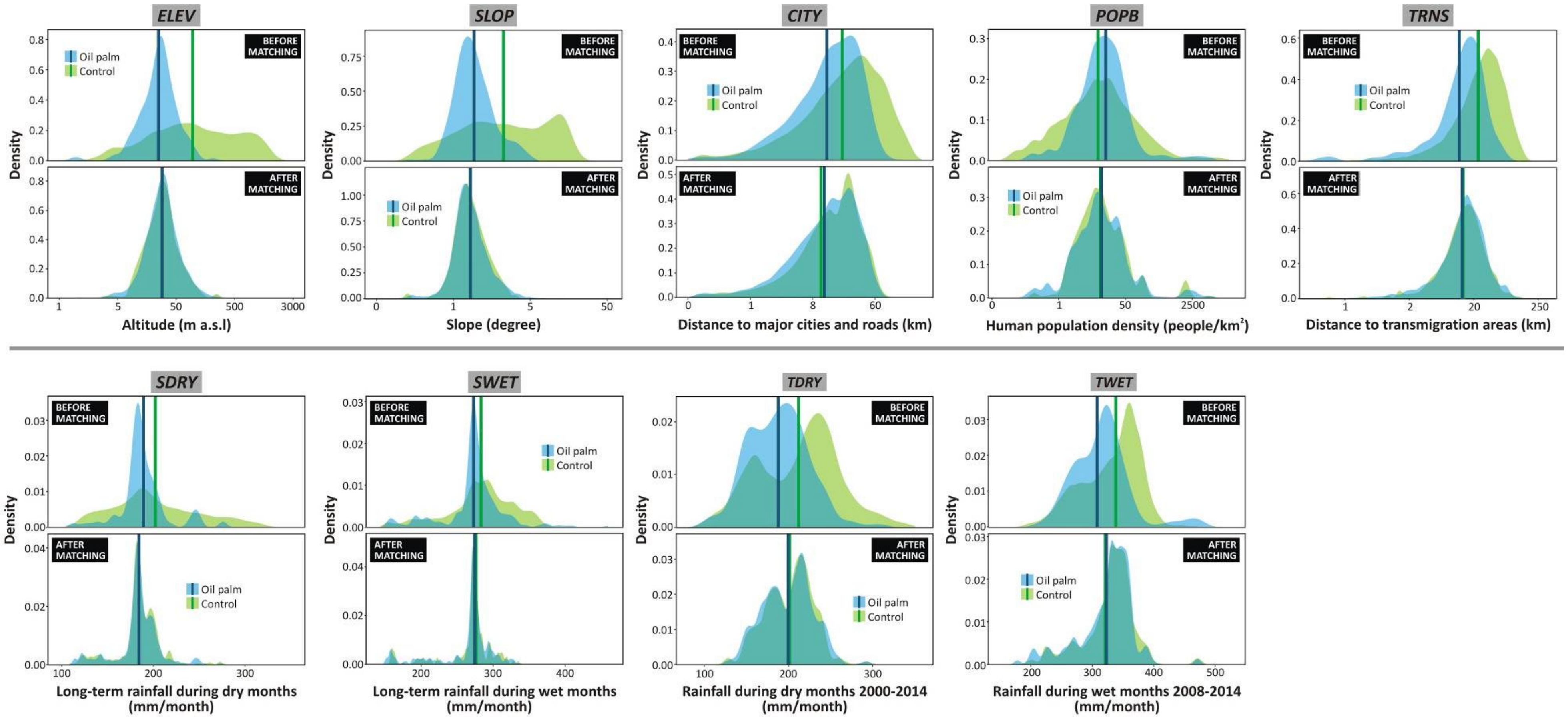

Fig. A5. The distributions of continuous variables characterizing oil palm plantation and control villages in Kalimantan, before and after matching, aggregated across time periods used in the analyses. Variables include: mean elevation (*ELEV*), mean slope (*SLOP*), mean distance to large cities or arterial roads (*CITY*), mean human population density (*POPB*), mean distance to transmigration areas (*TRNS*), mean long-term mean monthly rainfall during the dry and wet season (*SDRY* and *SWET*), and mean monthly mean rainfall during the dry and wet season between 2000 and 2014 (*TDRY* and *TWET*). The degree of overlap between the distributions of variables for oil palm villages and controls increased after matching, indicating increased similarity in the characteristics of oil palm villages and matched controls. Vertical lines indicate the mean value for oil-palm villages and controls, with the gap between the two lines decreased after matching.

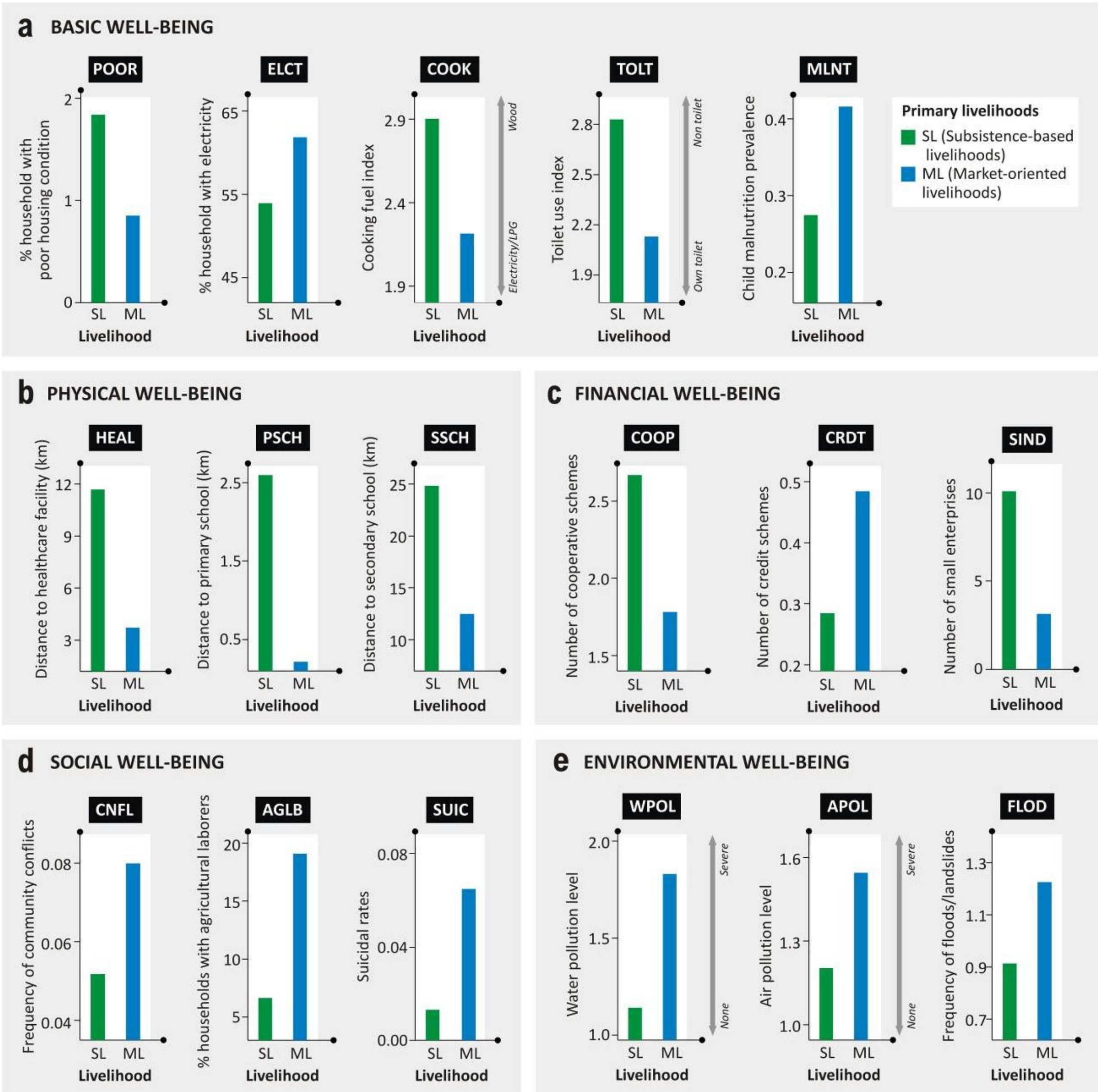

Fig. A6. Baseline community welfare prior to oil-palm plantation developments: (a) Basic wellbeing (living condition), (b) Physical wellbeing (infrastructure), (c) Financial wellbeing (income support), (d) Social well-being (security and social equity), and (e) Environmental wellbeing (prevention of natural hazards), in villages with different main livelihood sectors: subsistence-based livelihoods (SL; swidden farming of dryland rice (inter-cropped with banana, maize, and cassava, and typically supplemented by market exchange for forest and/or agroforest products) and inland fishing) and market-oriented livelihoods (ML; including polyculture plantations (e.g. coffee, rubber, oil palm, coconut), horticulture, aquaculture, agricultural services, and non-agricultural sectors). Detail explanation of socioeconomic indicator is provided in Table 1.

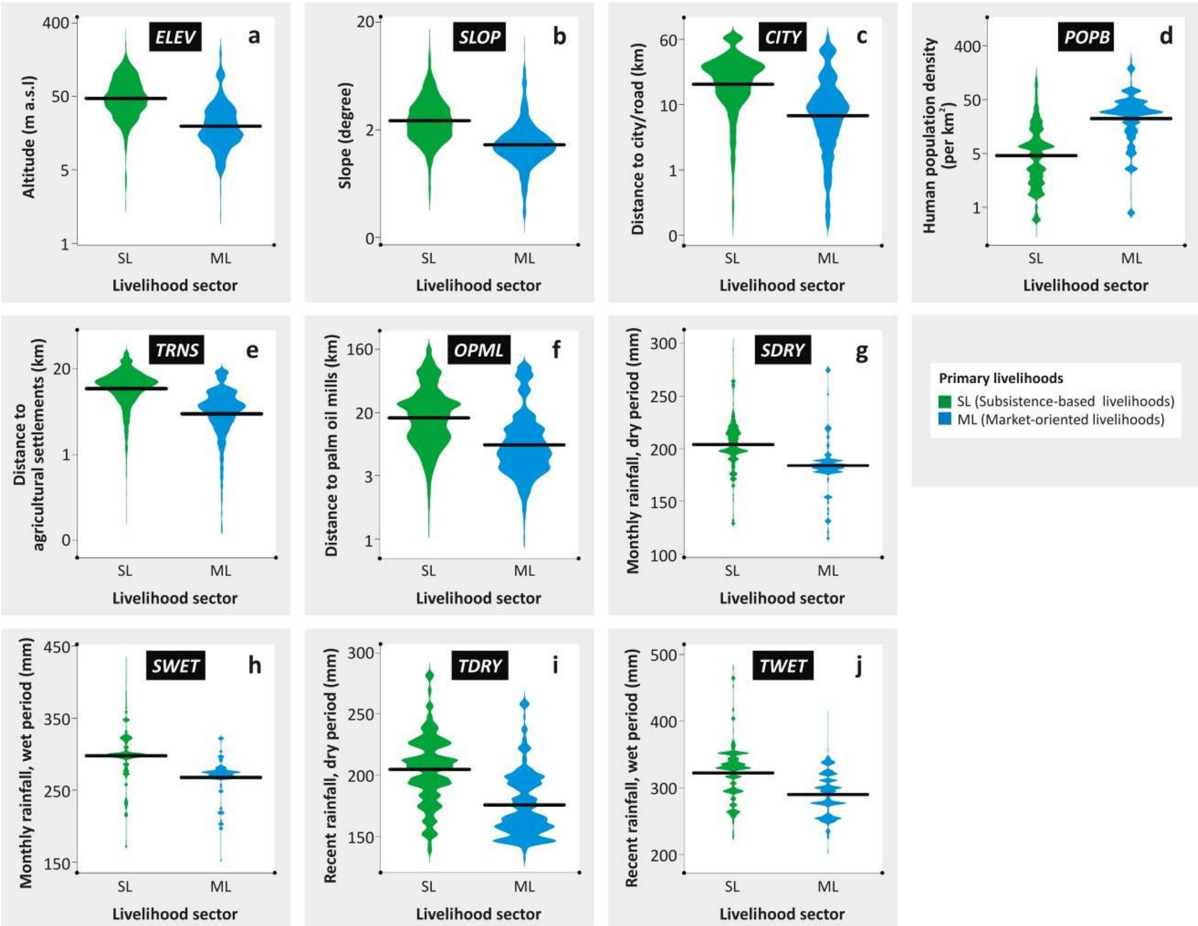

Fig. A7. Biophysical characteristics of villages with different main livelihood sectors: subsistence-based livelihoods (SL; swidden farming of dryland rice (inter-cropped with banana, maize, and cassava, and typically supplemented by market exchange for forest and/or agroforest products) and inland fishing) and market-oriented livelihoods (ML; including polyculture plantations (e.g. coffee, rubber, oil palm, coconut), horticulture, aquaculture, agricultural services, and non-agricultural sectors). Biophysical characteristics include: (a) elevation: *ELEV*, (b) slope: *SLOP*, (c) distance to major cities and roads: *CITY*, (d) human population density: *POPB*, (e) distance to transmigration areas: *TRNS*, (f) distance to palm-oil mills: *OPML*, (g-h) long term monthly rainfall during the dry and wet seasons: *SDRY* and *SWET*, and (i-j) monthly rainfall between 2000 and 2014 during the dry and wet seasons: *TDRY* and *TWET*.

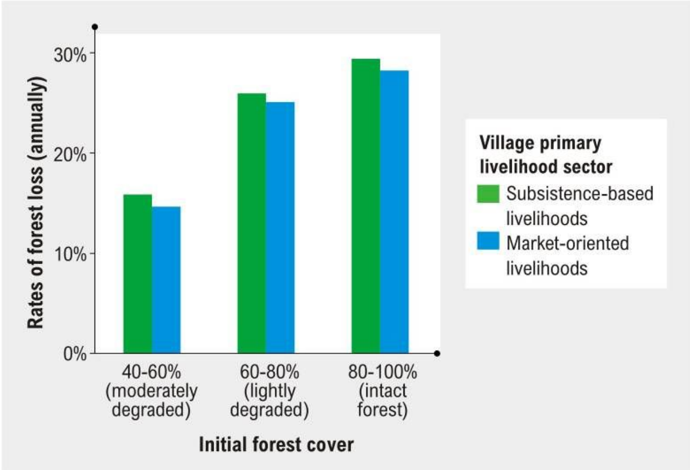

Fig. A8. The rates of annual forest loss over a five year period prior to oil palm developed between 2000 and 2014, by initial forest cover in villages where most communities had relied on subsistence-based livelihoods or market-oriented livelihoods.

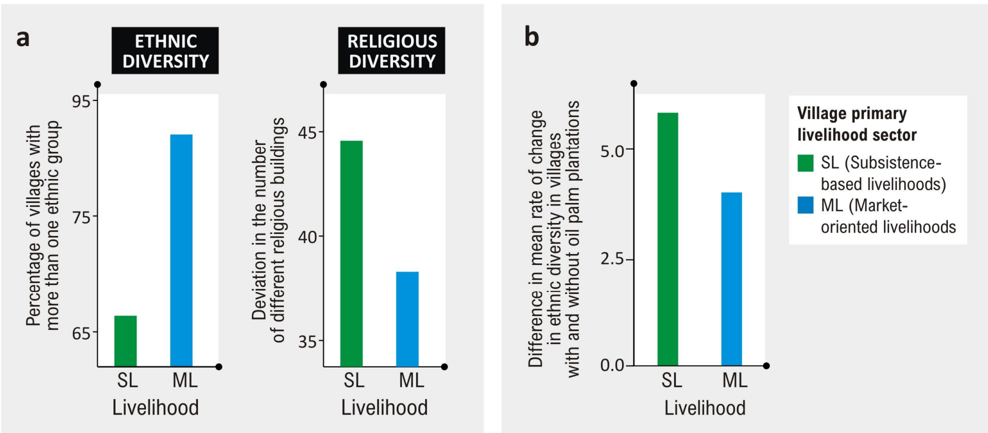

Fig. A9. (a) Ethnic and religious diversity of oil-palm villages where communities formerly relied on subsistence-based livelihoods (SL) and market-oriented livelihoods (ML). We used indicators of percentage of villages with more than one ethnic group (where higher value indicates higher ethnic diversity in communities) and deviation (i.e. standard deviation) in the number of different religious buildings (where lower value indicates more religiously diverse communities). (b) Difference in mean rate of change in ethnic diversity for villages with and without oil-palm development, where most communities formerly depend on subsistence-based livelihoods and market-oriented livelihoods.

Appendix B. Supplementary Tables

Table B1. Past evaluations on the social impact of industrial-scale oil-palm plantations on rural well-being in developing countries (in chronological order of references for each aspect of well-being), showing a generally positive association between oil palm and socioeconomic aspect of well-being and negative association between oil palm and social and environmental aspects of well-being.

Aspect of well-being	Indicator of well-being	Study area	Time frame	Case-control study ≭	Subsistence-based livelihoods §	Oil palm impact ‡	Reference
Socioeconomic	Income, consumption, employment, and developments	4 communities in West Kalimantan province	2008	N	Y	—	Sirait (2009)
		Bungo district, Jambi province, Sumatra	2007-2009	N	N	+	Feintrenie *et al.* (2010)
		Bungo district, Jambi province, Sumatra	2007-2009	N	N	+	Rist *et al.* (2010)
		78 villages in 8 provinces in Sumatra, Kalimantan & Sulawesi	2010	N	N	+	Budidarsono *et al.* (2012)
		Dabat village, Sanggau district, West Kalimantan province	2010	N	N	+	Julia & White (2012)
		Manokwari district, West Papua province	2011	N	Y	+	Obidzinski *et al.* (2012)
		Kubu Raya district, West Kalimantan province	2011	N	Y	—	Obidzinski *et al.* (2012)
		Boven Digoel district, Papua province	2011	N	Y	—	Obidzinski *et al.* (2012)
		3 oil palm estates in Riau province, Sumatra	2012	N	N	—	Sinaga (2013)
		2 communities in Polochic Valley, Guatemala	2009-2011	N	Y	+	Mingorría *et al.* (2014)
		1 oil palm estate in Bayelsa, Nigeria	2013	N	N	+	Ohimain *et al.* (2014)
		271 households in Riau province, Sumatra	1990-2015	Y	N	+	Alwarritzi *et al.* (2015)
		100 municipalities in Colombia	1993-2009	Y	YN	+	Castiblanco *et al.* (2015)
		245 households in Jambi province, Sumatra	2010	N	N	+	Cahyadi & Waibel (2016)
		Kutai Kertanegara district, East Kalimantan province	2014	N	N	+	Dharmawan *et al.* (2016)
		682 households in Jambi province, Sumatra	2012	Y	N	+	Euler *et al.* (2017)
		98 villages in Jambi province, Sumatra	1992-2012	Y	N	+	Gatto *et al.* (2017)
		682 households in Jambi province, Sumatra	2012	Y	N	+	Krishna *et al.* (2017)
		Summary			N = 12 Y = 5 YN = 1	N+ = 11 (92%) Y+ = 2 (40%) YN+ = 1 (100%)	

‡ Oil palm impact on indicator wellbeing: Positive (+), Negative (—)
≭ Whether or not case-control study was conducted: Yes (Y), No (N)
§ Whether or not the majority of communities within study area have relied on subsistence-based livelihoods prior to oil palm development: Yes (Y), No (N), YN (Mixed)

Table B1. (Continued)

Aspect of wellbeing	Indicator of wellbeing	Study area	Time frame	Case-control study ≭	Subsistence-based livelihoods §	Oil palm impact ‡	Reference
Social	Security, social equity, gender equity	4 communities in West Kalimantan province	2008	N	Y	—	Sirait (2009)
		Bungo district, Jambi province, Sumatra	2007-2009	N	N	—	Rist *et al.* (2010)
		Community along Lemanak River and resettlement site along Tinjar River, Sarawak, Malaysia	1990-2010	N	Y	—	Cramb & Sujang (2011)
		41 households in Bumbun village, Carey Island, Malaysia	2007	N	Y	—	Lai (2011)
		Pru district, Brong Ahafo, Ghana	2009	N	Y	—	Schoneveld *et al.* (2011)
		Dabat village, Sanggau district, West Kalimantan province	2010	N	N	—	Julia & White (2012)
		Manokwari district, West Papua province	2011	N	Y	—	Obidzinski *et al.* (2012)
		Kubu Raya district, West Kalimantan province	2011	N	Y	—	Obidzinski *et al.* (2012)
		Boven Digoel district, Papua province	2011	N	Y	—	Obidzinski *et al.* (2012)
		Jambi province, Sumatra	2012	N	N	—	Manik *et al.* (2013)
		3 oil palm estates in Riau province, Sumatra	2012	N	N	—	Sinaga (2013)
		2 communities in Polochic Valley, Guatemala	2009-2011	N	Y	—	Mingorría *et al.* (2014)
		100 municipalities in Colombia	1993-2009	Y	YN	—	Castiblanco *et al.* (2015)
		4 communities in Berau district, East Kalimantan province	2005-2010	N	N	—	Elmhirst *et al.* (2015)
		1 community in East Kutai district, East Kalimantan province	2005-2010	N	Y	—	Elmhirst *et al.* (2015)
		Meliau, Sanggau district, West Kalimantan province	2010-2012	N	N	—	Li (2015)
		Kampung Lebor, Serian, Sarawak, Malaysia	2012	N	Y	—	Yong & Pang (2015)
		Coastal villages in West Kalimantan province	2013-2015	N	N	—	de Vos (2016)
		682 households in Jambi province, Sumatra	2012	Y	N	—	Euler *et al.* (2017)
		Summary			N = 8 Y = 10 YN = 1	N+ = 0 (0%) Y+ = 0 (0%) YN+ = 0 (0%)	

‡ Oil palm impact on indicator wellbeing: Positive (+), Negative (—)
≭ Whether or not case-control study was conducted: Yes (Y), No (N)
§ Whether or not the majority of communities within study area have relied on subsistence-based livelihoods prior to oil palm development: Yes (Y), No (N), YN (Mixed)

Table B1. (Continued)

Aspect of wellbeing	Indicator of wellbeing	Study area	Time frame	Case-control study ≭	Subsistence-based livelihoods §	Oil palm impact ‡	Reference
Environmental	Water, air or soil quality	Beluran district, Sabah, Malaysia	2007-2008	N	Y	—	Dayang Norwana *et al.* (2011)
		Manokwari district, West Papua province	2011	N	Y	—	Obidzinski *et al.* (2012)
		Kubu Raya district, West Kalimantan province	2011	N	Y	—	Obidzinski *et al.* (2012)
		Boven Digoel district, Papua province	2011	N	Y	—	Obidzinski *et al.* (2012)
		Wilberforce Island, Nigeria	2013-2014	N	N	—	Ohimain & Izah (2014)
		Siak watershed, Riau province, Sumatra	2009-2010	N	N	—	Comte *et al.* (2015)
		Bungku village, Jambi province, Sumatra	2013-2014	N	N	—	Merten *et al.* (2016)
		Kutai Kertanegara district, East Kalimantan province	2014	N	N	—	Dharmawan *et al.* (2016)
		Summary			N = 4 Y = 4 YN = 0	N+ = 0 (0%) Y+ = 0 (0%) YN+ = NA	

‡ Oil palm impact on indicator wellbeing: Positive (+), Negative (—)

≭ Whether or not case-control study was conducted: Yes (Y), No (N)

§ Whether or not the majority of communities within study area have relied on subsistence-based livelihoods prior to oil palm development: Yes (Y), No (N), YN (Mixed)

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Table B2. Survey questionnaire in PODES that used to generate the data represented in Table 1.

Aspect of well-being	Variable (abbreviation)	Associated survey question in PODES (original translation in Bahasa Indonesia in italic font)
Basic (Living conditions)	Proportions of households with poor housing conditions (POOR)	Number of households occuring in slums or poor housing neighbourhoods. *Jumlah rumah tangga yang tinggal di pemukiman kumuh.*
	Proportions of households with electricity (ELCT)	Number of households with electricity. *Jumlah rumah tangga pengguna listrik.*
	Cooking fuel for majority of households (COOK)	Cooking fuel for the majority of households. (1=electricity or liquefied petroleum gas (LPG), 2=kerosene, 3=wood or others). *Bahan bakar yang digunakan sebagian besar rumah tangga untuk memasak. (1=listrik atau LPG, 2=minyak tanah, 3=kayu bakar atau lainnya).*
	Toilet facilities for majority of households (TOLT)	Toilet facility for the majority of households. (1=own toilet, 2=joint toilet, 3=public toilet, 4=no toilet). *Tempat buang air besar sebagian besar rumah tangga. (1=jamban sendiri, 2=jamban bersama, 3=jamban umum, 4=bukan jamban).*
	Child malnutrition incidence in the last year (MLNT)	Number of child malnutrition cases in the last year. *Jumlah balita penderita gizi buruk setahun terakhir.*
Physical (Infrastructure)	Distance to nearest healthcare facility (HEAL)	Distance to the nearest health facilities (hospital, doctor's practice, clinic, public health center, village health center). *Jarak ke sarana kesehatan terdekat (rumah sakit, praktek dokter, poliklinik, puskesmas, puskesdes).*
	Distance to nearest primary school (PSCH)	Distance to the nearest primary schools. *Jarak ke Sekolah Dasar (SD) terdekat.*
	Distance to nearest secondary school (SSCH)	Distance to the nearest secondary (junior high) schools. *Jarak ke Sekolah Menengah Pertama (SMP) terdekat.*
Financial (Income support)	Number of active village cooperative schemes or other schemes (COOP)	Number of cooperative schemes that are actively operated (including KUD, Kopinkra, Kospin, etc). *Jumlah koperasi yang masih aktif beroperasi (termasuk KUD, Kopinkra, Kospin, dll).*
	Number of credit for farmers or communities (CRDT)	Number of credit facilities received by communities in the last year (including KUR, KKP, KUK, KPR, etc). *Banyaknya fasilitas kredit yang diterima penduduk selama setahun terakhir (termasuk KUR, KKP, KUK, KPR, dll).*
	Number of small industries (<20 employees) (SIND)	Number of small or micro-scale industry (less than 20 employees). *Jumlah industri kecil dan mikro (kurang dari 20 pekerja).*

Table B2. (Continued)

Aspect of well-being	Variable (abbreviation)	Associated survey question in PODES (original translation in Bahasa Indonesia in italic font)
Social (Security and social equity)	Frequency of conflicts among communities in the last year (CNFL)	Frequency of conflicts among communities in the last year. *Jumlah kejadian perkelahian massal selama setahun terakhir.*
	Proportion of families with agricultural wage labourers (AGLB)	Number of families with at least one family member working as an agricultural wage labourer. *Jumlah keluarga yang ada anggota keluarganya menjadi buruh tani.*
	Suicidal rates in the last year (SUIC)	Number of suicidal victims in the last year. *Banyaknya korban bunuh diri yang terjadi selama setahun terakhir.*
Environmental (Natural hazard prevention)	Water pollution over the last 3 years (WPOL)	The occurrence of water pollution in the last year (1=none, 2=yes but the issue has not been formally reported by communities, 3=yes and the issue has been formally reported by communities). *Pencemaran air selama setahun terakhir. (1=tidak ada, 2=ada tetapi tidak ada pengaduan dari masyarakat, 3=ada dan ada pengaduan dari masyarakat).*
	Air pollution over the last 3 years (APOL)	The occurrence of air pollution in the last year (1=none, 2=yes but the issue has not been formally reported by communities, 3=yes and the issue has been formally reported by communities). *Pencemaran udara selama setahun terakhir. (1=tidak ada, 2=ada tetapi tidak ada pengaduan dari masyarakat, 3=ada dan ada pengaduan dari masyarakat).*
	Frequency of floods and landslides over the last 3 years (FLOD)	Frequency of floods, flash floods, or landslides in the last three years. *Banyaknya kejadian banjir, banjir banding, dan tanah longsor selama tiga tahun terahkir.*

Table B3. The use of PODES data in studies on socioeconomic and developments across Indonesia (in alphabetical order of references).

References	Study		Use of PODES data	
	Scope	Area	Year	Aspect
Barron *et al*. (2016)	Distributions of conflicts	Indonesia	2003	Population demographics, economic, institutional
Barron *et al.* (2009)	Characteristics of social conflicts	Indonesia	2003	Population demographics, economic, institutional
Budidarsono *et al.* (2012)	Socioeconomic impact of oil palm	Indonesia	2008	Social, economic, infrastructure
Cameron & Shah (2013)	Social impact of cash transfer programs	Indonesia	2006	Population demographics, social, economic
Cameron & Shah (2015)	Risk-taking behaviour given exposure to natural disaster	Indonesia	2008	Social, economic, environment
Cooley *et al.* (2016)	Impact of maternal undernutrition on child health	Indonesia	2011	Social, infrastructure
De Juan *et al.* (2015)	Religious conflicts	Indonesia	2003	Social
Grimm *et al.* (2015)	Impact of electricity on fertility	Indonesia	1996, 2000, 2003, 2006, 2008	Infrastructure, livelihood
Hasan *et al.* (2013)	Early education and development	Indonesia	2003, 2006, 2008, 2011	Population demographics, social, infrastructure
Hashiguchi & Higasikata (2017)	Human capital externalities	Indonesia	1996, 2006	Social, economic, infrastructure
Jagger & Rana (2017)	Impact of REDD+ on social welfare	Kalimantan	2008, 2011	Infrastructure, land use
Korkeala & Obidzinski (2012)	Oil-palm expansion and household welfare	Kalimantan	2003	Land use
Lewis (2016)	Impact of local political fragmentation on fiscal and service	Indonesia	2003, 2006, 2008, 2011, 2014	Social, economic, infrastructure
Maharani & Tampubolon (2014)	Impact of fiscal decentralisation on child immunisation	Indonesia	2011	Population demographics, economic, infrastructure
Makovec *et al.* (2016)	Impact of restrictive emigration policies on social welfare	Indonesia	2006	Population demographics, social, economic
Miguel *et al.* (2005)	Impact of social capital on industrialization	Indonesia	1986	Population demographics, social, economic, institutional
Miteva et al. (2015)	Impact of forest management certification on human wellbeing	Kalimantan	2000, 2006, 2008	Population demographics, infrastructure, land use
Liu & Yamauchi (2014)	Impact of population growth on income	Indonesia	2000, 2006	Infrastructure, environment
Olsson & Valsecchi (2015)	Impact of fiscal decentralisation on economic and social welfare	Indonesia	2003, 2006, 2008	Infrastructure

Table B3. (Continued)

References	Study		Use of PODES data	
	Scope	**Area**	**Year**	**Aspect**
Parmanto *et al.* (2008)	Multidimensional visualization of village health statistics	Indonesia	2003	Social, environment
Rokx (2010)	Provision of health services	Indonesia	1996, 2006	Population demographics, social, infrastructure
Sparrow (2008)	Effectiveness of health card programs	Indonesia	1996	Social, economic, infrastructure
Sparrow & Pradhan (2014)	Efficiency of district's public health and education programs	Indonesia	2003, 2006, 2008	Population demographics, infrastructure
Sujarwoto & Tampubolon (2016)	Access to internet facilities	Indonesia	2011	Population demographics, economic, infrastructure
Sugiarto *et al.* (2017)	Impact of climate change on water resources and agriculture	East Java	2014	Economic, infrastructure, land use, environment
Tan Soo (2017)	Valuation of air quality	Indonesia	2006	Economic
Vothknech & Sumarto (2011)	Impact of violent conflicts on economic growth	Indonesia	2003, 2006, 2008	Social, economic
Widayati *et al*. (2014)	Livelihoods and access to clean water	South Sulawesi	2011	Population demographics, social, economic
Yamauchi *et al.* (2009)	Dynamics of village economies	Indonesia	1996, 2006	Infrastructure

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Table B4. PODES censuses used to assess the change in village well-being (indicated in check marks) over varying plantation ages: 2-3, 6-8, and 11-14 years, and the number villages included as treatment units and control units for each time period of analysis.

Plantation age	**Analysis time frame**	**PODES census year**						**Number of unit**	
		2000	**2003**	**2006**	**2008**	**2011**	**2014**	**Treated**	**Control**
2-3 years	2000-2003	√	√					100	5673
	2003-2006		√	√				51	5579
	2006-2008			√	√			116	5241
	2008-2011				√	√		343	5170
	2011-2014					√	√	70	4829
6-8 years	2000-2006	√		√				100	5673
	2000-2008	√			√			99	5223
	2003-2011		√			√		50	5168
	2006-2014			√			√	116	4827
	2008-2014				√		√	70	4829
11-14 years	2000-2011	√				√		99	5153
	2003-2014		√				√	50	4826
	2000-2014	√					√	99	4812

Table B5. The robustness of the matching analysis against hidden bias due to an unobserved confounder, as indicated by the minimum value of the sensitivity parameter Γ_C across wellbeing indicators, for the overall analysis and each of the livelihood subgrouping analysis (subsistence-based livelihoods and market-oriented livelihoods), for each time period. Γ_C=1 means that unobserved confounder needs to be at least as strong as the included effects to have an influence. Thus, larger min(Γ_C) indicates a more robust analysis against hidden bias.

Analysis type according to plantation age	**Analysis time frame**	**min(Γ_C)**
2-3 years	2000-2003	2.24
	2003-2006	1.88
	2006-2008	1.74
	2008-2011	2.16
	2011-2014	1.98
6-8 years	2000-2006	1.82
	2000-2008	2.01
	2003-2011	1.92
	2006-2014	1.72
	2008-2014	2.06
11-14 years	2000-2011	2.11
	2003-2014	1.94
	2000-2014	2.04