Journal of Cleaner Production 100 (2015) 140–149

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Trends in global palm oil sustainability research

Sune Balle Hansen [a, *], Rory Padfield [b], Khadijah Syayuti [b], Stephanie Evers [c], Zuriati Zakariah [b], Sharifah Mastura [d]

[a] UTM Palm Oil Research Center, Universiti Teknologi Malaysia, Kuala Lumpur Campus, Jalan Semarak, 54100 Kuala Lumpur, Malaysia
[b] Malaysia–Japan International Institute of Technology, Universiti Teknologi Malaysia, Kuala Lumpur Campus, Jalan Semarak, 54100 Kuala Lumpur, Malaysia
[c] University of Nottingham Malaysia Campus, Jalan Broga, Semenyih, Selangor, Malaysia
[d] Institute of Climate Change, Universiti Kebangsaan Malaysia, Jalan Reko, 43600 Bangi, Selangor, Malaysia

ARTICLE INFO

Article history:
Received 19 September 2014
Received in revised form
17 March 2015
Accepted 17 March 2015
Available online 24 March 2015

Keywords:
Palm oil
Sustainability
Industry–university collaboration
Publications
Trends
Bibliometric

ABSTRACT

In the past decade, palm oil has risen to become the most produced and consumed vegetable oil in the world. Growth of commercial plantations in Southeast Asia and recent expansions in West Africa and Latin America have led to a growing call for the sustainable production of palm oil, driven to a large extent by concerns over the associated impacts of deforestation and biodiversity losses. This study investigates the academic response to the calls for the sustainable production of palm oil by identifying and analysing Thomson Reuters Institute for Scientific Information indexed palm oil sustainability related publications from 2004 to 2013. The results show that the total number of publications has increased exponentially from 11 in 2004 to 713 by 2013. However, this growth is shown to be carried mainly by research within technical aspects of palm oil residue use; publications in the categories of land use & land use change, biodiversity and socio-economic aspects have increased, but the growth has been markedly slower. It is thus argued that there is currently an imbalance in research strategies since the focus towards technical topics is at odds with the major sustainability issues raised about palm oil production. To address the current imbalance in palm oil research, this study proposes a holistic framework for palm oil sustainability research with the aim of achieving multidisciplinary studies and emphasizing collaboration between industry and academia. Research sponsors and public bodies in charge of science, social science and technology research frameworks will thus benefit from improved understanding of where research and development resources can be allocated to facilitate the transition towards improved sustainability.

© 2015 Elsevier Ltd. All rights reserved.

1. Introduction

With a global production of almost 60 million tonnes and a global vegetable oil market share of more than 35% by weight in 2012 (MPOB, 2013), palm oil is the most produced vegetable oil in the world. The diverse range of uses in food, cosmetics and other commodities, as well as biofuel, combined with a market price below that of its competitors (MPOB, 2013), makes palm oil and its co-product, palm kernel oil, attractive products. Oil palms grow in humid tropical environments and compete for space with carbon and biodiversity rich tropical rainforest, referred to as high carbon stock forest (HCS) and forests of high conservation value (HCV). Southeast Asia is the leading region for palm oil production but commercial plantations are on the rise in Latin America and West Africa. Past expansion of oil palm plantations have to some extent come at the expense of HCS and HCV (Wicke et al., 2011), which leads to greenhouse gas (GHG) emissions and a decline in biodiversity (Danielsen et al., 2009). From a life cycle perspective, GHG emissions from land use change (LUC) can be several multitudes higher than the GHG emissions from palm oil production itself (Hansen et al., 2014).

Significant sustainability concerns are also associated with palm oil production at plantations and mills. The environmental impacts are mainly due to open lagoon treatment of palm oil mill effluent

Abbreviations: ARPOS, Academic Research on Palm Oil Sustainability (Malaysian Research Network); GHG, Greenhouse Gases; HCS, High Carbon Stock; HCV, High Conservation Value; iLUC, Indirect Land Use Change; ISI, Institute for Scientific Information; LCA, Life Cycle Assessment; LUC, Land Use Change; LULUC, Land Use & Land Use Change; POME, Palm Oil Mill Effluent.

* Corresponding author. Tel.: +60 3 2203 1406.
E-mail address: sunebh@utm.my (S.B. Hansen).

http://dx.doi.org/10.1016/j.jclepro.2015.03.051
0959-6526/© 2015 Elsevier Ltd. All rights reserved.

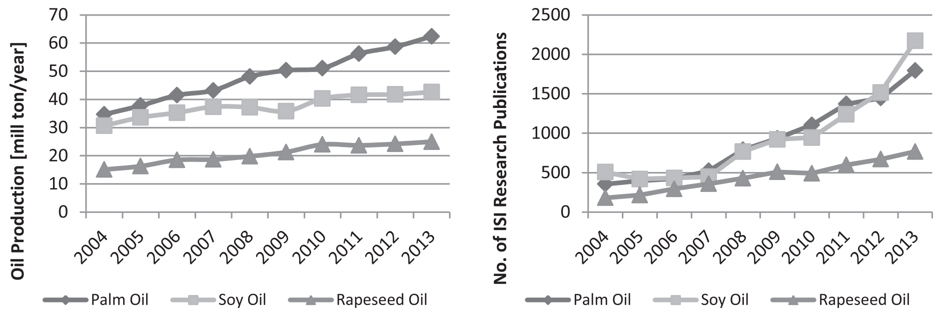

Fig. 1. Oil production and research publications related to the three major vegetable oils a. Oil production data from MPOB (2013) b. Publications data from (WoS, 2014) 'Topic' search for 'palm oil', 'soy oil', 'rapeseed oil' respectively c. Palm oil quantities include crude palm oil and crude palm kernel oil.

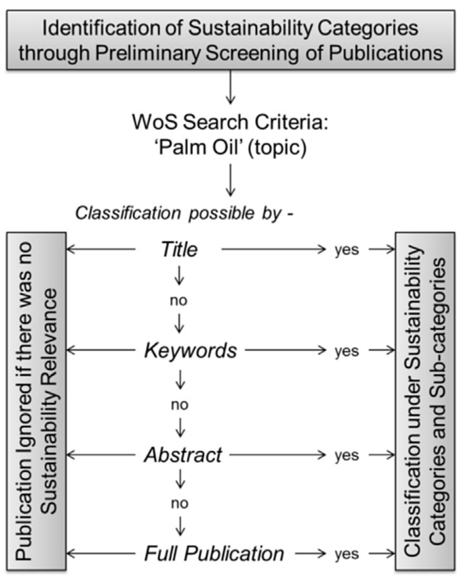

Fig. 2. Research methodology flow diagram.

(POME) (Reijnders and Huijbregts, 2008) and fertiliser and pesticide use (Choo et al., 2011). The potential use of palm oil residues was reviewed for the first time in 2006 (Yusoff, 2006). Hansen et al. (2012b) quantified the potential GHG emissions and benefits from residue use and concluded that use of residues may significantly improve the environmental performance of palm oil production. Socio-economic aspects of sustainability, such as plantation worker safety and health (Pye et al., 2012) and land tenure rights (Cramb and Sujang, 2011) have also been researched.

Whilst palm oil has been grown commercially since the 1960s (McCarthy and Cramb, 2009), it is since the mid-2000s that palm oil related research activity has accelerated (Turner et al., 2008). As shown in Fig. 1, the number of palm oil related publications has increased exponentially over the past decade – from 355 publications in 2004 to 1796 publications in 2013 – which follows the trend of the other large global vegetable oils, namely soy oil and rapeseed oil.

Bibliometric analysis methods have previously been used to document research trends by describing patterns in the distribution of specific aspects, such as topic, geography and collaborative partners (e.g. Du et al., in press; Wang et al., 2010). In 2008, Turner et al. (2008) applied bibliometric methods to describe the broad trends in palm oil research publications between 1970 and 2006. Their study found that the primary focus of palm oil research was towards uses in food and the resultant health issues. After 1996 there was a marked increase in the number of publications on: i) by-products from the oil palm industry, ii) chemistry, engineering and biotechnology, and iii) the production of biofuel. The number of publications on biodiversity and other environmental issues was reported to be extremely low (Turner et al., 2008).

In recent years, holistic approaches to sustainability frameworks have grown in popularity across various disciplines and sectors. Examples include corporate social responsibility (Lozano, 2015), solid waste management (Papargyropoulou et al., 2014), bioenergy (Hayashi et al., 2014) and the automotive industry (Tarroja et al., 2014).

In order for academic research to contribute to a holistic sustainable development in the palm oil industry, all aspects of sustainability must be addressed in a balanced manner. Despite the increase in total palm oil research publications, the growth of global palm oil production and the sustainability concerns associated with current expansion strategies and production processes, it is not clear to what extent the international research community is addressing the key issues and questions related to palm oil sustainability. This study applies a bibliometric analysis with the aim of depicting specific trends in sustainability related palm oil research over the period 2004 to 2013. Potential drivers have been identified to explain the overall and specific publication trends. The

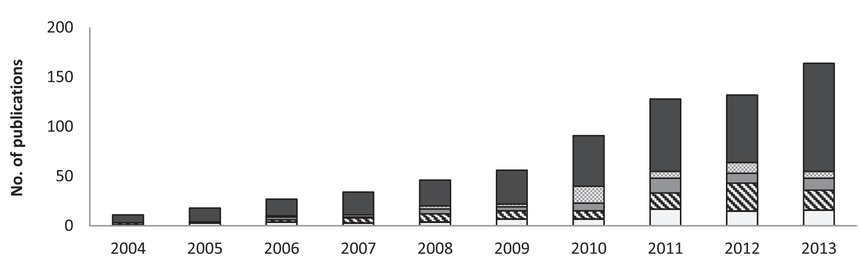

Fig. 3. Total number of ISI publications on palm oil sustainability aspects from 2004 to 2013.

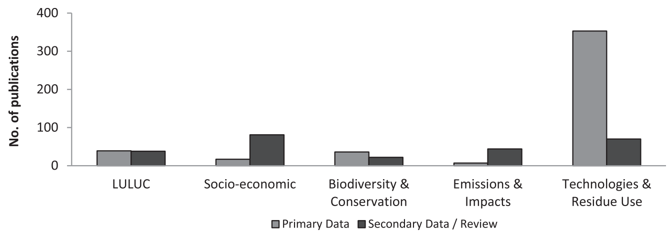

Fig. 4. Data originality of ISI publications on palm oil sustainability aspects from 2004 to 2013.

output from this study will provide researchers and policy makers with an overview of research conducted on the topic which, in turn provides a platform for developing balanced research programmes for sustainable palm oil production.

2. Methods

Adopting the approach taken in past bibliometric analyses (e.g. Turner et al., 2008; Li and Zhao, 2015), the present study used Thompson Reuters Web of Science (WoS, 2014) to investigate the trends of publications on sustainability related palm oil research over a ten year period, 2004–2013. WoS contains ISI indexed publications and is commonly used for bibliometric analyses since its databases have a comprehensive coverage of 14,000 journals, including science, engineering and humanities/social science categories (WoS, 2014). The scope of the study was limited to the production of crude palm oil and its upstream processes. The term 'sustainability' is understood in line with the World Commission on Environment and Development's (1987) definition of sustainable development – an approach that aims to address current and future stakeholder needs whilst recognising the limitations of the environment (IISD, 2014).

Fig. 2 depicts the method flow undertaken for the research. The first step involved defining the different categories of research for palm oil sustainability. This was achieved by undertaking a preliminary screening of publications so as to allow the broad categories to emerge. The screening process resulted in the identification of the following five categories (see Table 1): (1) Technologies & Residue Use, which includes research on emission and technology aspects in the treatment of solid and liquid residues, as well as research on the production of value added products from the residues; (2) Land Use & Land Use Change (LULUC), which includes non-biodiversity aspects related to land conversion into oil palm plantations, as well as biomass in the plantations; (3) Emissions & Impacts, which focuses on environmental assessments

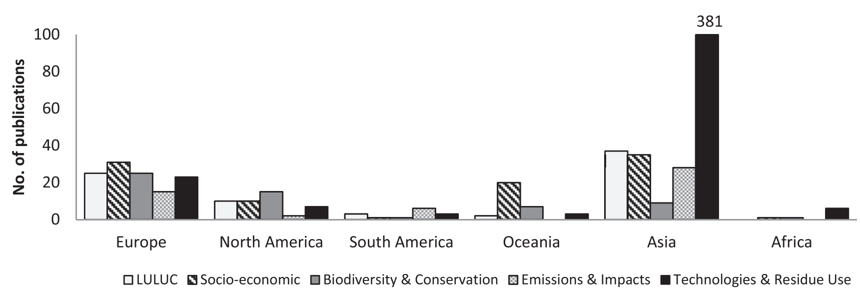

Fig. 5. Global distribution of ISI publications on palm oil sustainability aspects from 2004 to 2013.

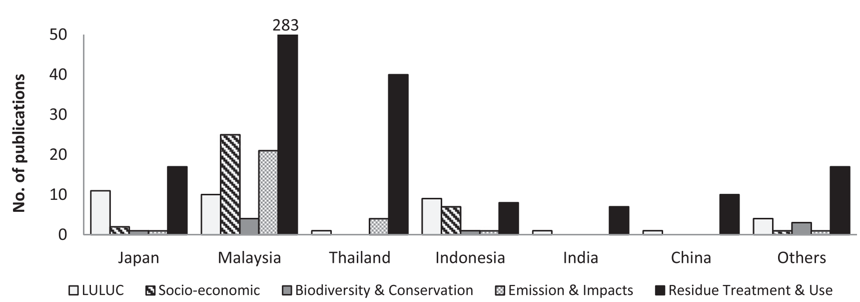

Fig. 6. Asian distribution of ISI publications on palm oil sustainability aspects from 2004 to 2013.

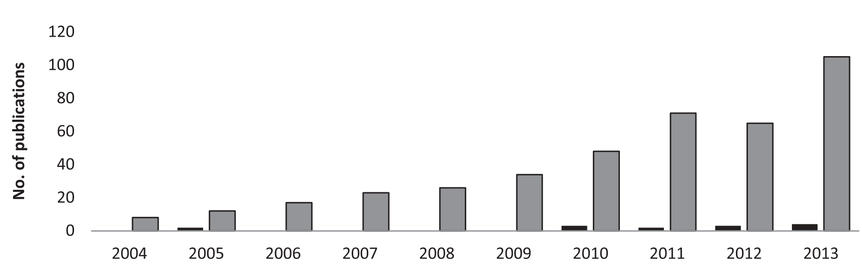

Fig. 7. Technologies & Residue Use related ISI publications on palm oil sustainability aspects from 2004 to 2013.

Table 1
Palm oil sustainability categories and sub-categories selected for the categorisation of publications.

Topics	Technologies & Residue Use	Land use & Land use Change	Emissions & Impacts	Biodiversity & Conservation	Socio-economic
Sub-topics	i. Environmental aspects ii. Technical aspects	i. Carbon ii. Peatland iii. Other	i. LCA[a] (Multiple impacts) ii. LCA[a] (Energy) iii. LCA[a] (Global warming) iv. Emission mapping	i. Birds ii. Mammals iii. Amphibians & Reptiles iv. Insects v. Plants vi. Ecosystem function vii. Mapping viii. Policy & Regulation	i. Certification ii. Community & Livelihoods iii. Economic Assessment iv. Policy/Overview v. Governance & Politics vi. Land tenure vii. Markets & Investments

[a] Life Cycle Assessment.

such as life cycle assessment (LCA) and emission mapping not related to Technologies & Residue Use or LULUC; (4) Biodiversity & Conservation, which includes biodiversity quantification, assessment and biodiversity related conservation research; and (5) Socio-economic, which looks at a broad range of socio-economic aspects including community livelihood, land tenure and certification studies. Water related impacts (not including wastewater, which is included in Technologies & Residue Use) were initially included as a sustainability category, but due to a very low number of only six (6) identified publications, the category was omitted.

In the second step the keyword 'palm oil' was used to search for research articles published between 2004 and 2013 (a topic search for 'oil palm' brings identical results as for 'palm oil'). The search returned a total of 9137 publications and each one was assessed to determine whether it could be classified into one or more of the defined sustainability categories. Article classification was achieved via a 4 tier assessment of (1) Title, (2) Keywords, (3) Abstract and (4) Full Publication. If it was clear from the title whether or not a publication was sustainability related, and if so, to which sustainability category it belonged, it would be classified accordingly. If the title was not sufficient, the second tier, namely keywords were taken into consideration and so forth. In addition, each publication was analysed to determine the geographical origin of the lead research institution as well as the data originality of the research (i.e. primary or secondary/review research). Double counting of publications covering more than one category was avoided by categorising the publications in accordance with their primary research focus.

The third and final step involved identification of sub-categories for each sustainability category and classifying the publications under these (see Table 1). The 'Technical aspects' subcategory of the Technology & Residue Use category dominated the total number of publications and thus special attention was given to this sub-category with a further breakdown into residue uses (see Fig. 8 in Section 3.2). The 'Technical aspects' subcategory includes studies on technology and residue uses, which focus on technological development and feasibility without quantifying environmental impacts or benefits. Five major uses of the residues have been identified, namely (1) 2nd generation biofuel, which includes biomass energy, methane production, hydrogen production etc., (2) biochemical applications, which include production of e.g. acids, enzymes and bioethanol unless the publication specifies that the bioethanol is for fuel purposes in which case it is listed under biofuel, (3) the use of boiler ash or shells in concrete production, (4) the production of composites and, (5) pyrolysis including uses of activated carbon. Products not fitting any of these categories, such as land application, composting, nano-technology etc. are labelled under 'Other'. In addition, studies which focus on residue treatment without a specific product output are labelled under 'Treatment' (see Fig. 8). Studies quantifying the production of e.g. methane for a biogas technology are included as Technical aspects studies unless the energy consumption of the technology and environmental benefits of using the methane are documented; in such cases, the articles have been sub-categorised under 'Environmental aspects'.

Due to a lack of consensus over whether yield increases improve the sustainability of an agricultural crop, oil palm yield improvement publications have not been included as a sustainability category in this study. As argued by Villoria et al. (2013) substantial disagreement exists on whether crop yield increases are correlated with environmental sustainability benefits, such as lower deforestation. While Stevenson et al. (2013) concur with other studies in that the effect of broadly distributed yield growth has spared natural lands from agricultural expansion, research has also found that increases in crop productivity can increase the profitability of agriculture in comparison with forestry uses, thereby encouraging area expansion at the expense of forests (Angelsen and Kaimowitz, 2001).

3. Findings

This section presents the general and specific results and findings for each palm oil sustainability category and sub-category.

3.1. Overview

Of the 9137 screened publications for palm oil, 713 (or nearly 8%) were classified under one of the five defined sustainability

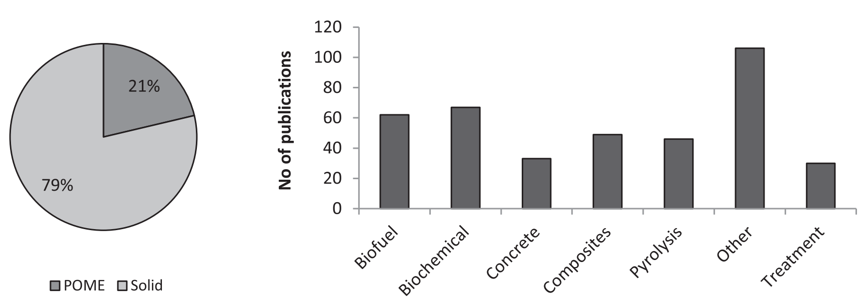

Fig. 8. Residue use focuses in ISI publications on palm oil sustainability aspects from 2004 to 2013.

categories. There is an exponential increase in publications over the study period as demonstrated by the growth from 11 publications in 2004 to 164 publications in 2013 (Fig. 3). The only year to differ from this trend is 2011 which had almost the same number as 2012 (129 and 136 articles respectively). Technologies & Residue Use has consistently been the most researched sustainability topic. Socio-economic studies have the second largest number of articles followed by LULUC; however, these two categories do not have the consistent exponential growth trend of the Technologies & Residue Use. Emissions & Impacts is the least researched topic. More details will be given to each of the subcategories in Section 3.2–3.6.

Examining the data originality of the publications shows that Technologies & Residue Use publications are largely based on primary data, whereas Socio-economic and Emissions & Impacts research have generally made use of secondary data (see Fig. 4). One may have expected to see a large portion of primary data under the Emissions & Impacts category. This is partially explained by emissions data related to LULUC and Technologies & Residue Use being included in those specific categories and not in the Emissions & Impacts category. For the most part, research under the Emissions & Impacts is life cycle assessment (LCA) related and primary data generation is seldom practiced in LCA.

Notwithstanding the Asian contribution to Technologies & Residue Use studies, there is a relatively even distribution of palm oil sustainability research between European and Asian institutions (by first author affiliation) with Asia having a slight lead in most categories except Biodiversity & Conservation (see Fig. 5). It seems natural that these continents are leading as Asia is the major producer and Europe is a major importer. Africa, however, is poorly represented despite considerable recent land acquisitions by the palm oil industry in central African countries (Penikett and Park, 2013). Analysing the Asian Technologies & Residue Use in detail, Malaysia is the largest producer of publications within all subtopics except for LUC, in which Japan is well represented (see Fig. 6). Malaysia is producing three quarters of all publications within palm oil Technologies & Residue Use (283 articles) followed by Thailand (40) and Japan (17). The world's largest palm oil producer, Indonesia, is remarkably absent in the Technologies and Residues category (8) and as a contributor to all categories of palm oil sustainability (26 articles in total). The world's two largest palm oil importers, China and India are likewise displaying little academic interest in sustainability related palm oil research.

3.2. Technologies & Residue Use

Residues from palm oil production include fronds and oil palm trunks from the plantations and empty fruit bunches, palm press fibre, palm kernel shells, boiler ash and POME from the palm oil mills.

The increase in Technologies & Residue Use publications follow an exponential trend from just 8 publications in 2004 to 109 publications in 2013 (see Fig. 7). Furthermore, Fig. 7 shows that whereas the treatment and use of the residues are by default related to sustainability, only a small fraction (3%) of the studies quantify or discuss the environmental emissions and/or benefits of the treatment. The vast majority of the residue studies focus solely on the technical feasibility of technologies or the characteristics of the products produced from the residues. Research on residue uses, and in particular the technical feasibility of technologies is conducted mainly in palm oil producing countries in Southeast Asia.

As shown in Fig. 8 and 21% of the Residue and Technology studies focused on liquid wastes (i.e. POME) and the remaining 79% considered the various solid palm oil residues. In terms of the application of these studies, biochemical and biofuel applications are the most researched topics as compared with concrete and treatment applications which are the least researched.

3.3. Land Use & Land Use Change (LULUC)

LULUC publications have been sub-categorized into (1) Carbon, which includes carbon stocks and fluxes related to above and below ground biomass as well as soil carbon on non-peat soils, (2) Peat studies, and (3) Others, which include mapping, policy perspectives etc. Biodiversity and conservation aspects are analysed separately in Section 3.5.

Following minor increases in LULUC publications between 2004 and 2009, there has been a rise in the number of publications from 2010 (see Fig. 9). In terms of the sub-categories, the increase of publications within Carbon and Others has been relatively even except for a decrease in 2010. The number of Peat related publications has followed the overall trend for the LULUC category; relatively small numbers of publications between 2004 and 2009 but rising from 2010. It should be noted that the Others subcategory had an increasing trend from 2011 to 2013 whereas the other subcategories had a declining trend in this period implying there is growing interest in the softer aspects of LULUC, such as mapping and policies.

3.4. Emissions & Impacts

Environmental assessment studies of palm oil have been sub-categorized into emission mapping and three LCA approaches, namely (1) energy balance, (2) GHG related emissions, and (3) multi-impact categories. Although increasing from 1 publication in 2006 to 7 in 2013 (see Fig. 10), the trend for Emissions & Impacts studies does not follow the general exponential trend of studies as seen in Fig. 1 and some of the other research topics. Instead, there is an increase in 2010 followed by a declining trend. In terms of the sub-categories, there is increasing publication trend towards life cycle assessments in relation to global warming impacts, especially since 2010.

3.5. Biodiversity & Conservation

Biodiversity & Conservation publications included in this study are limited to biodiversity and conservation in oil palm plantations and biodiversity impacts due to palm oil related land use change. The sub-categories are Birds, Mammals, Amphibians & reptiles, Insects, Plants, Ecosystem function, Mapping and Policy & regulation. Studies examining biodiversity and/or conservation without making direct links to oil palm expansion are not included.

Overall, there is an upward trend over the study period as demonstrated by the increase from one publication in 2004 to twelve in 2013 (Fig. 11). There were a total of 59 articles published during this period with a peak of 15 publications in 2011. Notwithstanding the overall low count of publications in this category, a number of indicative trends amongst the sub-categories are observed. Overall studies on ecosystem function increased from 2009 to 2011 illustrating a greater focus on ecosystem as opposed to species-specific assessments of biodiversity and conservation research. Studies on birds and insects were prevalent throughout the years 2010–2013. Mammal related research articles are small in number with the exception of 2012 (and limited to Elephant and Orang-utan studies only). Similarly, plants show a notable absence in the literature with only forest structure studies contributing to this field. Recent article additions have included an expansion of the application of geospatial technologies in relation to this field, as well as enhanced research examining policy implications for biodiversity conservation.

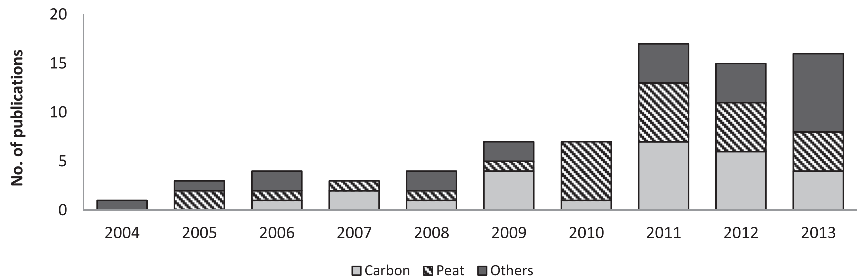

Fig. 9. LULUC related ISI publications on palm oil sustainability aspects from 2004 to 2013.

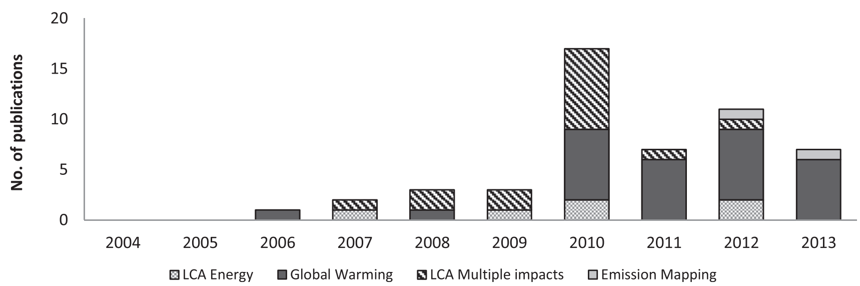

Fig. 10. Emissions & Impacts related ISI publications on palm oil sustainability aspects from 2004 to 2013.

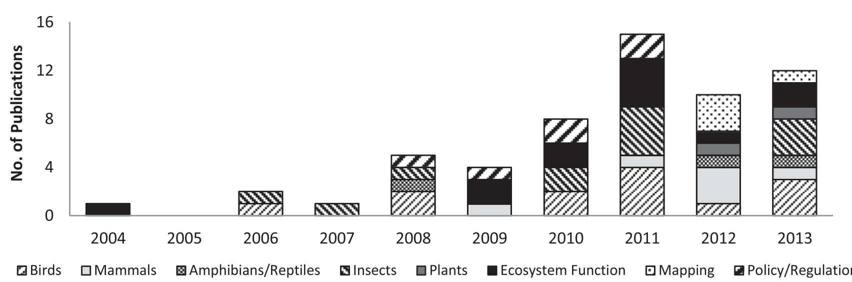

Fig. 11. Biodiversity & Conservation related ISI publications on palm oil sustainability aspects from 2004 to 2013.

3.6. *Socio-economic*

The socio-economic related publications are sub-categorised into seven sub-categories: Markets & investments, Land tenure, Governance & politics, Policy/overview, Economic assessment, Community livelihoods and Certification. Socio-economic publications are consistent with the broader trend of sustainability research as shown by an increase from 1 publication in 2004 to 20 publications in 2013 (see Fig. 12). The total number of publications during this period is 95 and the year with the most publications was 2012 (28 publications). The most frequent category of Socio-economic publications is Policy/overview which covered broad analyses on aspects such as policy perspectives, i.e. (McCarthy and Cramb, 2009), food security, i.e. (Nesadurai, 2013) and stakeholder planning models, i.e. (Collier et al., 2011). Whereas most of the Socio-Economic sub-categories do not display clear trends, Communities & livelihoods publications have increased over the study period.

4. Discussion

The upward trend in sustainability related palm oil research over the period 2004–2013 indicates a collective effort by the research community to improve the scientific understanding of palm oil in relation to social, economic and environmental aspects.

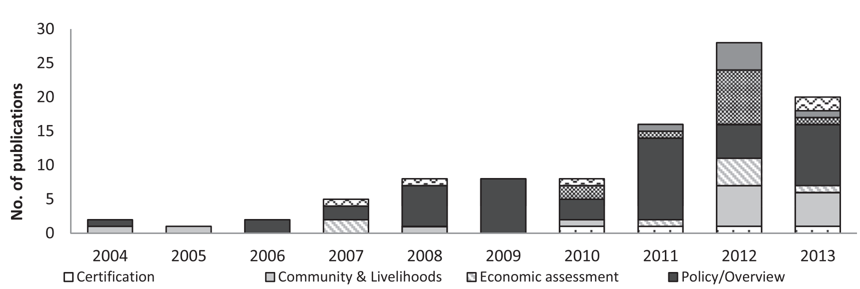

Fig. 12. Socio-economic related ISI publications on palm oil sustainability aspects from 2004 to 2013.

This trend corresponds with four factors, which are potential drivers for the noted research publication growth.

Firstly, the 2000s was a period of increasing production and consumption of palm oil (see Table 1) and growing scrutiny over the industry's sustainability credentials. Deforestation, GHG emissions, associated losses of biodiversity and plantations on peat were some of the headline issues (Koh and Wilcove, 2008; Padfield and Hansen, 2010). Furthermore, anti-palm oil advocacy by non-governmental organisations (e.g. Greenpeace and Friends of the Earth) and less favourable publicity in the international media (e.g. The Guardian's provocatively titled: ‘The slippery business of palm oil’ in 2008 (Pierce, 2008)) has brought the on-going sustainability challenges of palm oil expansion in tropical countries to a wide public audience. Academic studies into palm oil during this period intensified while offering increasingly diverse analyses of palm oil impacts. One of the most debated issues has centred on LULUC, iLUC and associated GHG emissions of palm oil development. Discussion over GHG emissions revealed high variations and uncertainties in the data and thus a need for further research in order to draw more concrete conclusions.

Secondly, the 2000s coincides with important international and national policy developments related to palm oil. A policy of international significance is the European Union's Renewable Energy Directive (EU-RED) (European Parliament, 2009), which requires that 20 percent of the energy consumed within the European Union is renewable by 2020. Under EU-RED, eligibility of renewable energy sources, including biofuels depends on the GHG emissions associated with the production of the feedstock and the conversion to biofuel. The life cycle GHG emissions of the biofuel must be at least 35% lower than the life cycle GHG emissions of the fossil counterpart in order for the biofuel to be considered renewable. This policy is a likely factor in explaining the growth in GHG related LCA and LULUC studies to support the evidence base on the GHG emissions of palm oil. Whereas the spike in LCA publications occurred in 2010, the spike in LULUC publications ensued one year later in 2011. This is a logical development based on two factors: 1) Whereas some of the published LCAs included LULUC impacts, it is clear from the diverse results of LULUC impact contributions that more reliable LULUC data was needed; 2) LULUC studies spurred directly from the EU-RED would likely take longer to complete than LCA studies due to the preparation for and execution of primary field data generation. The decrease in LCA publications after 2010 could be explained by the increasing international focus on indirect land use change (iLUC) at that time. The absence of a global iLUC assessment standard may have been a factor in deterring researchers from the topic. The very limited number of emission mapping publications identified in this study supports the position made by some LCA researchers that the data foundation for holistic environmental assessments is generally weak, thus allowing biased results through subjective assumptions (Hansen et al., 2012a).

The period also coincided with direct emphasis on palm oil development in national policies in Southeast Asia. In Malaysia, for example, palm oil features as a priority industry in the 9th and 10th National Plans (EPU, 2010) as well as in the National Key Economic Areas (Pemandu, 2010). The National Renewable Policy & Action Plan in 2009 (KeTTHA, 2009) (including Feed-in-Tariff launched in 2011) and the Malaysia Biomass Plan from 2010 (AIM, 2011) also support the growth of the Malaysian palm oil industry. Similar initiatives exist in Indonesia and Thailand such as the Indonesian Sustainable Palm Oil Initiative (UNDP, 2012) and the Thai Eleventh National Economic and Social Development Plan 2012–2016 (NESDB, 2011). Furthermore, indicative of the international pressure on the palm oil industry to address sustainability and supply chain concerns, the Roundtable for Sustainable Palm Oil (RSPO) was launched in 2004 with a view of developing a widely adopted sustainability standard for palm oil production and certification. Whilst the RSPO do not directly fund research their existence reflects the wide interest in palm oil and sustainability related policies.

Thirdly, the 2000s was a period of increased funding for research and development in Southeast Asia, particularly in Malaysia (Jailani, 2012). In addition to a spike in Malaysian Government research grants, the Malaysian palm oil industry has also invested in research as demonstrated in funding commitments by two of the largest firms in Southeast Asia, Sime Darby and Felda Holdings. The Sime Darby Foundation has funded research into amongst others, the management and ecology of elephants, conservation of proboscis monkeys, and a long-term project investigating the Stability of Altered Forest Ecosystems (SAFE) in East Malaysia (Ewers et al., 2011). In 2013, the Sime Darby Foundation spent 11.2 million Malaysian Ringgit (~3.5 million USD) on conservation and environmental protection (SimeDarby, 2014) and Felda Holdings pledges 2% of its yearly net profit to social and environmental development through its Felda Foundation (Felda, 2014).

Finally, closer scrutiny of the publication trend reveals a disproportionately large contribution from Malaysian universities with almost 63% of total publications and three-quarters of the Technologies & Residue Use publications. Over the past decade, Malaysia has embarked on a national strategy to develop the research and development capabilities of its universities and colleges (ASM, 2000). In 2006 the Malaysian Ministry of Higher Education initiated the National Higher Education Strategic Plan (NHESP) with a view to ‘drive R&D excellence’ and ‘increase publications in reputable journals worldwide’ (Jailani, 2012). Through increased funding for research, programmes to develop researcher skills, and development of laboratory facilities, R&D outputs have rapidly expanded; according to Jailani (2012) ‘Malaysia is recognized for achieving the world's fastest growth rate in numbers of journal publications' having grown from 4000 publications in 2005 to 15,000 in 2010. The topic of palm oil has inevitably become a target for research in this context; with good accessibility to plantations, milling and downstream technologies and related industries, a rapid growth in publications from researchers based at Malaysian universities has occurred (see Fig. 6).

The rapid growth of Technologies & Residue Use publications does call into question the overall framework and funding allocation for palm oil research. Whereas the large proportion of residue related publications are likely to be the result of a desire amongst academics to contribute to technological development to the palm oil industry, the one-sided approach appears at odds with the major sustainability issues raised about palm oil – namely, LUC, GHG/LCA and biodiversity (Koh and Wilcove, 2007; Turner et al., 2008). Compared with Europe and North America where there is a more balanced distribution of research across the various sustainability topics, Asia displays a somewhat disproportionate focus towards residue publications. Moreover, whilst aspects of residue related research do address certain critical environmental aspects (i.e. methane emissions from palm oil mill effluent), analysis of the residue publication sub-topics reveals heavy emphasis on topics of secondary sustainability importance such as technological feasibility of biomass technologies or characterisation of residue products. Rather than being one part of a comprehensive framework of sustainability research, the high proportion of residue publication indicates a disproportionate allocation of funding and resources relative to the other topics.

Related to this, analysis of the non-residue topics reveals a number of under-represented topics and themes. Whereas Socio-economic is the second largest category in terms of number of publications, it should also be noted that this category covers a wide range of sub-categories (see Fig. 12) each of which only has few publications to its name. The relatively small number of publications in the various sub-categories is likely related to less funding availability, the sensitivity of such research projects, and difficulty in accessing plantation communities. However, this lies in contrast to industry arguments supporting the development of the industry. One of the main points made by the palm oil industry for further palm oil expansion is that it provides socio-economic benefits, both locally and nationally (SOPPOA, 2011). However, very few published studies have examined or justified such a claim as reflected in the low number of Community & livelihood studies within the Socio-economic category. Indeed, only three publications within the Community & livelihoods sub-theme were undertaken by Asian universities; the remaining twelve publications were undertaken by HEIs in Europe (4), Australia (5), America (2) and Africa (1). Studies into the true socio-economic outcomes of the palm industry – from the plantation workers up to national socio-economic benefits – would contribute constructively to this discussion.

Whilst research into Biodiversity & Conservation has been shown to increase over the study period, this topic still remains under represented relative to the total number of palm oil sustainability publications. Turner et al. (2008) argue that the focus on larger flagship species and the associated decline in insect studies pre-2006 was insufficient in providing a realistic assessment of ecosystem functional change in oil palm affected areas. The present analysis indicates that there has been an increase in insects, amphibians/reptiles and plants studies although investigations should be undertaken to define what further research is required to ensure a more complete understanding of palm oil impacts on biodiversity and ecosystem function. Furthermore, despite growing media attention and several NGO campaigns for the protection of orangutans, elephants and tigers, it is one of the least researched sub-categories in the past decade. It is thus clear that academic research within Biodiversity & Conservation is not driven by public sentiments. Interestingly, from an almost complete absence in the first half of the studied period, Ecosystems services, Mapping and Policy/Regulation have become substantial contributors, perhaps reflecting an increasing demand for greater transparency in oil palm coverage and conversion rates, and the realisation that quantifying biodiversity alone is not enough to ensure increased conservation. It should also be noted that only 7 publications or 12% of the total publications on Biodiversity & Conservation have been led by Southeast Asian institutions. With both Indonesia and Malaysia being amongst the 17 mega-diverse countries in the world (Mittermeier et al., 1997) and taking pride in that fact, it is surprising that local academics are not more involved in quantifying the direct and indirect biodiversity impacts of oil palm expansions.

Maintaining the status quo for palm oil research has important implications going forward. Considering the projected increase in palm oil across tropical areas spanning Asia, Africa and Latin America (Wicke et al., 2011; MPOB, 2013), the conversion of lands into new plantations will continue to have a variety of positive and negative environmental, social and economic impacts. Without new knowledge – especially in the under researched domains of social and environmental topics as highlighted in this study – a move towards more sustainable production strategies will be slow to materialise. Turner et al. (2008) argued for further research into the specific biodiversity impacts from palm oil expansion in order to facilitate the setup of appropriate management systems, which balance ecosystem considerations and productivity. This argument could be applied to a wide range of environmental and social aspects, such as broad ecosystem functioning, water management for peat soils, plantation emission losses, community livelihoods and so on, with a view that improving our understanding of palm oil impacts will facilitate the development of appropriate mitigation strategies.

4.1. A holistic framework for sustainable palm oil research

As highlighted by Uiterkamp and Vlek (2007) and Fitzherbert et al. (2008), multidisciplinary considerations are essential in achieving sustainability. Whereas some of the publications identified in the present study do address more than one of the defined sustainability categories, few publications display a truly multidisciplinary approach that aims towards holistic solutions and applicability in the palm oil industry or government policy development. These shortcomings in the existing knowledge base are likely to negatively affect applicability and assimilation of academic research into the palm oil industry thus delaying widespread sustainable palm oil production. In the opinion of the authors, some of the imbalance in research focuses and palm oil sentiments could be overcome by increased stakeholder participation in research projects as described in Padfield et al. (2015). Despite Fig. 6 showing that Malaysia is one of the leading countries within palm oil sustainability research, the application and assimilation of this research into the local palm oil industry is very limited (personal observations). Conversations with palm oil industry players in Malaysia have revealed a certain scepticism in the industry towards academic research as the derived results and recommendations are often left in an academic format with little or no assessment and guidelines for practical applicability (personal communication).

To address the current imbalance in palm oil research, a holistic framework is proposed with strong emphasis placed on multidisciplinary and multi-stakeholder participation (see Fig. 13). In line with the concept of 'action research' which emphasizes problem solving research and closer interactions between academic researchers and industry players (Velazquez et al., 2000; Wells et al., 2009), the framework proposes the development of local and international collaborative partnerships which, importantly, include direct links to the palm oil industry. These connections will allow constructive dialogue between stakeholders with traditionally opposing perspectives on palm oil sustainability, with the aim of finding consensus on the prospects for sustainability. Such a network would also be in a position to bring researchers of various disciplines together to undertake multidisciplinary research. With the inclusion of non-academic stakeholders, it would have the potential to deliver a demand driven approach which would enhance industry applicability (Burritt and Tingey-Holyoak, 2012). Through this framework universities can aim to become 'anchor institutions' (Tewdwr-Jones and Goddard, 2014) – moving from a

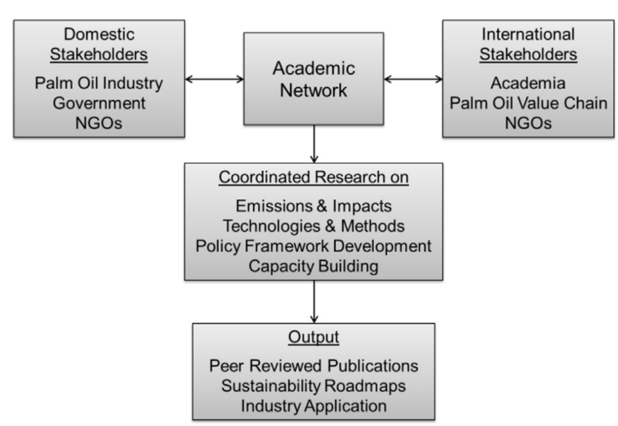

Fig. 13. Proposed framework for holistic sustainability research on palm oil.

position of marginality located at the periphery of industrial development and policy making towards an active and centralised role. Whilst this framework has been developed for the sustainable production of palm oil in mind, the concept could be applied to other topics, sectors or society wide problems.

There are indications that a balanced multidisciplinary approach to palm oil sustainability research may be taking shape. In 2014, Malaysian universities aided by stakeholders from the local palm oil industry, took the initiative to set up a research network called the Academic Research on Palm Oil Sustainability (ARPOS) Network (Sabran, 2014). The network builds upon the framework proposed in this study and has the specific aim of enabling Malaysian academia to offer the palm oil industry high quality and applicable sustainability research rather than small, decentralized projects. Upon completion of the ARPOS Network framework, an academic publication is expected to be produced, which further details the framework proposed in this paper. A global expansion of this concept could bring together palm oil stakeholders worldwide to work towards a common goal. The inclusion of African and Latin American stakeholders in such a network is of high importance as palm oil production is expanding rapidly in these regions. Participation from Chinese and Indian research institutions, particularly on topics related to supply chain traceability and consumer perceptions of palm oil is also a priority since these two countries are the leading global importers of palm oil and related products. Implementing holistic sustainability considerations into the early stages of the palm oil industry development in these regions has a better chance of success if local government, industry, academia (local and international) and NGOs collaborate in a constructive manner.

5. Conclusions

In the past two decades, palm oil has risen to become the most produced vegetable oil in the world, surpassing 50 million metric tonnes in 2012 (MPOB, 2013). Local and global sustainability impacts associated with palm oil production have been raised, especially in the two largest producing countries of Malaysia and Indonesia. With the prospect of continued high demand in the largest importing countries and regions (India, China and Europe) and development of new plantations in frontier areas (West Africa and Latin America), identifying strategies for sustainable palm oil production represents an important and necessary step forward. Whilst efforts have been made by the palm oil industry to address sustainability concerns (e.g. SimeDarby, 2014), academic stakeholders can play an important role in facilitating a shift towards more sustainable production. In particular, academic research can help identify and fill knowledge gaps as well as devise technical and policy related solutions.

With a view of determining the broad and specific research trends in the field of palm oil sustainability over the period 2004–2013, this study has found there to be an exponential increase in ISI article publications related to the topic of palm oil sustainability – from 11 in 2004 to 713 in 2013. The growth is carried mainly by technical topics associated with palm oil residues (60%) with Malaysia being an outstanding contributor to this subcategory. Biodiversity, economic, social and environmental articles related to GHG emissions are few in comparison. It is argued that there is an imbalance in current research strategies since the heavy focus towards technical topics is at odds with the major sustainability issues raised about palm oil production.

To address the imbalance this study proposes a holistic framework with emphasis placed on multi-disciplinary research projects and multi-stakeholder participation. The framework supports the development of sustainable and holistic research studies, as well as local and international collaborative partnerships and direct links to the palm oil industry. The authors believe that such a framework will support the development of the palm oil industry in a way that recognises the need for industry growth whilst placing sustainability – including the creation of new knowledge to achieve sustainable production – at the core of its strategies going forward. With this knowledge in hand researchers and policy makers have a platform for developing balanced research programmes in order to enhance research applicability and sustainable palm oil production. Moreover, research sponsors and public bodies in charge of science, social science and technology research frameworks will thus benefit from improved understanding of where R&D resources can be allocated to facilitate the transition towards improved sustainability. Finally, further research is required to i) develop the detail of the framework, including a number of possible flagship projects; and ii) investigate how such a framework could contribute towards existing research frameworks and funding mechanisms.

Acknowledgements

The authors would like to thank the UKM-YSD Chair in Climate Change project code' (ZF-2014-005), Institute of Climate Change, Universiti Kebangsaan Malaysia for providing financial support for this study.

References

AIM, 2011. National Biomass Strategy 2020: New Wealth Creation for Malaysia's Palm Oil Industry. Agensi Inovasi Malaysia, Putrajaya, Malaysia.
Angelsen, A., Kaimowitz, D., 2001. Agricultural Technologies and Tropical Deforestation. CABI Publishing, Wallingford, Oxon, UK.
ASM, 2000. National Science and Technology Policy II: 2001-2010: Building Competitiveness in a Knowledge-driven Economy. Academy of Sciences Malaysia, Ministry of Science, Technology and the Environment, Kuala Lumpur, Malaysia.
Burritt, R.L., Tingey-Holyoak, J., 2012. Forging cleaner production: the importance of academic-practitioner links for successful sustainability embedded carbon accounting. J. Clean. Prod. 36, 39–47.
Choo, Y.M., Muhamad, H., Hashim, Z., Subramaniam, V., Puah, C.W., Tan, Y., 2011. Determination of GHG contributions by subsystems in the oil palm supply chain using the LCA approach. Int. J. Life Cycle Ass. 16, 669–681.
Collier, N., Campbell, B.M., Sandker, M., Garnett, S.T., Sayer, J., Boedhihartono, A.K., 2011. Science for action: the use of scoping models in conservation and development. Environ. Sci. Policy 14, 628–638.
Cramb, R., Sujang, P.S., 2011. 'Shifting ground': renegotiating land rights and rural livelihoods in Sarawak, Malaysia. Asia Pac. Viewp. 52, 136–147.
Danielsen, F., Beukema, H., Burgess, N.D., Parish, F., Brühl, C.A., Donald, P.F., Murdiyarso, D., Phalan, B., Reijnders, L., Struebig, M., Fitzherbert, E.B., 2009. Biofuel plantations on Forested lands: double jeopardy for biodiversity and climate. Conserv. Biol. 23, 348–358.
Du, H., Li, B., Brown, M.A., Mao, G., Rameezdeen, R., Chen, H. Expanding and shifting trends in carbon market research: a quantitative bibliometric study. J. Clean. Prod. (in press).
EPU, 2010. Tenth Malaysia Plan. The Economic Planning Unit, Prime Minister's Department, Putrajaya, Malaysia.
European Parliament, 2009. Directive 2009/28/EC (Energy from Renewable Sources). The European Parliament and the Council of the European Union, EU.
Ewers, R.M., Didham, R.K., Fahrig, L., Ferraz, G., Hector, A., Holt, R.D., Kapos, V., Reynolds, G., Sinun, W., Snaddon, J.L., Turner, E.C., 2011. A Large-scale Forest Fragmentation Experiment: the Stability of Altered Forest Ecosystems Project.
Felda, 2014. Sustainability Report 2013. Felda Global Ventures Holdings Berhad, Kuala Lumpur, Malaysia.
Fitzherbert, E.B., Struebig, M.J., Morel, A., Danielsen, F., Bruehl, C.A., Donald, P.F., Phalan, B., 2008. How will oil palm expansion affect biodiversity? Trends Ecol. Evol. 23, 538–545.
Hansen, S.B., Olsen, S.I., Hauschild, M.Z., Wangel, A., 2012a. Environmental Impacts and Improvement Prospects for Environmental Hotspots in the Production of Palm Oil Derived Biodiesel in Malaysia. Technical University of Denmark, Kgs. Lyngby.
Hansen, S.B., Olsen, S.I., Ujang, Z., 2012b. Greenhouse gas reductions through enhanced use of residues in the life cycle of Malaysian palm oil derived biodiesel. Bioresour. Technol. 104, 358–366.
Hansen, S.B., Olsen, S.I., Ujang, Z., 2014. Carbon balance impacts of land use changes related to the life cycle of Malaysian palm oil-derived biodiesel. Int. J. Life Cycle Assess. 19, 558–566.

Hayashi, T., van Ierland, E.C., Zhu, X., 2014. A holistic sustainability assessment tool for bioenergy using the Global bioenergy partnership (GBEP) sustainability indicators. Biomass Bioenergy 66, 70–80.
IISD, 2014. What Is Sustainable Development? International Institute for Sustainable Development. http://www.iisd.org/sd/.
Jailani, M.N., 2012. The Malaysian experience: a new approach in managing multidisciplinary research projects. Acad. Exec. Brief 2, 2.
KeTTHA, 2009. National Renewable Energy Policy & Action Plan. Ministry of Energy, Green Technology and Water (KeTTHA), Putrajaya, Malaysia.
Koh, L.P., Wilcove, D.S., 2007. Cashing in palm oil for conservation. Nature 448, 993–994.
Koh, L.P., Wilcove, D.S., 2008. Is oil palm agriculture really destroying tropical biodiversity? Conserv. Lett. 1, 60–64.
Li, W., Zhao, Y., 2015. Bibliometric analysis of global environmental assessment research in a 20-year period. Environ. Impact Assess. Rev. 50, 158–166.
Lozano, R., 2015. A holistic perspective on corporate sustainability drivers. Corp. Soc. Responsib. Environ. Manag. 22 (1), 32–44.
McCarthy, J.F., Cramb, R.A., 2009. Policy narratives, landholder engagement, and oil palm expansion on the Malaysian and Indonesian frontiers. Geogr. J. 175, 112–123.
Mittermeier, R.A., Robles-Gil, P., Mittermeier, C.G., 1997. Megadiversity: Earth's Biologically Wealthiest Nations. CEMEX, Mexico City.
MPOB, 2013. Malaysian Palm Oil Statistics 2012. Malaysian Palm Oil Board, Ministry of Plantation Industries & Commodities, Malaysia.
Nesadurai, H.E.S., 2013. Food security, the palm oil-land conflict nexus, and sustainability: a governance role for a private multi-stakeholder regime like the RSPO? Pac. Rev. 26, 505–529.
NESDB, 2011. The Eleventh National Economic and Social Development Plan (2012-2016). National Economic and Social Development Board, Office of the Prime Minister, Bangkok, Thailand.
Padfield, R., Hansen, S.B., 2010. Striking a balance in the palm oil debate. Environmentalist 107, 2.
Padfield, R., Waldron, S., Drew, S., Papargyropoulou, E., Kumaran, S., Page, S., Gilvear, D., Armstrong, A., Evers, S., Williams, P., Zakaria, Z., Chin, S.Y., Balle Hansen, S., Campos-Arceiz, A., Latif, M.T., Sayok, A., Tham, M.H., 2015. Research agendas for the sustainable management of tropical peatland in Malaysia. Environ. Conserv. 43 (1), 73–83.
Papargyropoulou, E., Lozano, R., Steinberger, J.K., Wright, N., bin Ujang, Z., 2014. The food waste hierarchy as a framework for the management of food surplus and food waste. J. Clean. Prod. 76, 106–115.
Pemandu, 2010. Economic Transformation Programme – a Roadmap for Malaysia – Executive Summary. Performance Management & Delivery Unit (PEMANDU), Malaysian Prime Minister's Department, Malaysia.
Penikett, J., Park, J., 2013. Asian Palm Oil Producers Forey into Fronteer African Markets. ESG Insight Asia. Sustainalytics.
Pierce, F., 2008. Nov 2008. The Slippery Business of Palm Oil, vol. 6. The Guardian, UK.
Pye, O., Daud, R., Harmono, Y., Tatat, 2012. Precarious lives: transnational biographies of migrant oil palm workers. Asia Pac. Viewp. 53, 330–342.
Reijnders, L., Huijbregts, M.A.J., 2008. Palm oil and the emission of carbon-based greenhouse gases. J. Clean. Prod. 16, 477–482.
Sabran, M.S., 2014. July 2014. ARPOS Mantap Penyelidikan Sawit, vol. 8. Harian Metro, Malaysia.
SimeDarby, 2014. Sime Darby Sustainability Report 2013. Sime Darby Berhad, Kuala Lumpur, Malaysia.
SOPPOA, 2011. March 2011. SOPPOA's Position on the WETLANDS Article, vol. 2. Borneo Post, Sabah, Malasyia.
Stevenson, J.R., Villoria, N., Byerlee, D., Kelley, T., Maredia, M., 2013. Green revolution research saved an estimated 18 to 27 million hectares from being brought into agricultural production. Proc. Natl. Acad. Sci. U. S. A. 110, 8363–8368.
Tarroja, B., Eichman, J.D., Zhang, L., Brown, T.M., Samuelsen, S., 2014. The effectiveness of plug-in hybrid electric vehicles and renewable power in support of holistic environmental goals: part 1-evaluation of aggregate energy and greenhouse gas performance. J. Power Sources 257, 461–470.
Tewdwr-Jones, M., Goddard, J., 2014. A future for cities? building new methodologies and systems for urban foresight. Town Plan. Rev. 85, 773–794.
Turner, E.C., Snaddon, J.L., Fayle, T.M., Foster, W.A., 2008. Oil palm research in context: identifying the need for biodiversity assessment. Plos One 3, e1572.
Uiterkamp, A.J.M.S., Vlek, C., 2007. Practice and outcomes of multidisciplinary research for environmental sustainability. J. Soc. Issues 63, 175–197.
UNDP, 2012. UNDP and Ministry of Agriculture Launch Indonesia Sustainable Palm Oil (SPO) Initiative UNDP Indonesia. http://www.undp.or.id.
Velazquez, L., Munguia, N., Platt, A., 2000. Fostering P2 practices in northwest Mexico through inter-university collaboration. J. Clean. Prod. 8, 433–437.
Villoria, N.B., Golub, A., Byerlee, D., Stevenson, J., 2013. Will yield improvements on the forest frontier reduce greenhouse gas emissions? A global analysis of oil palm. Am. J. Agric. Econ. 95, 1301–1308.
Wang, M.-H., Yu, T.-C., Ho, Y.-S., 2010. A bibliometric analysis of the performance of water research. Scientometrics 84, 813–820.
Wells, P., Bristow, G., Nieuwenhuis, P., Christensen, T.B., 2009. The role of academia in regional sustainability initiatives: Wales. J. Clean. Prod. 17, 1116–1122.
Wicke, B., Sikkema, R., Dornburg, V., Faaij, A., 2011. Exploring land use changes and the role of palm oil production in Indonesia and Malaysia. Land Use Policy 28, 193–206.
WoS, 2014. Web of Science. Thomson Reuters. Online. apps.webofknowledge.com.
Yusoff, S., 2006. Renewable energy from palm oil – innovation on effective utilization of waste. J. Clean. Prod. 14, 87–93.