Table S1: Breakdown by country of the online survey respondents

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Region | **Online survey 1** | | **Online survey 2** | | **Combined (Survey 1 and 2)** | |
| *Country* | *Nos. of Respondents* | *Country* | *Nos. of Respondents* | *Country* | *Nos. of Respondents* |
|  |  |  |  |  |  |  |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Asia | Malaysia | 67 | Malaysia | 141 | Malaysia | 208 |
|  | Indonesia | 10 | Indonesia | 19 | Indonesia | 29 |
|  | Thailand | 7 | Thailand | 4 | Thailand | 11 |
|  | Singapore | 1 | Singapore | 2 | Singapore | 3 |
|  | Japan | 4 |  |  | Japan | 4 |
|  |  |  | Hong Kong | 1 | Hong Kong | 1 |
|  |  |  | Bangladesh | 1 | Bangladesh | 1 |
|  |  |  | Sri Langka | 1 | Sri Langka | 1 |
|  |  |  |  |  |  |  |
| Africa | Egypt | 1 | Egypt | 1 | Egypt | 2 |
|  | Madagascar | 1 | Madagascar | 1 | Madagascar | 2 |
|  | DR Congo | 1 |  |  | DR Basin | 1 |
|  |  |  | Liberia | 1 | Liberia | 1 |
| Europe | UK | 44 | UK | 26 | UK | 70 |
|  | The Netherlands | 20 | Netherlands | 14 | The Netherlands | 34 |
|  | Germany | 16 | Germany | 15 | Germany | 31 |
|  | Belgium | 9 | Belgium | 3 | Belgium | 12 |
|  | France | 5 | France | 18 | France | 23 |
|  | Austria | 4 | Austria | 2 | Austria | 6 |
|  | Denmark | 4 | Denmark | 2 | Denmark | 6 |
|  | Italy | 3 | Italy | 4 | Italy | 7 |
|  | Ireland | 2 |  |  | Ireland | 2 |
|  | Sweden | 2 | Sweden | 1 | Sweden | 3 |
|  | Finland | 2 |  |  | Finland | 2 |
|  | Spain | 2 | Spain | 1 | Spain | 3 |
|  | Czech Republic | 1 |  |  | Czech Republic | 1 |
|  | Portugal | 1 |  |  | Portugal | 1 |
|  |  |  | Poland | 1 | Poland | 1 |
|  |  |  | Switzerland | 4 | Switzerland | 4 |
| North America | USA | 9 | USA | 17 | USA | 26 |
|  | Canada | 2 | Canada | 1 | Canada | 3 |
| Oceania | Australia | 8 | Australia | 7 | Australia | 15 |
|  | New Zealand | 2 |  |  | New Zealand | 2 |
|  |  |  | Papua New Guinea | 1 | Papua New Guinea | 1 |
| South America | Brazil | 3 | Brazil | 2 | Brazil | 5 |
|  | Colombia | 2 | Colombia | 1 | Colombia | 3 |
|  | Guatemala | 1 | Guatemala | 3 | Guatemala | 4 |
|  | Ecuador | 1 |  |  | Ecuador | 1 |
| Unspecified | | 24 |  | 35 |  | 59 |
| Total | | 259 |  | 330 |  | 589 |

Figure S1: Breakdown of university & researcher respondents to the online surveys by country

Figure S2: Breakdown of downstream manufacturer respondents to the online surveys by country

Table S2: Organisations who participated in the stakeholder engagement categorised by stakeholder type. Country of origin of each organisation stated in parenthesis or indicated in the organisation name. The list is not comprehensive of all stakeholders engaged in this study but represents those who gave their written consent to be named.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Universities and research institutes** | **Downstream manufacturers** | **Palm oil industry** | **Consultants** | **Government** | **NGO** | **Other** |
| Universiti Teknologi Malaysia  University of Nottingham Malaysia  Malaysian Palm Oil Board  NAHRIM (Malaysia)  Wageningen University (Netherlands)  Universiti Malaya (Malaysia)  Universiti Tenaga Nasional (Malaysia)  Universiti Kebangsaan Malaysia  King Mongkut's University of Technology Thonburi (Thailand)  University of Liverpool (UK)  University of Leeds (UK)  University Putra Malaysia  University of Warsaw (Poland)  UniKL (Malaysia)  Monash University (Malaysia)  University of Lausanne (Switzerland)  Maastricht University (Netherlands)  University of Leicester (UK)  Edge Hill University (UK)  Putra Business School (Malaysia)  Institute of Islamic Understanding Malaysia  Tropical Peat Research Laboratory (Malaysia)  Universiti Teknologi MARA (Malaysia)  Universiti Malaysia Sabah  CIRAD (France)  Mercu Buana University (Indonesia)  INRA (France)  CIFOR (Indonesia)  Indonesia Institute of Sciences  Universitas Gadjah Mada (Indonesia)  University of Jember (Indonesia)  University of Bengkulu (Indonesia)  Andalas University (Indonesia)  CIRAD (France) | Unilever (Netherlands)  Forno dásolo (Italy)  AFIA International (Egypt)  Youngs Seafood Ltd (UK)  Helmut Löser GmbH & Co. (Germany)  Huober Brezel (Germany)  Thurn Produkte GmbH (Germany)  Joseph Robertson (UK)  Dossche Mills (Belguim)  Industria Alimentare Ferraro (Italy)  Middleton Foods (UK)  Bright Blue Foods Ltd (UK) | FELDA (Malaysia)  Sime Darby (Malaysia)  Las Palmas SA (Guatemala)  Savonnerie Tropicale Huilerie Melville (Madagascar)  Agropalma S.A. (Brazil)  Golden Veroleum Liberia  N.Y.HIEW (Malaysia)  Morakot Industries Public Company Limited (Thailand)  Agroaceite, S.A (Guatemala)  Watawala Plantations (Sri Lanka) | Biochar Systems (Malaysia)  Institute for Development of Alternative Living (Malaysia)  YTL SV Carbon (Malaysia)  Dinamika Mitra Global (Indonesia) | Forestry Department Peninsular Malaysia (Malaysia)  Public Service Department (Malaysia)  Federal town & Country Planning Dept. (Malaysia)  Dinas Kehutanan Riau (Indonesia) | Oxfam (UK)  Wetlands International (Netherlands)  RSPO (Malaysia)  Danau Girang Field Centre (Malaysia)  Malaysian Nature Society  PM Haze Elimination Action Team (Singapore)  CERAH (Malaysia)  Point Defiance Zoo & Aquarium (USA)  Forum Sustainable Palm Oil (Germany)  WWF Malaysia  Global Environment Centre (Malaysia)  Indonesian Life cycle Assessment Network (ILCAN)  Forest Peoples Programme (UK)  Wild Asia (Malaysia) | Marks and Spencer (UK)  Compass Group PLC (UK)  Singapore Land Authority  Scoot Chemicals (Australia)  Pro Fair Trade AG (Switzerland)  IBD Certificações (Brazil)  Coop Switzerland  Mead Johnson Nutrition (USA)  TSL (UK) |

***Table S3: Priority research questions organised by theme from the online surveys***

**Bio-based energy & products**

|  |  |
| --- | --- |
| No | Question |
| 1 | In order to reach a consensus within the scientific community on the sustainability assessment criteria of energy from palm oil, what are the critical criteria to be included and how can these best be formulated and internationally agreed upon? |
| 2 | How can palm oil solid residues best be utilized from a technical and holistic sustainability perspective? |
| 3 | How can palm oil mill effluent (POME) best be utilized from a technical and holistic sustainability perspective? |
| 4 | How can the fertilizer value from palm oil residues be optimized? |
| 5 | How can existing and potential residue use technologies be optimized? |
| 6 | What are the options available to palm oil producers to achieve zero-waste by generating value added by-products for energy? |
| 7 | How will the use of palm oil as a biofuel impact land use and land use change? |
| 8 | How does biochar produced from palm oil residues enhance (e.g. fertility, carbon storage, etc.) plantation soils? |
| 9 | What are the net sustainability impacts and benefits from creating bioenergy and bio-products from oil palm residues? |
| 10 | What are the net sustainability impacts and benefits from creating bioenergy from palm oil? |
| 11 | What kind of POME treatment technology can be adopted for small and micro-scale palm oil mills? |
| 12 | How can biomass generated from palm oil development affect local and regional energy security? |
| 13 | To what extent do regulatory regimes on sustainable food products interact with regulatory regimes on bio-based energy in the context of palm oil? |

**Biodiversity & conservation**

|  |  |
| --- | --- |
| No | Question |
| 1 | What kinds of management practices are in place by commercial plantations to ensure the sustainability of natural flora and fauna in the area of plantations, while increasing plantation productivity? |
| 2 | To what extent and how can biodiversity initiatives improve the conservation value of oil palm production landscapes? |
| 3 | What is an optimal landscape for palm oil that takes into account issues of yields, eco-system services and biodiversity impacts? |
| 4 | What is the impact on biodiversity of converting land under various types of land cover to oil palm plantations? |
| 5 | What are the impacts of chemical application (i.e. pesticide) on biodiversity in oil palm plantations? |
| 6 | What is the role of biodiversity within plantations and how can potential ecosystem services be quantified and valued? |
| 7 | What is the minimum forest:plantation ratio needed to sustain biodiversity of an area? |
| 8 | How does biodiversity interact between plantation and neighbouring forest and can plantations potentially act as wildlife corridors? |
| 9 | What are the impacts of certification on plantation biodiversity? |
| 10 | What are the impacts on large mammals (e.g. orang-utans, elephants, etc.) by oil palm and other sectors respectively, and how can conditions be improved and communicated? |
| 11 | How can multifunctional agriculture (e.g. inter-cropping) in plantations improve biodiversity? |
| 12 | What is the impact of replanting on biodiversity and ecosystem functions? |
| 13 | What biodiversity indicators can be developed and how can biodiversity be effectively monitored in plantations of different sizes? |

**Economy & supply chain**

|  |  |
| --- | --- |
| No | Question |
| 1 | What are the costs-benefits within the supply chain of adapting and responding to sustainability requirements? |
| 2 | How are the profits of palm oil production distributed worldwide and what role are sovereign wealth funds playing in financing palm oil production in the developing world? |
| 3 | What is the impact of sustainable production methods on net income for producers (with and without premium prices)? |
| 4 | What is the economics of sustainable palm oil at varying scales (smallholders, plantation estates, local economy, national economy, etc)? |
| 5 | How do fluctuations in global oil palm prices impact the short and long-term economic prospects of sustainable producers of different sizes? |
| 6 | What is the elasticity of demand for sustainable palm oil? |
| 7 | What conditions and policies are required to encourage palm oil companies to switch to 100% sustainable palm oil irrespective of the market demand? |
| 8 | How does the diversity in the output market, both in terms of the many and different variety of uses of oil palm food processing shape the value chain? |
| 9 | How does the use of palm oil for energy purposes influence food security, demand for land and vegetable oil prices? |
| 10 | What are the potential economic benefits for various types of residue use for bio-products and biofuels? |
| 11 | What is the market demand for palm oil biomass in regions where there is no supporting regulations or incentives? |
| 12 | What are the socio-economic impacts of palm oil induced haze on countries in ASEAN? |
| 13 | What is the return on investment (ROI) of removing deforestation from palm oil supply chains? |
| 14 | What are the impacts of palm oil development on food price and food security? |
| 15 | What are the cost benefits of biodiversity conservation in plantations at a company, landscape and national scale? |
| 16 | What new business models can be developed to facilitate funding of new plantations or replanting by smallholders? |
| 17 | What is the cost benefit of sustainable land clearance (i.e. to avoid slash and burn practices) at the scale of the farmer and to society as a whole? |

**Feedback impacts of environmental change**

|  |  |
| --- | --- |
| No | Question |
| 1 | What are the implications of extreme weather conditions (e.g. drought, flood events, high temperature) on the palm oil industry, particularly on yields and fruit quality? |
| 2 | How can management practices be improved to cope with impacts of extreme weather conditions, such as drought, flood events, high temperatures? |
| 3 | What are the effects on oil palms if soil, air and water are irreversibly polluted? |
| 4 | Which environmental change feedback mechanisms could potentially impacts oil palms and what mitigating actions can be taken? |
| 5 | How do localized climatic changes from deforestation impact palm oil production? |
| 6 | How does peat compaction and subsidence affect long term yields of plantations? |

**Land use & land use change (LULUC)**

|  |  |
| --- | --- |
| No | Question |
| 1 | How can land use and land use change best be monitored on small and large scales and published transparently? |
| 2 | How can land use and land use change considerations incl. land suitability best be assessed and incorporated into development plans to maximize future plantation productivity and limit environmental impacts? |
| 3 | What at the obstacles to using degraded land for plantations and how can these obstacles be overcome? |
| 4 | What is the past, current and projected conversion rate of peatland into oil palm plantations? |
| 5 | How and how much do certification schemes effectively limit land use change from high conservation value and high carbon stock areas? |
| 6 | What is the fate of high conversion value land which is privately owned and which cannot be officially converted due to implementation of a certification scheme? |
| 7 | How can careful and considerate land use change management minimize the environmental and social impact of conversion? |
| 8 | What is the magnitude of deforestation and forest degradation caused by oil palm plantation compared to other sectors (e.g. rubber, timber, paper & pulp)? |
| 9 | How much carbon is sequestrated and stored by tropical land uses (e.g. primary, secondary forests, plantations) and set aside High Conservation Value (HCV) areas in oil palm plantations? |
| 10 | What are the direct and indirect contributions of oil palm growers (e.g. smallholders, plantation estates, etc.) and other sectors to the forest fires in Southeast Asia? |
| 11 | How can multifunctional agriculture (e.g. inter-cropping) in oil palm plantations increase production value per ha and limit the need for agricultural expansions? |
| 12 | How is the hydraulic flow and water quality in peat soils affected by oil palm growing? |
| 13 | In the context of income generating opportunities in peatlands, what alternative economically viable crops can be grown without drainage of peat? |
| 14 | What are the consequences of peat subsidence in oil palm plantations and how can these be mitigated? |
| 15 | How does forest conversion to oil palm impact connectivity of forests in Indonesia and Malaysia and thus their ability to support significant wildlife populations? |
| 16 | What type of land (e.g. inland/coastal, elevation soil type) are palm oil producers of different sizes targeting and why? |

**Livelihoods, gender & human rights**

|  |  |
| --- | --- |
| No | Question |
| 1 | What are the health implications for plantation communities, what health care is being provided and in which ways could plantation companies improve the health needs of these communities? |
| 2 | What are the living and working conditions of plantation communities, do they meet the basic minimum legal and human rights requirements and what can be done to improve working conditions? |
| 3 | From a socio-economic perspective, how does palm oil development affect local communities and what tools and mechanisms are most appropriate to ensure fair distribution of socio-economic benefits to these communities whilst also protecting against any undesirable impacts? |
| 4 | How do various local stakeholders living in proximity to palm oil (communities, indigenous people, and local industry) perceive the existence of large and small-scale palm oil development and what is influencing their perceptions? |
| 5 | How are the interests of indigenous communities being protected and safeguarded in relation to palm oil development (i.e. land rights / livelihoods / land compensation)? |
| 6 | What is the profile of foreign workers in the palm oil industry and what are the socio-economic impacts of the foreign workers at local and national scales? |
| 7 | With respect to gender dimensions of palm oil how does palm oil development impact women and how effective are current multi-stakeholder initiatives in raising up the views of women in affected communities? |
| 8 | How do certification schemes impact the livelihood of plantation communities and communities in close proximity to palm oil development? |
| 9 | To what extent are palm oil industry actors respecting and/or acknowledging human and labour rights? |
| 10 | Do plantation workers have knowledge of their rights and do they have effective and easy legal recourse mechanisms to defend their rights in case of violation of these? |
| 11 | What dynamics of differentiation occurs between men and women, between smallholders and larger plantations and between plantation owners and plantation workers? |
| 12 | How can systems of ‘sweat equity’ be created so that palm oil workers acquire a capital interest and not just a wage? |
| 13 | How can moral and ethical obligations towards communities living on or adjacent to land developed for palm oil be defined and upheld to protect local communities? |
| 14 | With respect to land acquisition for palm oil development to what extent have customary land rights been mapped and how can such maps be drawn up in a participatory manner? |
| 15 | What is the socio-economic value of maintaining High Conservation Value (HCV) areas to smallholders and local communities? |
| 16 | What are the livelihood needs and strategies of smallholders and communities? |
| 17 | How can certification standards be improved to further enhance sustainable livelihoods? |

**Media, communication & knowledge exchange**

|  |  |
| --- | --- |
| No. | Question |
| 1 | How can downstream actors (i.e. manufacturers, retailers) communicate effectively their commitments to sustainable palm oil? |
| 2 | What role do the international, national and local media play in influencing government policies in palm oil producing and consuming countries and how can this be effectively analysed? |
| 3 | Is the media (incl. print, on-line news and social media) providing balanced information about the key issues and if not what interests are the media serving and how constructive is this to debates around sustainable palm oil? |
| 4 | How can scientific knowledge (technical and non-technical) be effectively communicated to policy makers and key stakeholders across the supply chain? |
| 5 | What role can digital technology (i.e. Smart phone technology, social media etc.) play in supporting rural communities communicate their voice in matters related to palm oil development? |
| 6 | How can research institutes, universities and other stakeholders (i.e. NGOs) studying palm oil work more effectively together to address the key sustainability issues? |
| 7 | Recent research highlights an imbalance towards technical topics in past palm oil research: what is causing this imbalance and how can more balanced sustainable research strategies be achieved? |
| 8 | How are the media in developing and emerging economies with high palm oil import volumes, especially India and China communicating the key issues of palm oil sustainability? |
| 9 | How is the media portraying palm oil in producing countries as compared with consuming countries? |
| 10 | How to improve capacity of smallholder and medium-sized growers on a range of technical topics, such as use of technology for higher yield of production and lower yield of residue, sustainability assessment, slope cultivation and biodiversity losses? |
| 11 | What role do certification schemes play in knowledge exchange of sustainability and how can the benefits and costs of certification be communicated to non-certified growers? |
| 12 | What strategies (e.g. incentives, corporate planning, training for smallholders) should be developed to assist supply chain stakeholders to make the transition to sustainable palm oil? |
| 13 | In relation to both the production and consumption of palm oil, what are the macro and micro-scale issues of most importance to the general public in Southeast Asia? (e.g. haze, price, international image, etc) |

**Policy, governance & institutions**

|  |  |
| --- | --- |
| No. | Question |
| 1 | How do state, private sector and civil society actors influence palm oil policies and governance? |
| 2 | To what extent are national policies upheld in palm oil producing countries and how do differences in national and local policies influence the governance of the palm oil industry? |
| 3 | What are the motivations for plantation companies to embrace sustainability policies in their business operation and how do changes in corporate policy influence operations and the industry as a whole? |
| 4 | What are the political obstacles at local and national levels that restrict the sustainability of the industry and how can these be overcome? |
| 5 | What are the advantages of a jurisdictional approach (or 'landscape approach') and how can such an approach be adopted? |
| 6 | How can supply chain regulation support the sustainable development of the palm oil industry? |
| 7 | What key policy interventions in emerging economies, such as China and India would help a shift to sustainable procurement of palm oil? |
| 8 | What are the different policy scenarios for a sustainable palm oil industry and to what extent can these scenarios be implemented? |
| 9 | How can sustainable palm oil policy harmonisation at local, national and international levels occur? |
| 10 | How can data on sustainable palm oil inform policy discussions? |
| 11 | How to incentivize palm mill to treats their soil and liquid residues in the most sustainable way possible? |
| 12 | What institutional changes and capacity building needs to be effected to allow for a clear mapping exercise to improve understanding of palm oil plantation land expansion, types of companies, ownership, etc.? |
| 13 | Do current national plans for land use allow for sustainable land use planning, what reforms are required and how can these be enforced? |
| 14 | What policy instruments can be explored to protect forests (primary and secondary) found within plantations? |
| 15 | To protect from deforestation by palm oil actors how can high conservation value (HCV) and high carbon stock (HCS) areas be effectively gazetted and protected? |
| 16 | In light of the worsening annual haze events in Southeast Asia, what policies and governance reforms should be explored to strengthen bi-lateral and multi-lateral initiatives to prevent unsustainable land management practice? |
| 17 | What direct and indirect benefits have sustainable palm oil brought to palm oil producing countries and how can these benefits be measured? |
| 18 | What kind of policies can ensure traceability of sustainable palm oil throughout the supply chain? |
| 19 | What role can the state play in improving transparency across the industry to help identify sustainable and unsustainable practices? |
| 20 | How can a balance be achieved between ecosystem conservation and the right to development in palm oil producing countries? |

**Process, technology & management**

|  |  |
| --- | --- |
| No | Question |
| 1 | How can technology advancements and management practices be utilized to improve the holistic sustainability of palm oil production? |
| 2 | How can certification bodies, industry and other stakeholders best collaborate in terms of development and promotion of best management practices and novel technology? |
| 3 | How can mechanised plantation technology (e.g. harvesting, disease detection & fertilizer application) be developed to replace manual labour? |
| 4 | What are the limitations and obstacles for mills and plantations to adopt new technologies and procedures? |
| 5 | To what extent and how can plantations and mills become self-sustaining (e.g. eliminate the use of fossil derived input)? |
| 6 | How can mill processing technology be made multifunctional (e.g. gasification or pyrolysis systems) to ensure optimal efficiency? |
| 7 | To what extent and how can increased animal labour improve plantation sustainability? |
| 8 | How can a multi-functional agriculture setup be designed in the plantations and what are the environmental, social and economic benefits for smallholders and plantation estates? |
| 9 | How can chemical fertilizer and pesticide application in plantations be reduced without affecting yield? |
| 10 | To what extent and how can plantations shift to organic cultivation? |
| 11 | How to solve the problem of harmful insects and disease of oil palms? |
| 12 | What techniques can be used to reduce the loss of soil nutrients of oil palm plantations over time? |

**Resources, emissions & environmental impacts**

|  |  |
| --- | --- |
| No | Question |
| 1 | What are the gross and net emissions to water and air from direct and indirect land use change, including peat? |
| 2 | Considering the direct and indirect role of oil palm development in the Southeast Asian fires what are the impacts of palm oil induced haze on local and regional human health? |
| 3 | What is the average and ranges of life cycle carbon footprint of palm oil production compared to other tropical crops and other vegetable oils? |
| 4 | What are the life cycle emissions (production and land application) to water and air from industrial and organic fertilizer application? |
| 5 | What are the environmental emissions and impacts of certified versus non-certificated palm oil production? |
| 6 | How can methane emissions from palm oil mill effluent best be mitigated? |
| 7 | What are the emissions from handling solid and liquid waste from plantations and mills? |
| 8 | How can management practices be upgraded to reduce ecological impacts on water quality in and downstream of oil palm plantations? |
| 9 | In terms of alternatives to chemical pesticides and fertilizers, how effective are biological plantation management practices in relation to technical feasibility and environmental benefits? |
| 10 | How does the application of chemicals and management practices impact soil quality? |
| 11 | How can nutrient loss from plantation soils be limited by the use of biochar? |
| 12 | What is the life cycle water footprint of palm oil production? |
| 13 | What are the impacts of palm oil development on water security? |

**Smallholders**

|  |  |
| --- | --- |
| No. | Question |
| 1 | What are the social, economic and environment impacts of smallholders as compared with medium and large scale planters? |
| 2 | How resilient are smallholders to economic fluctuations and what methods should they employ to improve their economic resilience? |
| 3 | How has the health of the different types of small holders (i.e. independent, assisted) been affected by the introduction of palm oil? |
| 4 | What kind of support mechanisms (e.g. communication technique, education, knowledge, resources and technology sharing) are required for smallholders to improve sustainability and livelihood? |
| 5 | From the perspective of various stakeholders what motivates the integration of smallholders into palm oil value chain? |
| 6 | Is it more favourable for surrounding communities to be engaged with commercial estates as plantation workers or as smallholders? |
| 7 | What is the importance of smallholder integration into the sustainable process/certification programs and how can these certification schemes ensure their effective integration? |
| 8 | How are different types of smallholders (i.e. independent, assisted) affected by changing priorities at a national and industry scale? |
| 9 | What benefits do sustainability certification schemes (i.e. MSPO, ISPO and RSPO) bring to smallholders? |
| 10 | How can group smallholder certification be strengthened and what potential impacts can it have on their autonomy? |
| 11 | How can the interests of smallholders be protected within a vast supply chain and how are they impacted by supply chain strategies? |
| 12 | What is the nature of the relationship between smallholders and mills and how can dedicated, longer-term business relations [instead of exploitative short term relations] contribute to mutual quality and efficiency improvements? |
| 13 | What is the culture of smallholder group formation and how does the creation of certification groups interface with this? |

**Standards & certification**

|  |  |
| --- | --- |
| No. | Question |
| 1 | What kind of incentives are required to facilitate an increase in the numbers of sustainably certified producers? |
| 2 | Where, how and when do the various certification schemes contribute effectively to sustainable transitions and where, how and when do they become inhibitive? |
| 3 | Does the establishment of national sustainable certification standards (e.g. ISPO and MSPO) have a negative or positive impact on RSPO, and to what extent are national certification standards accepted in international markets? |
| 4 | What is driving the proliferation of sustainability standards in palm oil and how are the stakeholders implementing them? |
| 5 | In terms of the needs and concerns of smallholders how can lessons from other standards (e.g. GlobalGAP and Fairtrade), including content and governance systems be incorporated in palm oil standards? |
| 6 | What is the state's role in supporting the transition from uncertified to certified palm oil production? |
| 7 | How can the certifications schemes effectively engage players throughout the supply chain? |
| 8 | How can the RSPO standards be strengthened by scientific input (i.e. implementation of FPIC, peatland conversion, GHG emissions and pesticides)? |
| 9 | What are the overall impacts of current RSPO certification scheme and what will be the additional impacts of RSPO +? |
| 10 | What are the overall implications of the different certification schemes and are they addressing or perpetuating inequalities in the industry? |
| 11 | Will a harmonization of standards improve the transition towards sustainable palm oil and if so how can such a standard be achieved? |
| 12 | Within the context of a 'landscape approach' to palm oil sustainability, which assessment criteria can be developed and used? |
| 13 | How is the consistency, quality and transparency of 3rd party certification assured? |
| 14 | To what extent and how can the clarity of RSPO Principles and Criteria be improved, especially for medium sized planters since there is currently ‘room for interpretation’? |
| 15 | To what extent and how can collaboration between state and non-state actors contribute to more integrated and effective standards? |
| 16 | What are the roles for government, private sector, civil society and the certification schemes themselves in certifying at a state level? |
| 17 | How well understood amongst the palm oil supply chain are the rules, requirements and benefits for labelling under the various certification schemes? |
| 18 | In the context of certification-land acquisition scenarios, how to strengthen the methods and processes in which Free Prior and Informed Consent (FPIC) is achieved, such as improving understanding of 'community consent', increased transparency of information between developers and communities and improved consultation processes? |
| 19 | Would an alternative to the sustainability certification concept improve the transition to towards a sustainable palm oil industry what may these alternatives be? |
| 20 | What are the barriers and opportunities for companies in complying with certification requirements on equitable treatment of local communities and workers? |

**Sustainable consumption**

|  |  |
| --- | --- |
| No. | Question |
| 1 | How does labelling affect purchasing, consumer awareness and consumption of palm oil products? |
| 2 | How are the various upstream stakeholders (e.g. industry associations, planters) presenting palm oil sustainability and how does this impact consumption practices? |
| 3 | What are the characteristics (e.g. education status, age, gender) of consumer groups with various levels of concern towards sustainable palm oil and how is this changing over time and across countries? |
| 4 | How can businesses incorporate palm oil sustainability into their corporate responsibility strategies, what are their motivations and what are the impacts of such efforts? |
| 5 | What are the main factors determining sustainable consumption patterns of palm oil in different regions? |
| 6 | How will trends in palm oil consumption affect uptake of sustainability standards? |
| 7 | What role can the state play in helping consumers make conscious decisions on the consumption of sustainable palm oil? |
| 8 | How do consumers perceive current sustainable certification standards and how does it influence their consumption practices? |
| 9 | Which end uses of palm oil are likely to be responsible for increased demand over the coming years? |
| 10 | What kind of labelling strategies should be considered so that sources of sustainable palm oil can be easily identified for both individual and commercial consumers? |
| 11 | What are the alternatives to product labelling to inform consumers of the palm oil source whether sustainably sourced palm oil or otherwise? |
| 12 | Does awareness of the link between palm oil and issues such as deforestation and peatland planting translate into sustainable purchasing decisions? |

***Table S4: Priority research questions organised by theme from the residential workshop***

**Biodiversity & conservation**

|  |  |
| --- | --- |
| No | Question |
| 1 | What industry changes would encourage palm oil producers to be more motivated to consider biodiversity and carbon conservation? |
| 2 | What is the permeability of oil palm plantations for biodiversity and how can riparian reserves be designed to enhance landscape connectivity? |
| 3 | What is the long-term viability of HCV forest patches in oil palm estates for retaining biodiversity? |
| 4 | Do oil palm plantations that use intercropping increase permeability for biodiversity? |
| 5 | How can we better standardise the HCV monitoring and assessment process to ensure long-term conservation of biodiversity? |
| 6 | Which mechanisms and policies can couple higher palm oil production with biodiversity and habitat preservation? |
| 7 | What is the value of remnant patches of forest that are not suitable for oil palm for understudied taxa (e.g. reptiles) and how does this vary with increasing fragment size? |
| 8 | What are the main sources of conflict between humans and IUCN red listed species (elephants, sun bears, orang-utans) in oil palm plantations and how can this be mitigated? |
| 9 | Does native biodiversity provide valuable pest control in oil palm plantations? |
| 10 | What are the impacts on population genetics and the flow of biodiversity between forest areas following land use change from forest to oil palm? |
| 11 | How can we design landscapes to safeguard connectivity for important keystone species that support priority ecosystem services? |
| 12 | How can we improve replanting practices in oil palm plantations to enhance biodiversity and ecosystem functioning while maintaining yield? |
| 13 | What is the impact of certification on biodiversity values at the landscape scale? |
| 14 | Is hunting and removal of animals for the pet trade from oil palm estates a significant threat to biodiversity, and if so how can it be mitigated? |
| 15 | How does fragment size and degree of isolation in oil palm plantations affect genetic diversity of vertebrate species? |
| 16 | How does the age of oil palm plantations affect their faunal communities and associated ecosystem functions? |
| 17 | How do carbon sequestration and other functional traits of tree species vary across an oil palm disturbance gradient? |
| 18 | To what extent does width, vegetation structure, and forest quality influence terrestrial communities of riparian reserves? |
| 19 | What are the ecosystem services and disservices associated with spill over from native forest fragments into oil palm plantations? |
| 20 | To what extent does automated acoustic sampling capture patterns of biodiversity across different habitats within the oil palm matrix? |
| 21 | How can environmental DNA be used for rapid and comprehensive freshwater biodiversity surveys outside and inside palm oil plantations, including the detection of fish, invertebrates and riparian mammals? |
| 22 | How do increases in microclimate temperatures found in oil palm plantations affect the structure of biological communities? |
| 23 | How are biodiversity, ecosystem function, and yield affected by re-planting of oil palm? |
| 24 | What taxa are good bio-indicators for the environmental quality in oil palm plantations? |
| 25 | How do wildlife corridors affect species movements across the oil palm landscape? |
| 26 | How should riparian reserves be designed (in terms of width, vegetation structure etc.) to support freshwater biodiversity, and also prevent soil erosion and flooding in oil palm? |
| 27 | In oil palm, do species diversity losses and ecological changes in small fragments predict those that will eventually ensue in large fragments? |
| 28 | What is the comparative value in native versus invasive species in providing ecosystem services across the oil palm landscape? |
| 29 | What are the impacts of successful and abundant species in oil palm plantations on adjacent native forest? |

**Bio-based energy & products**

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| No | Question |
| 1 | What value added products can be obtained from palm oil biomass waste to be used for bioenergy production? |
| 2 | What is the role of bio-energy and products from oil palm production in improving local economic growth? |
| 3 | What is the significance of chemical and biological pre-treatment on scum reduction to enhance renewable gas production from palm oil mills? |
| 4 | What is the effectiveness of chemical conversion technologies and inventions associated with oil palm biomass recycling on improving carbon sequestration? |

**Economy & supply chain**

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| No | Question |
| 1 | What is the difference in the economic cost-benefit associated with oil palm production in intact versus degraded landscapes? |
| 2 | How can global demand for oil palm be predicted and what are the implications of this demand for future land-use in tropical regions |
| 3 | How does the policy environment and consumer preferences for certified palm oil in demand-side countries influence demand internationally and thus impact oil palm companies? |

**Feedback impacts of environmental change**

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| No | Question |
| 1 | What is the impact of oil palm plantation water management systems on local and regional hydrological regimes? |
| 2 | What is the relationship between oil palm pollination and distance from forest patches? |
| 3 | What are the effects of hunting/overexploitation on animal populations in remnant forest patches that were designed to act as refugia, and how can this be mitigated? |
| 4 | What is the impact of local and regional hydrological regimes on oil palm plantation water management systems? |
| 5 | How does riparian buffer zone width and vegetation quality (e.g. forest structure, biomass) affect channel morphology, soil erosion, sediment transport, organic matter, and dissolved organic carbon fluxes? |
| 6 | What is the contribution of oil palm in reducing base flow and increasing flooding possibility compared to other land uses (e.g. forest, rubber, urban), and how is this affected by seasonality? |
| 7 | Are soils in oil palm plantations sources or sinks of volatile organic compounds, and how does this influence overall emissions in plantations? |
| 8 | What is the effect of periods of extreme drought (e.g. El Nino) on the production of palm oil fruits? |
| 9 | How far does chemical input (e.g. fertiliser and pesticide) spread and affect the functioning of forest fragments within and around plantations, and how can we minimise this impact? |
| 10 | What is the relationship between oil palm yields and distance from the nearest forest patch? |
| 11 | How will ecological interactions be modified under altered species compositions in oil palm landscapes, and will there be cascading effects on ecosystem health? |

**Land use & land use change (LULUC)**

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| No | Question |
| 1 | To what extent can oil palm plantations be restored to native habitat, and how will this be affected by land-use history (e.g. number of rotations, prior land-cover)? |
| 2 | How can we minimise the environmental impact of the conversion of peat lands to oil palm plantations? |
| 3 | To what extent does the uptake of oil palm agriculture by local communities improve income / alleviate poverty? |
| 4 | How can remote sensing (e.g. unmanned aerial vehicles, radar, LiDAR, satellite) be optimised for oil palm management (e.g. land-use plan, monitoring the oil palm crop and forest quality/recovery of native-habitat areas within plantations)? |
| 5 | How is oil palm expansion affecting displacement of other land-uses into forested areas in new oil palm producing countries (e.g. Myanmar, Colombia, Liberia)? |

**Livelihoods, gender & human rights**

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| No | Question |
| 1 | What are the socio-economic and demographic impacts of oil palm production once certified on local communities? |
| 2 | How can certified oil palm production improve free, prior and informed consent in decision-making processes to reduce social conflict and equitable land tenure? |
| 3 | How are household dynamics (e.g. gender equality, child labour, level of literacy) influenced by certification of oil palm production? |

**Media, communication & knowledge exchange**

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| No | Question |
| 1 | How can environmental education programmes for oil palm plantation workers be most effective? |
| 2 | Are labels like the RSPO certified sustainable palm oil certification an effective tool for guiding consumerism towards sustainable palm oil consumption? Would increased education improve their effectiveness? |
| 3 | What is the best way to increase awareness of the HCV scheme in the scientific community and create positive synergies between academia and palm oil production? |
| 4 | Do scientific recommendations on oil palm environmental sustainability result in meaningful changes in management practices, and how can scientists improve communication with the industry? |

**Policy, governance & institutions**

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| No | Question |
| 1 | How can scientific evidence be better incorporated into the HCV approach in oil palm landscapes? |
| 2 | How should the conservation sector engage plantation workers to implement better practices for biodiversity conservation? |
| 3 | What is the most effective way to incentivise oil palm companies to conserve wildlife? |
| 4 | What are the political impediments to aligning pro-forest conservation objectives with pro oil palm development policy in emerging oil palm markets and what lessons have been learned from elsewhere? |

**Process, technology & management**

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| No | Question |
| 1 | How can natural predators increase oil palm yield? |
| 2 | Can the oil palm matrix be multi-use, e.g. inter-cropping, cattle etc, and what might be the effects of this on oil palm yield? |
| 3 | How effective are new design measures for maintaining hydrology and water quality? |
| 4 | What plant species and management strategies work best for restoration of oil palm plantations back to forest in both mineral soils and peat swamp? |
| 5 | How can we best manage the oil palm understory vegetation to increase biodiversity (including soil biodiversity), and yield? |
| 6 | How can we best manage the oil palm understory vegetation to increase ecosystem function (including soil processes), and yield? |
| 7 | How can palm oil extraction processing be designed to reduce energy consumption? |
| 8 | What socio-technical measures can reduce negative environmental and social impacts from palm oil supply chains? |
| 9 | The global oil palm supply is largely dependent on a single pollinating weevil, making the crop very vulnerable if weevils were to suffer with a disease or parasite (e.g. continued problems with nematode worms). Are there any alternative pollinators to the weevil that would help to provide resilience for oil palm production? If so, how can they be supported in plantations? |
| 10 | How do different management practices, such as the use of herbicides or insecticides, affect biodiversity, and its role in ecosystem functioning? |
| 11 | How do a range of different fertilizers (including organic) affect the trace gas fluxes (in particular N2O and CH4) from soil in an oil palm plantations, and then how does this affect oil palm yield and remaining patches of natural vegetation? Can the fluxes be mitigated through reduced or more targeted application? Is this different in mineral vs. peat soil? |
| 12 | What are appropriate indicators of stream ecosystem structure and function, and how should they be used as management targets for oil palm plantation streams? |
| 13 | What is the environmental impact of using organic fertilizers (i.e. chicken dung) on a large scale in oil palm plantations? |
| 14 | How does artificial regeneration enhance forest structure and carbon sequestration in fragmented forests within oil palm landscapes? |
| 15 | How does the Ganoderma fungus invade oil palm and do efforts to control the stem rot have an impact on the environment? |

**Resources, emissions & environmental impacts**

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| No | Question |
| 1 | What is the role of fragmented forests in oil palm plantations for carbon sequestration, and what options exist for maintaining or enhancing their capacity to store carbon? |
| 2 | How do certification standards affect carbon emissions from oil palm estates? |
| 3 | What is the level of erosion and pollution (i.e. fertilizers and pesticides) from certified, non-certified and smallholder plantations? |
| 4 | What is the quantity of peat carbon emissions from smallholder plantations on tropical peat and how does this compare to industrial plantations? |
| 5 | How does the relationship between carbon cycling and resource use by above-ground taxa vary between primary forest, continuous secondary forest and remnant forest fragments characteristic of HCVs retained in oil palm concessions? |

**Smallholders**

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| No | Question |
| 1 | How do smallholders perceive and interact with intact forest, including remnants, and initiatives to conserve such areas? |
| 2 | What are the impacts of palm oil prices crashes on smallholder household economics and can certification reduce vulnerability? |
| 3 | How can we incentivise smallholders to participate in certification schemes for oil palm production? |
| 4 | What is the potential for income diversification from growing oil palm to improve the economic resilience of smallholder households? |
| 5 | What is the difference in knowledge and skill level between smallholders and bigger oil palm companies, and what can be done to improve knowledge transfer between the two? |

**Standards & certification**

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| No | Question |
| 1 | To what extent are non-compliance and compliance with sustainability criteria occurring across RSPO certified plantations? |
| 2 | To what extent will Indonesia Sustainable Palm Oil (ISPO) and Malaysian Sustainable Palm Oil (MSPO) affect uptake of RSPO, and what are the implications of this for environmental and social sustainability in oil palm landscapes? |
| 3 | How can oil palm estate design be optimised to maximise biodiversity, carbon sequestration and ecosystem functioning? |
| 4 | To what extent does palm oil certification generate measurable environmental benefits at the plantation and landscape scale? |

**Sustainable consumption**

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| No | Question |
| 1 | How far does the integration of different agricultural practices into oil palm plantations go to ensure the preservation of natural forest in Malaysia? |
| 2 | How does pressure from the consumer for sustainably sourced oil palm vary around the world, and can this help to identify where there is a lack of public knowledge surrounding the issues? |