Oil Palm Adaptive Landscapes: Final scientific report

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1. Objectives

The overall vision of the OPAL project was to improve the management of oil palm landscapes across Asia, Africa and Latin America. To do so, we devised three overarching objectives at project level:
(O1) Describe the socio-ecological system and drivers of change;
(O2) Construct integrated models and scenarios of change;
(O3) Engaging institutions for change.

We confirmed our initial assumption that the overall vision for oil palm was interpreted differently in each of the three countries where we worked. Our objectives were thus contextualized and adapted/specified at the country level.

In **Cameroon**, **O1** focused on the management methods and socio-environmental impacts of intercropping in the main oil palm production basins. We also analysed the rate of expansion of palm plantations, the related deforestation and loss of biodiversity, changes in the landscape, methods of plantation management (seeds, fertilization, production, income). Models and scenarios of change (**O2**) were oriented towards better understanding the supply and value chains, its constraints, bottlenecks, limitations as well as identifying trigger points for improvement. **O3** aimed at installing a constructive dialog between policy makers, agribusinesses and smallholders. These objectives were achieved as a result of several phases of field activities. From a close collaboration with local actors emerged the objective of experimenting with pilot plots in which the oil palm will be associated with forest tree species of high conservation value.

In **Indonesia**, the overall objectives were translated into specific ones to improve the management of oil palm landscapes by: (**O1**) understanding the consequences and responses associated with oil palm expansion, analysing its influence upon the processes of agrarian changes, livelihood and resilience strategies of smallholders; (**O2**) analysing, through serious games, the extent to which the adoption of different sustainability systems (e.g. Indonesian Sustainable Palm Oil [ISPO], Round Table on Sustainable Palm Oil [RSPO]) narrows the existing gaps between worse and best management practices for palm oil production; and (**O3**) assessing supply chain interventions for sustainable palm oil and their impacts on market configurations and independent smallholders. Those objectives were achieved thanks to engaging with target stakeholders in research activities, developing participatory models, having dialogues on pertinent issues with the help of the model and we engaged them in a series of knowledge sharing events aimed to disseminate key research results and discuss how they are relevant to policy development.

In **Colombia**, O1 and O2 objectives included understanding how relations work between ecological systems and oil palm landscapes. **O1** sought to understand and quantify the impact of landscape conversion (from rainforest, savanna or grassland into oil palm) across several indicators (soil organic carbon, C losses, soil fertility, fertilizer uses). **O2** was based on constructing integrated models around the issue of water allocation amongst competing users at the watershed level. **O3** was conceived as the product of O1 and O2 by engaging investors, producers, public and private environmental research organizations, biodiesel producers, and the oil palm sector to promote constructive dialogue among competing uses. The oil palm issue in Colombia is highly political, and engaging all relevant institutions to explore options for change (O3) at a national scale was not feasible with the means at our disposal. We instead focused on more local or regional municipalities through which successful engagement was achieved. New research objectives emerged: research on cooperation incentives at watershed level as inputs for changes in water governance systems, research on external factors that could influence the OP landscape such as climate change, political, and economic dynamics.

In Switzerland, delivery of **O1** focused on understanding changes in water fluxes (e.g., evapotranspiration, runoff) driven by forest conversion to OP plantations; evaluating impacts of alternative land use change scenarios (i.e. savanna and pasture converted into OP plantations) and OP management strategies on the hydrologic cycle; assessing the impact of climate variability on oil palm yields across the tropics; modelling impacts of oil palm expansion on vertebrate biodiversity in Indonesia and Colombia; and exploring local community perceptions on changes in ecosystem services and resources following oil palm expansion in Indonesia. The Swiss team also supported the delivery of **O2** and **O3** in each of the three oil focus countries, principally through training, and through participation in stakeholder dialogues. Through the work of one ETH Zurich PhD student (funded independently), we also delivered participatory modelling platforms exploring responses to, and consequences of, land use transitions in Indonesia.

2. Methods and approaches

Throughout the course of the project, we developed a multi-methodology portfolio to collect and analyse quantitative and qualitative data. All countries implemented ComMod as a participatory modelling platform to develop and explore scenarios of change. These platforms were built drawing on social and natural science conducted by the project (as well as existing information) as relevant to each of the three study areas.

In **Cameroon**, several research methods were mobilized: an exhaustive documentary review on the oil palm; companion modelling- games, geomatics (remote sensing and mapping); floristic and faunistic inventories; soil fertility analysis; estimation of carbon stocks; method of assessing landscape dynamics; questionnaires and participatory surveys; environmental impact study methods. All the above-mentioned methods are well adapted to a context where data are often non-existent. Certain approaches, such as survey questionnaires, sometimes raise reluctance and suspicion. Participatory methods (focus group) allow to overcome this barrier, and less-intrusive data collection such as geomatics, environmental impact study methods, and flora and fauna inventories could be conducted without difficulties.

In **Indonesia**, qualitative and quantitative methods included: review of existing literature, household surveys, in-depth interviews with key informants and focus group discussions, GIS analysis, statistics and modelling. Surveys and questionnaires were used in early stages to collect determine the influence of oil palm plantation expansion, driven by either smallholders or large-scale companies, on processes of agrarian changes (land-use, land-access, land-rights), livelihood structures and strategies of smallholders, oil palm governance, and supply chain structures. Geographic Information System (GIS) was used to analyse land use and cover changes over 30 years (1990-2019). Using satellite imagery, a Maximum Likelihood Classification was performed to produce a focused study area (subset), from which factors shaping land cover changes were extracted using binary logistic regression. In addition, nearest neighbour analysis was applied to measure the distribution of smallholders and oil palm mills across the district, allowing us to understand access to mills across smallholder communities. All studies applied complementary social science methods, including in-depth interviews, focus group discussions, and participant observation techniques to better understand how and why oil palm plantations have expanded. ComMod was particularly innovative in revealing new knowledge, and played an important role for facilitating dialogues between actors in the Indonesian context, or in East Kalimantan in particular. Topics addressed through this method included land use changes and allocation, unfair distribution of benefits, lack of collective action to negotiate with companies on FFB prices, access to credit and unclear tenure rights, and perceptions on environmental values.

In **Colombia**, EPFL led work on soil biogeochemical properties and ecosystem carbon storage in oil palm plantations. The ETH Zurich hydrological team used modelling techniques to simulate tropical forests and OP systems and then tropical savannas and pastures. Flux tower and meteorological data from 32 sites across the Amazon basin were used for calibration and validation of the models. The

outputs of both EPFL and ETHZ research were integrated in ComMod platforms that explored soil and water management issues in several basins in Colombia.

3. Results

Throughout the six years of activities, the OPAL team focused on both classical disciplinary science research (i.e. soil, biodiversity and ecology, hydrology and socio-economic research) and transdisciplinary research through the ComMod approach.

Disciplinary research

Soil sciences: Our research on soils sciences focused on understanding the long-term impacts of oil palm expansion on soil carbon and soil fertility in Colombia and Cameroon. We did not work on this topic in Southeast Asia given the extensive research done by other groups in this region (e.g. including the previous work of Thomas Guillaume before he joined OPAL). In Colombia, research focused on assessing the impacts of oil palm cultivation of two land transitions (i.e. natural savanna conversion to oil palm, and pasture conversion to oil palm), though the study of C isotope signatures using chronosequences in a space-for time substitution survey design. This approach proved to be of high relevance, as we filled two important knowledge gaps: i) the study of long-term changes in soil carbon and soil properties (at present most of the available studies are too short term or just focused on plantations of specific age), and ii) the study of impacts to soils from the conversion of pastures and savanna into oil palm plantations.

We showed that pasture conversion to oil palm is neutral from an ecosystem C storage perspective. This finding suggests that this land use change has a potential to mitigate greenhouse gas emissions as compared to the dominant practice of cultivation on previously deforested land. We also examined implications for management of soils within oil palm landscapes. For example, we found that soil fertility and soil carbon is maintained or even enhanced over a decadal time series, indicating the potential for sustainable (over the long-term) oil palm cultivation on former pasture lands in terms of carbon and soil fertility. Further evaluation of site-based management practices within plantations can result in substantial local heterogeneities in soil attributes which can outweigh the importance of broad scale land use change in terms of soil biogeochemical properties. This assumes, however, that local management practices can be scaled out across the plantation as a whole, and scaled up to landscape scales across all plantations in the region.

***Biodiversity and ecological research*:** Our research aimed to understand how vertebrate biodiversity and ecological processes respond to oil palm landscapes. We focused on four issues: (1) impacts of oil palm expansion on biodiversity, (2) forest edge responses to different land use configurations, (3) biodiversity movements and connectivity in oil palm landscapes, and (4) scale effects of land use changes. We intended to expand the knowledge on biodiversity and ecological research in palm oil landscapes in the Neotropics, and as such much of the field research centred in Colombia. Nevertheless, we also contributed to broadening conservation research in oil palm landscapes in Africa and Southeast Asia through modelling and synthesis activities.

Our findings in Colombia showed that there is (or can be) minimal overlap between suitable areas for oil palm production and threatened vertebrate distributions. There is room for oil palm to expand in Colombia (especially on former pasture lands) without incurring conservation risks for threatened vertebrates. Our work on forest edge responses showed little evidence of differences across land uses: forest edges along oil palm and irrigated rice land uses tended to be slightly more diverse than those adjacent to pastures. Our work on scale effects in habitat spatial structure of terrestrial mammals, showed that species abundances vary greatly in response to landscape structure. Edge density and forest aggregation were important predictors of these effects. This implies that supporting biodiversity at landscape scales would benefit from land use planning that takes account of landscape patterns, for which coordination among land use authorities and multiple land owners will be needed.

Eco-hydrological research: A new Tethys-Chloris landscape hydrological model was developed and applied in Colombia. The model provided a first mechanistic description of carbon and water flux

seasonality in tropical forests and reconciled conflicting results on observed dry season greening and increased Gross Primary Production versus decreased carbon uptake during droughts. The new T&C model accurately simulated evapotranspiration, sensible and latent heat fluxes as well as plant growth and yield of OP plantations across ages, e.g., from young to mature plantations. Thus, given the ability of T&C to satisfactorily reproduce both forest and OP systems, model simulations were used to assess the impact of forest conversion to OP on carbon/water fluxes. Model results revealed that in Southeast Asia young OP plantations decrease ecosystem evapotranspiration (ET), causing hotter and drier climatic conditions, while mature OP systems transpire more water than the forests they have replaced. Thus, the high land use efficiency (i.e. high yield, Mg/ha) of OP comes at the expense of water consumption in a trade of "carbon for water" that might jeopardize locally available water resources. This has been discussed anecdotally, as noted also in Colombia, but never previously demonstrated through evidence-based modelling. These findings, published in *Environmental Research Letters*, were integrated in ComMod initiatives to identify qualitative "biophysical rules" for the role-playing games in Indonesia and Colombia.

Model simulations at the pan-tropical scale have also been produced during a MSc project at ETH Zurich. The project investigated spatial patterns of oil palm evapotranspiration (ET), gross primary production (GPP) and potential yield across the tropics, to understand how different soil properties and climate characteristics influence productivity and water use in rainfed plantations. Model simulations suggested that precipitation, and particularly mean annual precipitation and its seasonality, are the main drivers of ET, GPP and yield variability. OP yield is particularly sensitive to the length of the dry season in the tropics.

Social sciences research: Socio-economic research in Indonesia focused on agrarian and rural livelihood strategies, the role of oil palm sustainability standards, and the implications of current supply chain structures in rural regional economic development. Key findings include:

- A shift in rural livelihoods from previously diverse sources (agriculture, fisheries, trade), to increasing dependence on oil palm, resulting in reduced income diversity. The expansion of large-scale oil palm plantations (i.e. nucleus-plasma systems) encourages what we called "silent expansion" by smallholders in the landscapes leading to drastic ecological transformation.
- The adoption and implementation of ISPO and RSPO standards is challenged by lack of legality and legitimacy around oil palm plantation development, especially in forested regions, in the district of Kutai Kartanegara. This poses a significant problem for achieving sustainability goals.
- Current sustainable governance is ineffective in suppressing the expansion of oil palm plantations into forest areas. This is attributed to lack of compliance to sustainable standards among all actors along the supply chain, including smallholders, middlemen, cooperatives and companies.
- Analysis of sustainability systems (e.g. ISPO, RSPO) highlighted the challenges of setting aside areas for conservation within plantations (i.e. high-conservation value areas), and the integration of independent smallholders within sustainable supply chains.

We continue to inform ongoing policy development efforts by the national governments to strengthen criteria and indicators for ISPO system. We participated in dialogues on whether RSPO contributes to lessening deforestation rates and provided insights on how its members are complying with principles and criteria for sustainable palm oil amid their efforts to increase production from available land banks.

Transdisciplinary research

We used ComMod as a transdisciplinary approach to study the sustainability of oil palm landscapes in Cameroon, Colombia and Indonesia. This methodology was the backbone of the OPAL project as it helped us frame and integrate the disciplinary research above described, while at the same time allowing us to engage with stakeholders and inform decision-making processes in these countries (see sections below). Through the ComMod approach we created integrated models of oil palm landscapes, represented as role playing games, and constructed and explored scenarios of landscape change across the three countries.

In **Colombia**, NES Naturaleza co-developed role-playing game model (SuPalCo) to explore farmer practices in the Los Llanos region, including management of oil palm diseases, land use conversion and biodiversity conservation strategies. The model is built on agronomic models of palm oil production, disease dynamics, and water management. The game allowed the project to engage stakeholders from different background to discuss the impact of their management decisions. We included scenarios of RSPO certification, international price changes and climatic variability (i.e. El Niño years). The ComMod approach was successful in comparison to conventional trainings where stakeholders are passive recipients of knowledge as opposed to active producers of it. A second ComMod model was constructed to support WWF Colombia and U. Javeriana in addressing water allocation conflicts in the Cravo Sur and Aracataca basins in Colombia. The resulting "La Cuenca" game allowed land users to understand the impact of water extraction decisions on water resource availability, and to explore collaborative scenarios for regional water governance. The model incorporated our ecohydrological modelling. Two Master theses at ETH Zurich used La Cuenca to explore participants' knowledge and perceptions of water management conflicts in Colombia. The approach was effective in communicating landscape approach principles for solving water resource conflicts. The "La Cuenca" game was also used in a Master thesis at U. Javeriana to understand the water management strategies for agroindustrial production in Colombia's Caribbean coast.

We developed with our partners in **Cameroon** the COPALCAM game, through engagement activities with national and local actors. The game explores the interactions between smallholder producers and artisanal and industrial mills, and how factors like transportation and payment mechanisms affect the decisions by actors in the system. The game enhanced dialogues for improved collaboration between palm oil smallholders and agro-industries, by exploring with stakeholders trajectories for sustainable palm oil development in Cameroon. The game was used with the interministerial panel for the control of the oil palm supply chain and then adopted in the MINADER (Ministry of Agriculture) as part of their outreach program for the development of cooperatives. The activities contributed to inform a decision by a group of smallholders around SOCAPALM Dibombari plantation to organize themselves into a cooperative. Cooperatives are explored as a viable option to optimize benefits of partnership with industry, which can lead to increase in productivity, disincentivise expansion, and contribute to increase revenue for the smallholders. The game was played with journalist to inform reporting around sustainability in the palm oil. The outcome of this has also influence policy processes through decision makers.

In **Indonesia**, we developed three role-playing games called ComMoDO, LUCOPE and ComMod ISPO. These games were constructed from context-specific models that aim to understand social interactions among different stakeholders related to the expansion of oil palm plantations in the district of Kutai Kartanegara. The games also helped the research team leverage policy discussions at sub-national and national level on potential steps that would lead the oil palm sector to comply with ISPO sustainable standards. Discussions centred on how the existing regulations could be enforced, on identifying policy areas for improvement, and on how communication among authorities, particularly between the Ministry of Agriculture and provincial and district plantation agencies can be made more effective in achieving sustainability goals. Our results have informed policy processes on certification schemes, on limiting encroachment of smallholders on state forestland, and on increasing smallholder capacities to adopt sustainability practices.

4. **Implementation of communication and application strategy, set up of relevant stakeholder interactions and engagements**

We targeted stakeholders across the palm oil supply chain from the producers in Colombia, Indonesia, and Cameroon, as well as consumers in Switzerland. We also targeted several political levels (from local to national) to enable change towards sustainable production.

In **Indonesia**, a strong focus was on engaging policy makers and strategic partners to participate in stakeholder-dialogue platforms. The team has built connections at province (East Kalimantan's Plantation Office), district (Kutai Kartanegara's plantation office) and national (Directorate of

Plantation Product Processing and Marketing, Directorate General of Plantations at the Ministry of Agriculture, Ministry of Environment and Forestry, Ministry of Foreign Affairs, and Ministry of Trade) levels. A dialogue was also established with the private sector, farmers' association and NGOs at the national level who are concerned with palm oil issues. In the near future, the team will continue advancing OPAL key results and products including smallholder's palm oil supply chain and readiness towards ISPO certification, and ComMod game. As follow-up activities, key results from the project (e.g. impacts of oil palm expansion on agrarian changes, livelihood) and innovative tools (i.e. participatory approaches) are being communicated through various channels, for example a series of webinars with international panelists.

In **Colombia**, the communications strategy operated through dissemination of easily-accessible communication packages for non-experts (flyers, videos, short reports). The information emphasized the benefits of active dialogues among stakeholders, in contrast to unplanned expansion of the crop. Several ComMod game workshops were used to explore strategies for oil palm development together with a diverse set of stakeholder groups. These were pursued through two parallel channels, the first led by WWF Colombia which focused on strategic land use planning and resource management involving municipalities, water companies, land owners, and NGOs, and a second led by NES Naturaleza, which placed more emphasis on smallholder farmers and oil palm managers.

In **Cameroon**, a special partnership was established with the media (television, radio and newspaper) and journalists. Media participated in several participatory workshops, and were thus instrumental in disseminating the results of the project to non-academic audiences. By participating in ComMod sessions, journalists were able to better understand the complexities of the oil palm production system and associated supply chain, and wwe thus able to report not only on research activities, but also on the complex realities of the oil palm sector. This ensured more informative news outputs.

In **Switzerland**, we engaged with the scientific community and the general public. We participated in several forums through presentations, webinars, and panel discussions. We communicated some of the realities relating to oil palm, including the sustainability challenges of alternatives to oil palm. Oil palm cultivation is associated with a very strong negative image, but this is often based on a simplified narrative of oil palm contexts. Our aim was not to present oil palm in a more positive light, but to promote more informed dialogues on oil palm, including consideration of the consequences of banning palm oil imports, or of switching to other vegetable oil crops. Associating oil palm with less negative environmental impacts tends to be perceived as an attempt to promote its development. We put special care to overcome this potential misunderstanding when publishing and presenting results. We also engaged the primary and secondary schools sectors through presentations and more directly through their playing of ComMod games using the Cameroon case study.

5. Pathways to Impact

What changes does the research seek to generate?

The project sought to influence changes in terms of policies, behaviour (practices) and worldview among relevant stakeholders on sustainable palm development. To this end, we developed an explicit Theory of Change at project inception and then revisited it regularly. The ToC was done globally for the project and also for each partner country. Across the partner countries, actors such as regional and district agencies, oil palm industry, oil palm smallholders become aware of the consequences of oil palm expansion on land cover changes and landscape, ecology, local livelihood, environmental services etc. Stakeholders at the national or even global level have also become aware of the findings and innovative tools generated from this research. Engaged interactions among actors and new knowledge helped reconcile different and often conflicting views on the consequences of oil palm development. NGOs, local government and local people expressed appreciation of the ComMod modelling approach as ancillary tools for dialogues that influence behaviours.

In Switzerland, the pathway to impact involved four directions: 1) implementing findings in management practices of agronomists to strengthen exemplarity of good practices, 2) publishing

findings in high impact factors scientific journals to increase research interest and so, publication about alternatives in oil palm development, 3) raising civil society awareness on alternatives taking advantage of the communication channels of WWF and 4) increasing policymaker interest by highlighting the potential of reducing greenhouse gas emissions at low economical cost.

In Colombia we sought to demonstrate that reducing negative environmental impacts (in terms of carbon storage, soil fertility, and biodiversity) of oil palm cultivation is possible. Our work suggests considerable scope to minimise impacts on biodiversity by allocating future expansion to zones of comparatively low biodiversity, while maintaining carbon storage and soil fertility can be achieved by developing oil palm on pasture lands. Pasture lands and degraded land areas provide an opportunity for deforestation-free oil palm agriculture. Moreover, different management practices, i.e., compost, cover crops and intercropping, can increase soil fertility and biodiversity in oil palm agroecosystems. While challenges remain for the adoption of improved management practices, the progress made by oil palm farmers, as well as the increasing awareness across multiple stakeholders of oil palm certification, provide opportunities favouring sustainable oil palm expansion.

In Cameroon, our research sought to improve the economic returns from oil palm to smallholder farmers, while also promoting sustainable management of natural ecosystems. This involved raising the awareness of planters on the socio-ecological issues linked to the development of oil palm cultivation. This was achieved through direct participation in our research activities by a range of stakeholders, ranging from smallholders to governmental representatives. Associated with this was the production and dissemination of videos on the project, participation in radio and TV broadcasts, scientific articles, and associated academic outputs. Through these activities the Cameroonian public is now better informed of the consequences of unregulated oil palm development, while the government-appointed Inter-Ministerial Panel on Oil Palm is better informed on the complexities of the sector as well as potential solutions that might alleviate some of the current challenges.

The hydrological team at ETH Zurich has elucidated and quantified the impacts of oil palm plantations on surface water and energy fluxes. The results have been published in top-ranked scientific journals and various media outlets (blogs, news), thus bringing the “water” component into the oil palm debate both within the scientific community and the general public. Scientific results have also been shared and discussed with the project partners during workshops and meetings, thus directly and indirectly influencing all the other project components. A direct integration of the physically-based simulations and ComMod approach was originally foreseen in the project, and this was achieved through the work in Colombia, where qualitative interpretations (derived from quantitative projections) on water and yield variability were included in the role-playing games allowing the different stakeholders to understand impacts and feedbacks between oil palm, water consumption, and local hydroclimate. This has been shown to enhance awareness and critical thinking in the context of water resource management and negotiation across stakeholder interests in the region. It is possible to integrate hydrological modelling outputs in future ComMod game models in other localities, but we chose not to do so in Indonesia and Cameroon as water was not considered to be a limiting factor based on outputs from stakeholder dialogues.

In Indonesia, project outcomes included (a) providing the wider science community with new information and analyses of impacts on land, livelihood, sustainability, (b) encouraging target stakeholders to have dialogues and communicate effectively through research activities, workshops and ComMod games, and (c) informing policy actors of our key results, and inclusion of project outcomes by way of our partners into policy dialogues.

Which communication channels are used to generate the desired change?

ComMod games are tailored to address, communicate, and negotiate solutions for, key issues in the oil palm sector. Inherent in the ComMod approach is the idea of direct communication among actors and the sharing of knowledge and co-development of solutions. On this basis, the research activities focusing on the district- and site-level contexts in Indonesia, Cameroon, and Colombia, as well as the demonstration of ComMod in Switzerland, is integral to our core communication channels

targeting the most relevant actors at local, provincial, national and international levels.

Using Indonesia as an example, local and regional actors were closely involved in the research process, which provided opportunities for communication among smallholders, middlemen, companies, village officers, and other officials at higher levels of governance. We partnered with the Kutai Kartanegara district plantation office to develop scenarios for sustainable palm oil. The working group comprised representatives from key government institutions, such as the plantation office (Dinas Perkebunan), district planning and development Agency or Bappeda, the National Land Agency's local office in Kutai Kartanegara, NGOs and farmer associations.

At the provincial level (East Kalimantan), OPAL participated contributed to the development of local regulations (Perda) on guidelines for determining high-conservation value areas across East Kalimantan province, coordinated by the Provincial Plantation Agency (Dinas Perkebunan Provinsi). Our involvement allowed us to be involved in facilitating smallholder readiness towards ISPO certification through the use of ComMod. We also engaged in a multi-stakeholder forum on low carbon development and green economy (launched by East Kalimantan Provincial Government in February 2017), which enabled us to enhance the capacity of district plantation officers to use GIS technique and validate HCVs across plantation as set by oil palm companies.

At the national level, we were active in policy processes addressing governance of land and forest management. We engaged in working groups, led by the Coordinating Minister for Economic Affairs, focusing on strengthening the Indonesia Sustainable Palm Oil standards, including developing principles and criteria for sustainability. We maintained our links to the Indonesian Palm Oil Platform (FOSKBI, organized by the Ministry of Agriculture and UNDP), that aims to increase smallholder capacity to adopt ISPO standards. We also participated in the working group "Sahabat Petani" (Friends of Farmers) coordinated by the oil palm farmers' worker union (SPKS). We shared ComMod concepts and tools with stakeholders beyond the East Kalimantan region (including through Lingkar Temu Kabupaten Lestari which convenes district governments across Indonesia concerned with sustainable and green economy).

At the global level, we used the Global Landscape Forum as a platform to disseminate research findings and products arising from OPAL. The project brought two local people from Kutai Kartanegara district to attend the GLF Peatland Matter event (18 May 2017 in Jakarta, http://www.landscapes.org/peatlands/). They provided testimonies, raising concerns on how oil palm has been expanded on peatlands surrounding their villages, leading to adverse environmental impacts. We continued to publish articles, blogs, and videos aired across the globe to ensure stakeholders become aware of the major issues threatening forests and people as a result of oil palm expansion, and of major efforts by stakeholders to avoid and rectify the situation.

What are the differences between the hypothesized changes from a scientific perspective and the actual situation?

A notable conclusion of our work is that the very large majority of scientific output to date is highly disciplinary (rather than inter- or trans-disciplinary) and hypothesis-driven and yet the hypothesised outputs and resulting conclusions of such studies are often rendered meaningless in terms of decision-making given the complex socio-ecological and political realities of the oil palm sector. It is this central issue of complexity that OPAL has sought to address. Our work is inherently trans-disciplinary through which understanding emerges from dialogues with a range of stakeholders, and by which strategies can be negotiated and tested. The OPAL project has demonstrated that there can be a convergence of views on oil palm issues despite the multi-faceted complexities, provided that appropriate enabling platforms are used, that these platforms embed science-based evidence, and that they capture the realities on the ground that actors recognise. Through these platforms negotiated solutions can emerge, though implementation and testing of these solutions continues to require appropriate institutional setups and political will.

What is being done that the research results contribute to the desired impact(s)/change(s)?

The project leaves a legacy of tools, approaches, trained practitioners, and informed policy-makers who will continued to apply and develop key results from OPAL project. This will be done through existing channels (e.g., policy-working groups) and through the young scientists that have been trained through OPAL, and who now skills in the continued use of the ComMod approach to explore solutions with a range of stakeholders.

How can unintended negative impacts be avoided and important trade-offs be communicated?

ComMod allowed us to anticipate and explore trade-offs. Emerging negative impacts were identified as different scenarios were explored in the ComMod modelling platforms. It is beyond the scope of the project to implement and monitor such scenarios, though the training provided provides the means to do so. Multi-stakeholder platforms along with monitoring could, therefore, be readily developed through the ComMod approach, and would be well suited for identifying and communicating important trade-offs. The OPAL project provided substantial training for this purpose across Colombia, Cameroon, Indonesia, and Switzerland.

In the Orinoquia region in Colombia, for example, the project helped to create a better understanding about the lack of planning in the oil palm socio-ecological systems, thereby facilitating potential agreements between actors on the allocation of soil, water, labour and infrastructure, after having considered trade-offs. In the Caribbean region (Aracataca river basin) the OPAL project helped identify obstacles to cooperation in basin-scale water management, including the need to improve and design better institutional arrangements. In both cases, actors recognised the value of the tools developed by the project (role playing games) as platforms to explore the management of trade-offs.

6. Research Partnerships

How were the research partnerships of your project initiated and established?

The partnerships were initiated on the basis of: (i) shared research interests and (ii) previous work collaboration and mutual knowledge. Key partners that could contribute to the objectives of the project were brought in at the start of the program. The project was built with key institutions in the different targeted countries including WWF and CIFOR. Partnerships were established based on working out mutual agendas, clear responsibilities and leeway in decision-making. Starting the project with a kick-off meeting to collaboratively create the theory of change was key in securing a good working relationship at project inception.

To what extent are KFPE's 11 principles respected?

Of the KFPE's 11 principles, we highlight our collective effort to determine the research agenda and theory of change jointly [P1] and by engaging with national and international level stakeholders [P2]. All partners shared clearly defined roles in implementing this project as knowledge generation and communication [P3], and we underlined the concept of transparency and ensured unrestricted flow of knowledge and information, which makes joint learning possible [P7]. The OPAL project involved many young scientists and enhanced the capacity of stakeholders to tackle oil palm issues through the use of ComMod and GIS techniques [P6]. We also generated and shared knowledge [P8] and engaged a diverse array of stakeholders in mutual learning [P5].

What have been the biggest challenges in research collaborations and were they addressed?

Maintaining effective communication among partners across a large project, multiple disciplines, and different organisations has been challenging. Nonetheless, we were able to build a very cohesive team even though the issues that were prioritised in each country differed substantially. Cohesion was achieved through regular communication both in person and online, and by the appointment of an ETH-based representative for each country in which the work was being done. Issues arising in each country could therefore be efficiently communicated through the representative to the project leadership team, and these issues could then be resolved through discussion across the leadership team and with the country personnel. In order to improve the communication between partners, we have clarified responsibilities and identified appropriate communication tools.

The integration of stakeholders in research activities required the clear transmission of project objectives and outcomes, and constant engagement across networks. This was achieved through good training provided to local project partners who were then well-placed to establish an effective relationship with local stakeholders. We were also greatly helped in this process by identifying and working with local 'champions', that is people who understood and agreed with our project's purpose, and were well known, respected and politically influential.

Developing and implementing a communication strategy proved challenging on account of the many different strands of work and the substantial demands on time and resources that such a communication strategy entails. The project made use of opportunities as they arose rather than pursuing a clearly developed communication strategy. This was particularly the case early in the project when the focus was on conducting the research rather than communicating output, and was only resolved near the end of the project when there was greater clarity on outputs and impacts.

Please list here also the academic degrees (BSc, MSc, PhD etc.) obtained within the projects by project team members in the partner countries.

Cameroon, 7 Bsc and Msc (Mbache Kenneth Mbunu, Marie Gaëlle No Njiki, Théo Martin, Bauclaire Azong Ngoko, Meli Djimeli Joel, Mindjeme Axel Willy, and Guy Donald Abassombe); **Switzerland**, 2 PhD (Juan-Carlos Quezada, Nur Hasanah Mufti), 2 Bsc (Nora Zeller, Manuel Stamm), 4 Msc (Sandra Deferne, Johanna Ruegg, Eliane Steiner, Helena Mühlhaus); **Indonesia**, 3 PhD (Bayu Eka Yulian, Rizka Amalia, Fakhrizal Nashr), and 1 PhD in progress (Faris Ramadian); **Colombia**, 4 Msc (Nathaly Garcia, David Chapeta, Valentina Fonseca, Gina Olarte)

7. Sustainable Development Goals

By examining oil palm management systems and the social and ecological impacts of their development, our research has sought to provide both knowledge and skills to promote more sustainable production of palm oil. This objective contributes to SDGs 1, 12 and 15. All OPAL outputs contribute to improving livelihoods, reducing poverty, and reducing inequality (SDGs 1 and 10). We highlight our efforts to enhance the ecological and economic sustainability of independent oil palm smallholders, and the need to build strategies that benefit smallholders by addressing asymmetric information and rent seeking behaviour. In Indonesia, the spatial analysis of land cover changes highlighted continuing deforestation across the district, and is being used to inform how government should respond (SDG 15). Our role in developing policies on HCV and facilitating district officials to identify and set legal rules governing how areas within concessions should be allocated to conservation has contributed to government's efforts to reduce deforestation (SDG 15) and greenhouse gas emissions (SDG 13). Our work in Colombia on water resource management and soil carbon storage and sequestration contribute to SDGs 6, 10, and 13.

8. Gender-sensitivity

The research team in all countries we worked in was well represented by women, and women were the majority in Colombia, including senior personnel, and there was close parity (at least 40% women) between men and women in all countries, including Switzerland, with women in senior positions in each of these countries. From the composition of the OPAL Indonesia team itself, 40% of the team members were women. We also considered gender issues in the collaboration with stakeholders, including, for example, work with women owners of oil palm smallholdings in Cameroon and Indonesia. The project team has also considered the prospect of a specific study on the role of women in the oil palm sector in Cameroon, though this was not ultimately conducted on account of limited time. In Indonesia, gender was included as part of the research through the consideration of women's participation in the oil palm sector as interpreted through their own perspectives, as well as the role of women in initiating change. A specific study in Indonesia on the impact of Oil Palm Development for Women is continuing, and aims to understand the impact of oil palm plantations, both large and small, on the role of women in the domestic and public sectors.