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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 oil palm 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.

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

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predominantly been developed in Sumatra and Kalimantan (Indonesian Borneo), with rapid expansion in recent decades (Figs. 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, Meijaard, & Wilson, 2015; Gaveau, Sheil, Husnayaen, Arjasakusuma, & Ancrenaz, 2016). Agricultural expansion into forested areas could have profound impacts on local and traditional communities who depend highly on forest produce and income (Sheil, Casson, Meijaard, Van Noordwjik, & Gaskell, 2009).

In 2017, the Indonesian oil palm industry was estimated to employ 3.8 million people (Directorate General of Estate Crops Indonesia, 2017), ca. 2.4% of the total Indonesian workforce (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; Li, 2016; Potter, 2012). Other developing and emerging countries, such as Brazil, Peru, Colombia, Nigeria, Gabon, Ghana, and Rwanda, are following similar steps (Byerlee, Falcon, & Naylor, 2017; Meijaard, Garcia-Ulloa, Sheil, Carlson, & Wich, 2018; Villela, D'Alembert, Rosa, & Freitas, 2014). 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 (Rist, Feintrenie, & Levang, 2010; Sheil et al., 2009), and consultation with indigenous peoples has not always occurred (Colchester, Jiwan, Andiko, Sirait, & Firdaus, 2006), leading to escalating conflicts with local people (Abram, Meijaard, Wilson, Davis, & Wells, 2017; Wakker, Watch, & de Rozario, 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, Andriani, Komarudin, & Andrianto, 2012; Obidzinski, Dermawan, & Hadianto, 2014; Zen, Barlow, Gondowarsito, & McCarthy, 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, Wilson, Abram, Nunn, & Gaveau, 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 et al. (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, Nanseki, & Chomei, 2015; Euler, Krishna, Schwarze, Siregar, & Qaim, 2017; Gatto, Wollni, Asnawi, & Qaim, 2017; Krishna, Euler, Siregar, & Qaim, 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, Sukapti, Maemunah, Prasetyohadi, & Tømte, 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 (Blaber-Wegg, Hodbod, & Tomei, 2015; Hodbod & Tomei, 2013). 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, Schwarze, Siregar, & Qaim, 2016; Jelsma, Schoneveld, Zoomers, & Van Westen, 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, Fisher, Ali, Beer, & Bond, 2007; Daniel, Muhar, Arnberger, Aznar, & Boyd, 2012). However, these are difficult to aggregate at the village-level and are not available within the PODES dataset.

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 the majority of households	−1	Categorical (1 = electricity or liquefied petroleum gas (LPG), 2 = kerosene, 3 = wood/others)
	TOLT	Toilet facilities for the 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 the nearest healthcare facility	−1	Continuous
	PSCH	Distance to the nearest primary school	−1	Continuous
	SSCH	Distance to the 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.

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, Meijaard, Wells, Abram, & Wilson, 2016), and (2) market-oriented livelihoods, including polyculture plantations (e.g. coffee, rubber, oil palm, coconut), horticulture, aquaculture, agricultural services, and non-agricultural sectors.

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 6600 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).

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, Salim, and Arjasakusuma (2016) and Santika (unpublished data). 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, Gillespie, & Zen, 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, Meyer, Dislich, Euler, & Faust, 2016), hence our analysis reflects more broadly the effects of all oil palm developments. In addition, the proportion of oil palm

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 90 m Digital Elevation Database v4.1 (Jarvis, Reuter, Nelson, & Guevara, 2008)
SLOP	Mean slope (Static)	Continuous (degree)	SRTM 90 m 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 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, Potapov, Moore, Hancher, & Turubanova, 2013) and Indonesia's primary and secondary forest map (Margono, Potapov, Turubanova, Stolle, & Hansen, 2014)
Agricultural productivity			
SDRY	Mean long-term monthly rainfall during the dry season (Static)	Continuous (mm)	WorldClim (Fick & Hijmans, 2017)
SWET	Mean long-term monthly rainfall during the 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 the 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 the 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, Bolvin, Nelkin, Wolff, & Adler, 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.

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 B1). 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, Chatterjee, Conconi, Seth, & Vaz, 2014), the Sustainable Livelihood Approach (SLA, Scoones, 1998), and the Nested Spheres of Poverty (NESP, Gönner, Haug, Cahyat, Wollenberg, DeJong, Limberg, Cronkleton, Moeliono, & Becker, 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.

2.4. Analysis methodology

2.4.1. 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,

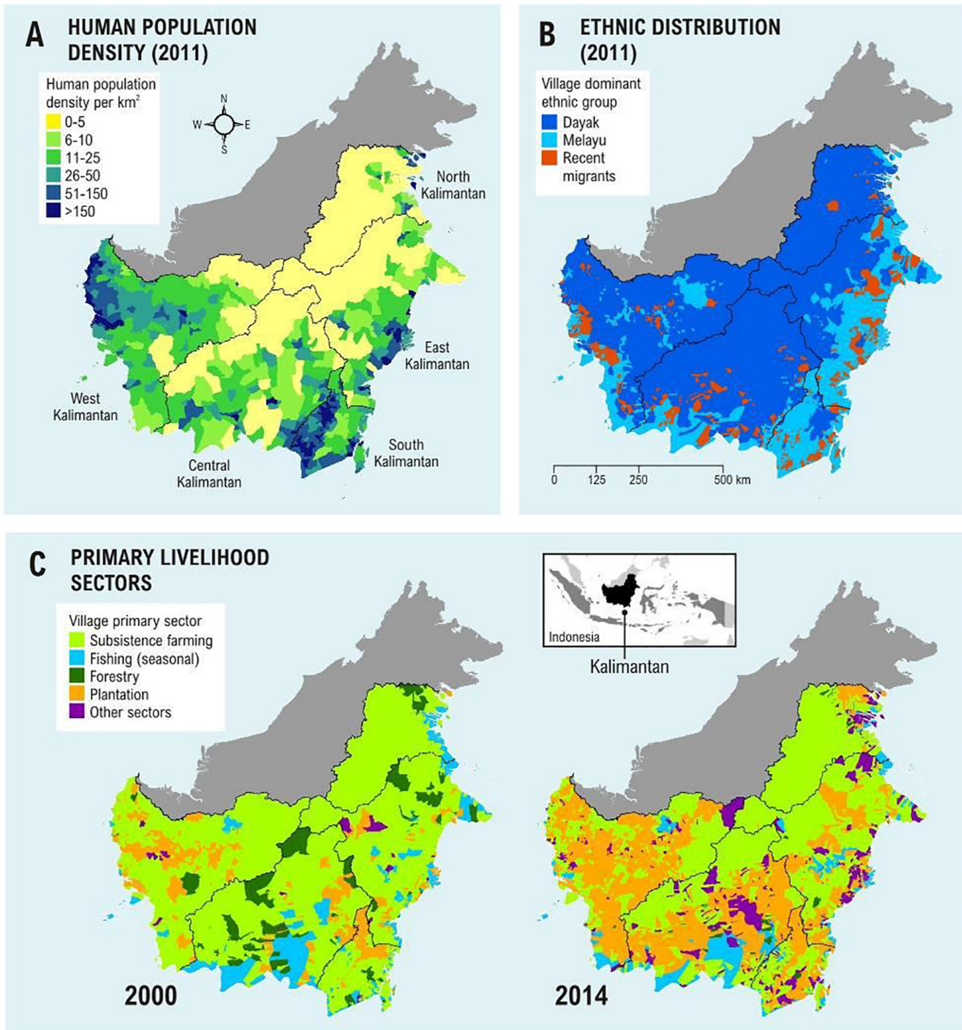

Fig. 1. (A) Human population density (per km^2), and (B) village dominant ethnic group, in Kalimantan based on PODES 2011 (data closely reflect the results of 2010 national census). (C) Change in village primary livelihood sectors between 2000 and 2014, which includes subsistence farming, seasonal inland 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.

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, Ghazoul, Obidzinski, & Koh, 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, Chong, & Levang, 2010). For independent smallholders, the realization of socioeconomic benefits would depend on land ownership and starting capital (Euler et al., 2016; Lee et al., 2014). 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 (Colchester et al., 2006; Rist et al., 2010; Wakker et al., 2004). 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, Colin, Whalen, Grünberger, & Caliman, 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 varies depending on the time frame of analysis, as shown in Table B4.

2.4.2. Confounding variables

We controlled for potentially confounding variables in the assessment of oil palm impact in terms of both selections 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 (Moeliono & Limberg, 2012; Resosudarmo, 2004). 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, Sanderson, O'brien, Wibisono, & Woolmer, 2003; Linkie, Smith, & Leader-Williams, 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, Achdiawan, & Dewi, 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, Ancrenaz, Wilson, Spehar, & Abram, 2017a). Soil type, i.e. mineral or peat soil, is also an important factor driving forest conversion to agriculture (Carlson, Curran, Asner, Pittman, & Trigg, 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, Meijaard, Budiharta, Law, & Kusworo, 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 (Merz, Aerts, Arnbjerg-Nielsen, Baldi, & Becker, 2014; Tosca, Randerson, Zender, Nelson, & Diner, 2011).

2.4.3. 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, Southworth, & Development Unit, 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, Lessler, & Stuart, 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).

2.4.4. 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, Rowland, Powell, Salim, & Sunderland, 2016). Moreover, the occurrence of cooperative schemes and micro enterprises (<20 employees, mainly in forest-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. A6b).

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).

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 the 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).

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).

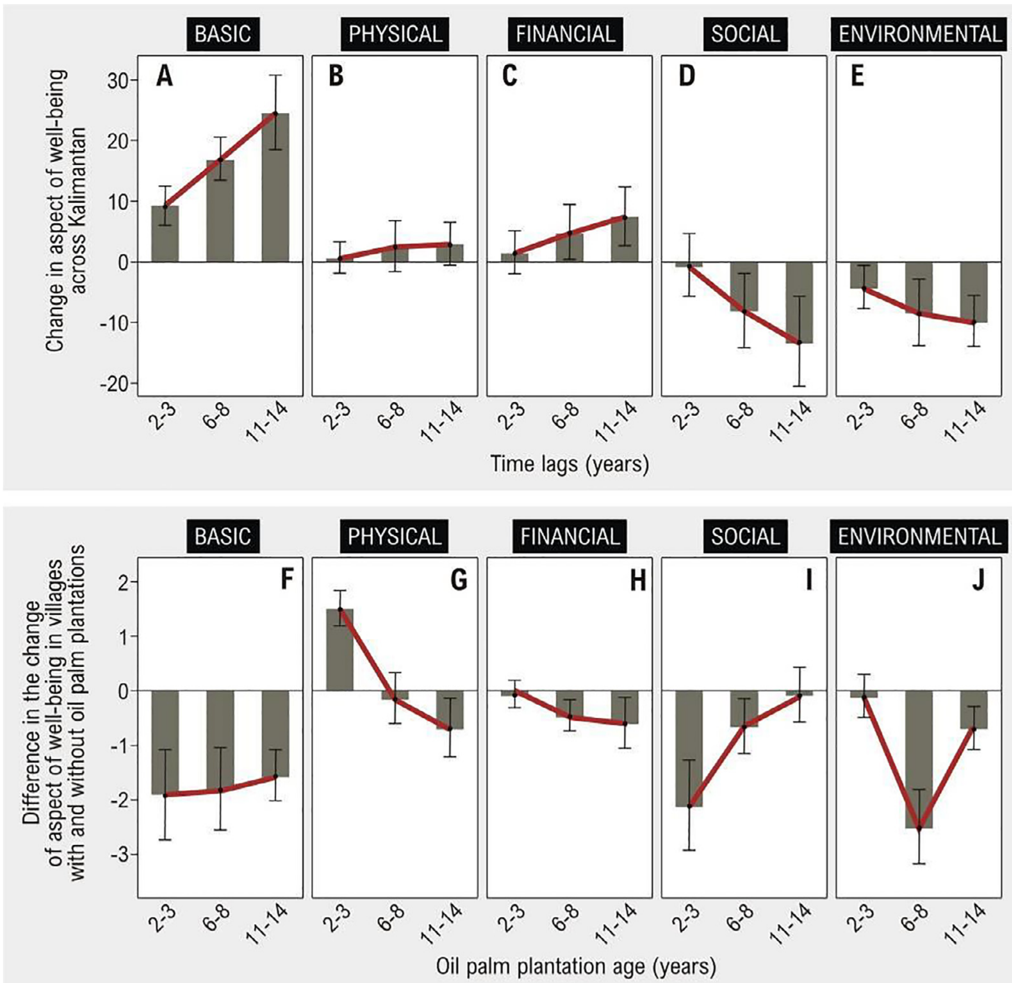

Fig. 2. (A–E) Mean rate of change in human-well-being across Kalimantan villages for varying time lags, which correspond to plantation ages since establishment. (F–J) Difference in the mean rate of change of well-being over the same time lags in villages with and without oil palm. Large negative values 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.

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, Iles, & Bacon, 2012) and increased scarcity of forest products, such as rattan (Meijaard, Achdiawan, Wan, & Taber, 2014).

3.4.2. Environmental impacts

Water and air pollution in oil palm landscapes is sometimes associated with the production of palm oil mill effluent (POME) in the oil extraction process after harvesting (Singh, Ibrahim, Esa, & Iliyana, 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, Finley, Fry, Jackson, & Willis, 2007). Excessive applications of pesticides and fertiliser could also contribute to water pollution (Comte et al., 2012; Meijerink, Langeveld, & Hellegers, 2008). It has been estimated that for every tonne of crude palm oil produced, about 2.5 tonnes of liquid waste is generated (Ahmad, Ismail, & Bhatia, 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

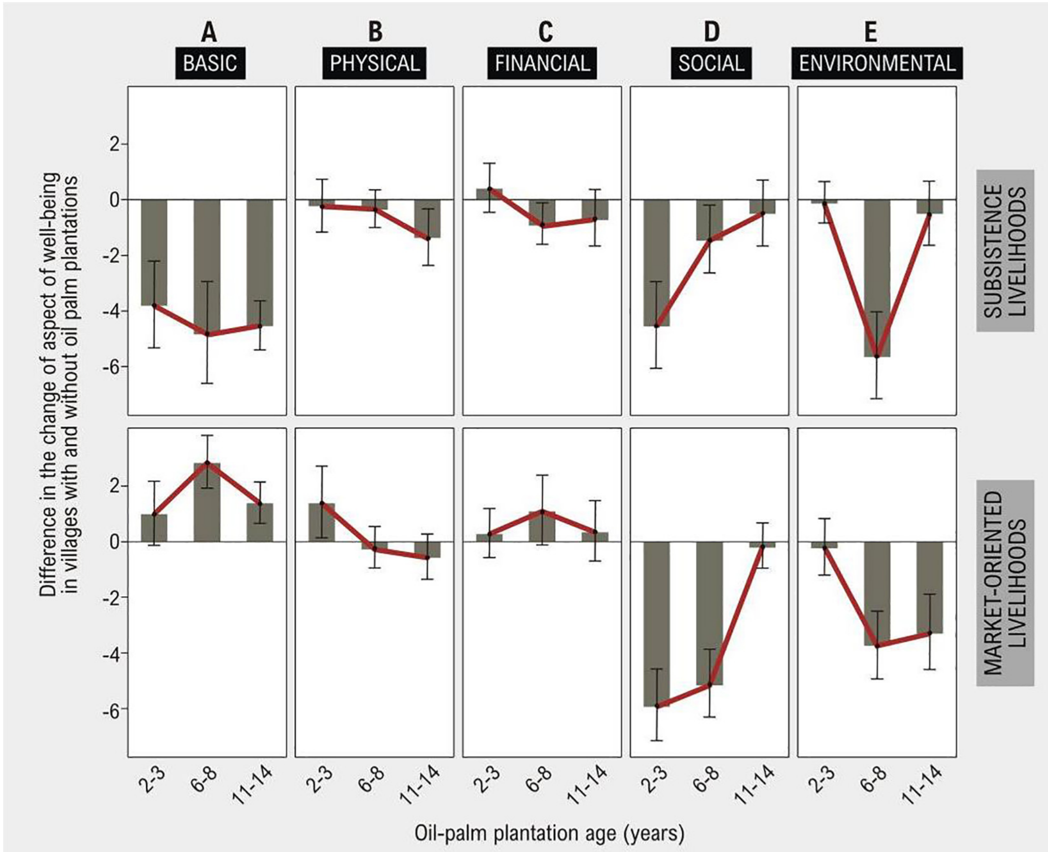

Fig. 3. Difference in the mean rate of change of aspects of well-being over varying oil palm plantation ages in years, in villages with and without oil palm, where most communities formerly depended on: subsistence-based livelihoods or market-oriented livelihoods. Large negative values indicate a greater 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.

it is possible that these conflicts are triggered by communities' discontent over insufficient company benefit sharing to local communities (Abram et al., 2017; Sheil et al., 2009) 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, van Noorloos, Otsuki, Steel, & van Westen, 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 into 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, Belcher, Achdiawan, Alexiades, & Aubertin, 2004; Shackleton, Delang, & Angelsen, 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 (Falconer, Mafira, & Sutiyono, 2015; McCarthy et al., 2012). However, to achieve this

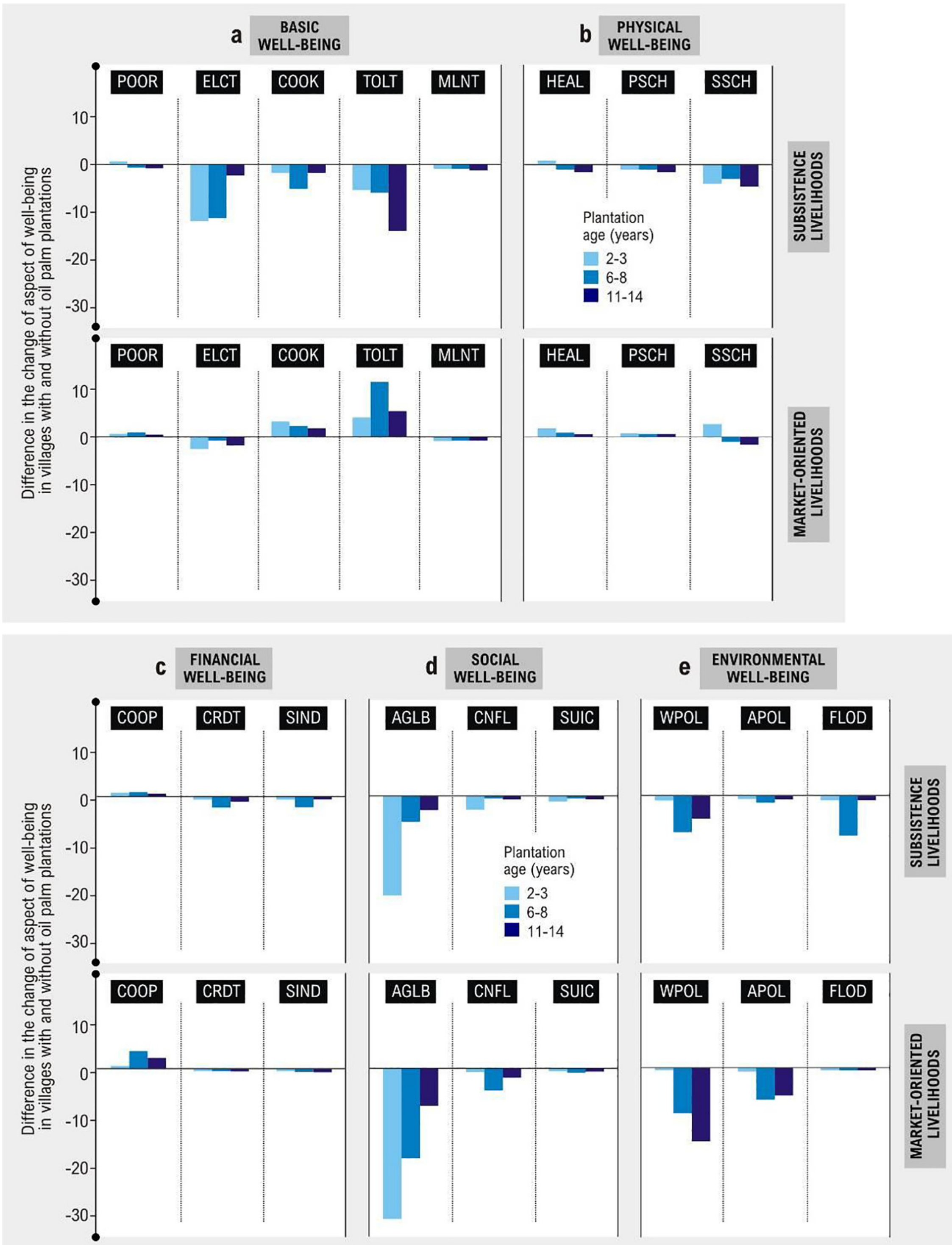

Fig. 4. Difference in the mean rate of change of aspects of well-being over varying oil palm plantation ages (in years) between villages with and without oil palm, where most communities formerly depended on subsistence-based livelihoods or market-oriented livelihoods. Large negative value indicates 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.

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; 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 (Indonesia, 2018; Tempo, 2016). 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 (Mongabay, 2018a; Tempo, 2017c). 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, Heilmayr, Gibbs, Noojipady, and Burns (2018) demonstrated that most of these plantations reduced deforestation rates. On the other hand, the impact of this scheme in reducing fire occurrences (Carlson et al., 2018; Cattau, Marlier, & DeFries, 2016; Noojipady, Morton, Schroeder, Carlson, & Huang, 2017) and delivering socioeconomic benefits to village communities are questionable (Morgans, Meijaard, Santika, Law, & Budiharta, 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, Padoch, Fox, Cramb, & Leisz, 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, 2017b). For the local government at *Kabupaten* or Regency level, the 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. Supplementary figures and tables

Supplementary data to this article can be found online at https://doi.org/10.1016/j.worlddev.2019.04.012.

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