Chapter 5

Seeds of Change — Plant Genetic Resources and People's Livelihoods

Thomas Hilger, Iris Lewandowski, Bastian Winkler, Barbara Ramsperger, Paulo Kageyama and Carlos Colombo

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/59984

1. Introduction

Since the dawn of mankind people explore the cornucopia of the plant kingdom to obtain food, feed, fiber, and fuel. Worldwide, the total number of higher plants is estimated to be 270,000 species. About 43% of them are crops, cultivated plants, and their wild relatives, nowadays being classified as plant genetic resources for food and agriculture. Throughout the history only 7000 species representing almost 2.5% of the total were cultivated by mankind in the one or other way [1].

Mankind has largely benefited from modern agriculture. Today, agriculture provides food, feed, fuel, and fiber for more than 7,000 million people whereas a hunter-gatherer lifestyle supported around 4 million people only. In the past four decades, global cereal production almost doubled. This strong increase was based on greater use of inputs such as fertilizer, water, pesticides, new crop varieties, and other technologies provided by the 'Green Revolution'. This helped to diminish hunger, improve nutrition, and spare natural ecosystems from conversion to cropland. By 2050, the population is expected to have increased by 50%. Increasing and sustaining food production for a growing world population will, therefore, be a major challenge in future; however achieving this without compromising environmental integrity and public health is even more challenging due to changing habits in food consumption in parts of the world, a rising demand for biofuel, diminishing returns to fertilizer, and an increasing water demand [2].

Although new crop varieties substantially contributed to increase crop yields, specialized plant breeding has led to a strong dependence on few crops only along with erosion of plant genetic resources. For thousands of years farmers have been domesticating plant species thereby developing a wide range of crop varieties adapted to specific needs and environmental conditions [3]. Over the past 100 years the importance of many crop species has decreased strongly and many adapted crop varieties diminished. The private agricultural sector increased significantly in both developed and developing countries during the past 20 years; however, the main focus of its interest has been high-value products, such as maize, wheat, rice, oil crops, pulse crops and vegetable crops [4]. Today, 30 crops provide 95% of human food energy needs, 12 crops together with five animal species deliver 75 % of the world's food today, and three of which, i.e. rice, wheat, and maize, are responsible for more than 60% of our energy intake [5]. Almost 90% of global vegetable oil is produced by four crops only; i.e. oil palm, soybean, oil seed rape and sunflower [6]. Nowadays, our food security depends on a tiny number of crops only; it is therefore essential to sustain a high genetic crop diversity for both coping with increasing environmental stresses and facilitating farmers and researchers with options to breed cultivars adapted to less favourable conditions, such as salinity, poor soils and extreme weather events and that can resist biotic stresses, such as pests and diseases [4].

Many studies and reports discuss the importance of plant genetic resources for crop production in view of climate change and their key role in adapting to adverse climatic conditions and, hence, for food security. Important is that underutilized or minor crops often harbour high levels of genetic diversity being maintained on-farm in small-scale farming systems; however they are relatively neglected by formal research and development strategies, including breeding programs. Results from Peru hosting a wealth of native agro-biodiversity including many underutilized crops indicated the potential of a breeding approach for indigenous Andean crops, based on a combination of evolutionary and participatory methods to reach a balance between yield improvement and maintenance of genetic diversity [7]. These authors also highlighted the importance for upscaling such activities but mentioned the need to address methodological, financial and institutional issues for further expansion. Such activities are particularly important for areas threatened by climate change and to safeguard local food production. A global analysis of climate risks for crops in 12 food-insecure regions indicated South Asia and Southern Africa as two regions that, without sufficient adaptation measures, are likely to suffer from negative impacts on several crops important to large food-insecure human populations [8]. Therefore, these areas need special attention in crop development and breeding for food security based on local seed systems.

Minor crops can be important at a local, regional and national level but are often neglected at an international level. They are staple foods, contributing to food supply in certain periods and to a nutritionally well-balanced diet but also supply raw materials such as oils, fibres and dyes, providing options for income generation. Plant genetic resources are sometimes also well adapted to marginal soil conditions, an important feature in face of climate change and increasing soil degradation in densely populated regions. Minor crops are neglected as their advantages are known only locally and due to lack of markets, infrastructure for processing, and international research activities. Their potential, however, is often only poorly addressed and the loss of plant genetic resources reduces current and future options for mitigation in the agricultural sector [3].

http://dx.doi.org/10.5772/59984

On this background, this chapter intends to reflect the importance of plant genetic resources for people's livelihood and the human impact on plant genetic resources in general, looks at opportunities how the use of genetic resources and introduction of new or minor crops can contribute to improve people's livelihood and discusses tools for impact assessment.

2. Plant genetic resources and people's livelihood

2.1. Global distribution of plant genetic resources

In general, the highest number of species of vascular plants is found in the humid tropics and subtropics [9]. The species number strongly declines from the tropics and subtropics towards the temperate and polar zone north and south of the equator, indicating that hotspots of biodiversity are mainly associated with warm and humid tropical conditions and pointing to the global importance of these zones. Biodiversity hotspots are also abundant in regions rich in orographic structure or high in geo-diversity such as mountains and coastal regions (Fig. 1). Biodiversity hotspots are also important in terms of agriculture as they often coincide with or are, at least, close to Vavilov's centres of origin and areas of agricultural development.

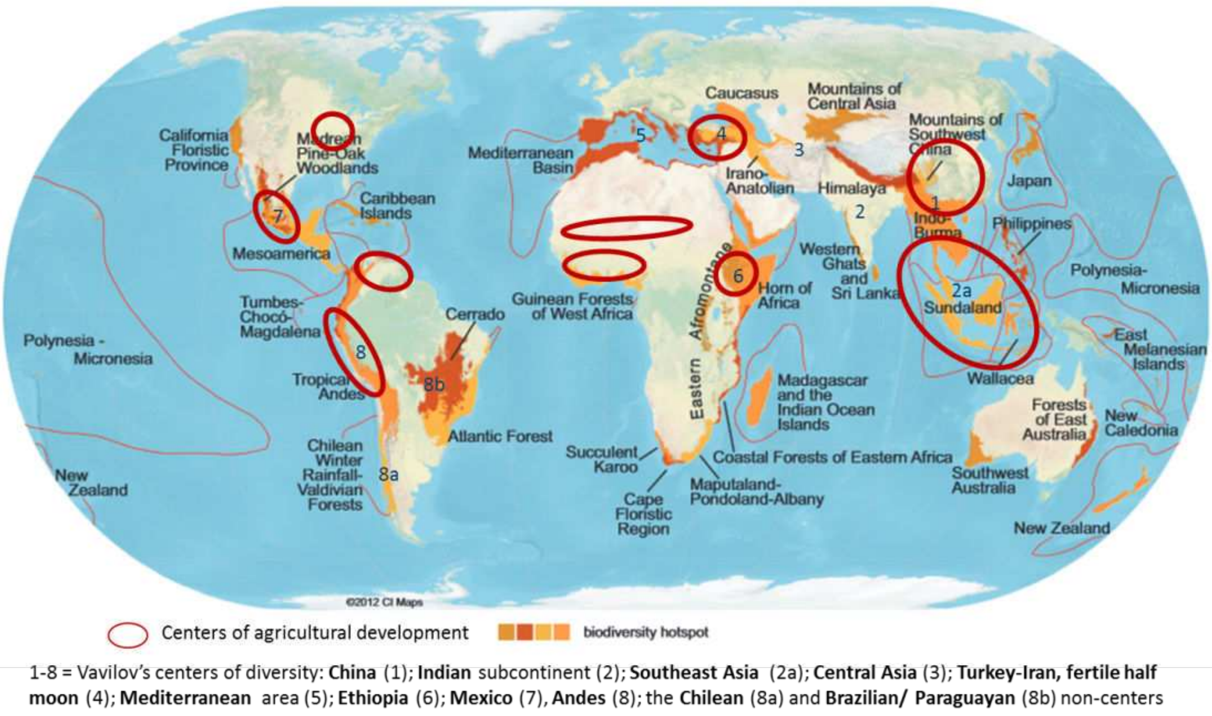

Figure 1. Biodiversity hotspots, Vavilov's centres of diversity, and centres of agricultural development. (Source: Image downloaded from Conservation International, 2013, modified)

In Africa, biodiversity hotspots are located in Madagascar and the Indian Ocean islands, the Congo basin, the eastern Arc Mountains and coastal forests, Guinean forests of West Africa, the Cape floristic province of South Africa, and the succulent Karoo. In Asia, hotspots are found in the Caucasus, the fertile half-moon region, Sundaland, Wallacea, the Philippines, the Indo-Burma region, the mountains of South-Central China, the Western Ghats of India, and Sri Lanka. Other important areas of biodiversity are located in the Mediterranean basin, South-western Australia, New Zealand, New Caledonia, and New Guinea and the Micronesian islands. Neotropical biodiversity hotspots are located in the tropical Andes, the Caribbean, Mesoamerica, the Atlantic forests, western Ecuador, the Chocó and Darién regions of northern South America, the Brazilian cerrados, central Chile, the upper Amazonia and Guyana shield, and the California floristic province. The estimated number of vascular plant species in Neotropical biodiversity hotspots ranges from 2-3000 up to more than 5000 species per 10,000 km² [9].

2.2. Plant genetic resources, minor crops and their potential in food, feed, fibre and fuel production

Diversity plays an important role as agricultural biodiversity is connected to nutrition and food security. Therefore, the primary justification for the conservation of plant genetic resources was given as their importance for breeding of improved varieties of crops for food, fuels and medicines [10]. In a rapidly changing world as today, conditions enhancing the adaptability and, hence, the resilience of family farms is crucial to their viability. Here, biodiversity can help farmers manage risks from new pests and diseases but can also lessen the effects of sudden natural disasters. Diversity allows natural adaptation to the environment which is vital in the face of climate change. Diversity also diminishes the risk of crop loss and contributes to productive, healthy farms [5].

Human infiltration into the tropical lowland rainforests of the Americas was late and slow as highlands and savannahs were easier to explore. This led to a lesser exploration of its biodiversity by mankind [11]. Nowadays, tropical rainforests of the Americas are esteemed as important biomes with regard to biodiversity, particularly when looking at industrial uses. Plant species originating from the Brazilian cerrado and Atlantic forest biomes provide promising bioactive secondary metabolites. These biologically active compounds are interesting for the pharmaceutical industry and present another option for a bio-products based income generation [12]. Palms originating from the Amazon lack key conditions for their sustainable management such as adoption of palm-climbing devices, not only for reducing wild palm felling but also for stimulating broader community-level conservation and efforts for their cultivation [13]. 'Improved extractivism' can be an appropriate way of growing wild plants, such as tucumã (*Astrocaryum* ssp.), a neotropical palm species rich in oil which can contribute to an increased farm income while increasing the economic value of disturbed areas in the central Amazon [14].

More than half the world's plant and animal species live in tropical forests. Hence, these biomes were often the cradle of food crops. The share of food crops derived from the tropics is high, estimated to be as much as 80%. They also provide genetic resources we will need if we are to produce new varieties, resistant to disease, insect pests, and climatic constrains, in the fight against world food shortages [15]. These biomes are also rich in non-timber forest products (NTFPs) important for developing new crops which include fruits and nuts, vegetables, fish and game, medicinal plants, resins, oils, essences, and a wide range of barks and fibres. Governments, conservation and development agencies and non-government organizations have encouraged their marketing and sale as a way of boosting income for poor people in the tropics and encouraging forest conservation. NTFPs are also of economic importance as basic raw material for various applications in industry, ranging from the development of new drugs against widespread diseases to bio-based compound composites [16].

The potential of Amazon's biodiversity in view of the automotive industry was underlined during a conference held at Belem, Para, Brazil in 1996 [17]. In particular, oil, fibre and resin producing plants are interesting in car manufacturing. Research results and experiences using natural fibres from the Amazon indicated their potential as reinforcement in composites for vehicles [18]. One of the tested fibres was curauá (*Ananas lucidus* syn. *A. erectifolius*), a hard-fibre producing bromeliad. Its fibre is well suited to substitute glass fibre in various parts of cars and trucks. Attempts to improve its productivity, harvest and processing, and to identify best agricultural practice were initiated [19-21]; however bridging the gap between needs of smallholders and industry improving the understanding of each other's bottlenecks was not possible due to a lack of both, use of participatory approaches and long-term commitment of the donor.

3. Human impact on plant genetic resources and options for their maintenance

There is rising awareness that habitat loss is associated with loss of genetic diversity; however the basic cause-effect relationships underlying the ecological roles of biodiversity are still poorly understood [22]. Major tropical wilderness areas show strong coincidence of biodiversity, people and concerns over watershed functions and are in a state of decrease or degradation as natural forests are converted into other land use classes and little area transforms back to natural forests or is reforested with plantations [23]. Various drivers are important for that. There is a high negative correlation of population density on species richness and tree diversity for tropical rainforests [24] but neither population nor poverty is the sole and major reason for land use and land cover change. It is driven by people's reaction to economic opportunities and constraints, created by local as well as national markets and policies. Additionally, global forces become main determinants as they intensify or weaken local factors [25].

Sustainability in agriculture suggests a focus on both improved understanding of the benefits of ecological and agronomic management, manipulation and redesign, and genotype improvements through the full range of modern biological approaches. A sustainable management of agro-ecosystems which includes aspects such as energy flows, nutrient cycling, human impacts and resilience may enhance reshaping of agriculture in landscapes. Sustainable cropping systems will influence food production, pesticide use and carbon stocks in a positive way. But the development of national and international policies supporting a stronger expansion of such systems in developed as well as developing countries still remains a major challenge [26]. Key drivers in the decline of biodiversity, its conservation and ecosystem services are the increased use of pesticides, herbicides and fertilizers, an increased homogeneity of landscapes associated with regional and farm-level specialization, drainage of water logged fields, loss of marginal and un-cropped habitat patches, and reduced fallow periods. Additionally, the intensification of agriculture has been fundamental to the degradation of ecosystem services and increases both, the production of greenhouse gases and a reduction of carbon sequestration [27].

Looking at the human impact on the earth system, nine planetary boundaries can be defined whereby the transgression of one or more of them is considered harmful due to abrupt environmental changes within continental- to planetary-scale systems. Three of them - climate change, the global nitrogen cycle and the rate of biodiversity loss - have already surpassed their threshold levels leading to consequences for global sustainability [28]. Strong negative impacts upon ecosystems are expected when the increasing annual global mean temperature rises above the pre-industrial mean by 2°C or more, especially in biodiversity hotspots [29].

The supply of non-timber forest products, timber and other services by forests resume a safety net function for rural populations providing both, income and jobs. Hence, fostering the role of forests in the political debate is essential, not only when looking at mitigation and adaption strategies for climate change but also for achieving sustainable developmental goals [30]. Experiences from Central Africa involving a wide range of stakeholders showed that focused research on priority sectors for poverty reduction are likely to raise public awareness of the forests' role and contribution to mitigate and to adapt to climate change at regional and national levels. A key for improving coherence and effectiveness of forest management policies is establishing the link between forests and climate change adaptation [30].

Plant genetic resources are essential for farmers to cope with future challenges, a feature emphasized by the FAO Commission on Genetic Resources for Food and Agriculture. New within-crop diversity will be needed to adapt to future conditions, and even new crops will be required under extreme conditions to reduce risks induced by climate change [4].

Despite progress in the past, crop wild relatives and underused species for food and agriculture need to be secured. The need for adapted germplasm is urgent and requires characterization, evaluation, and the availability of materials but gaps in *ex-situ* collections of selected crop gene pools are huge. The current focus on major crops leads to concerns due to a lack of *in-situ* and on-farm conservation. This neglects the importance of genetic, species, and ecosystems diversity. Currently, six million plant accessions are conserved in gene banks worldwide, representing a very limited number of species. Half of them are improved cultivars or breeders' lines. Only one third, however, represents landraces or old cultivars. About 15% refer to wild relatives of crop species and weeds. Minor crops and underutilized species are largely underrepresented in these collections, particularly primitive cultivars and wild relatives from the centres of origin’s diversity and cultivation. Another obstacle is that only a third of all gene bank accessions have been fully characterized [1].

However, for many other crops, especially neglected or underutilized species and wild relatives of crops, comprehensive collections still do not exist and considerable gaps remain to be filled. There is also need for a better communication, collaboration and partnerships among institutions dealing with the management of plant genetic resources, from conservation to plant breeding and seed systems [4].

Since farmers know best which materials meet their needs and are enthusiastic seekers of new varieties, "participatory plant breeding" represents a promising approach to enhancing agro-biodiversity [3]. Their participation in the whole process from the selection of plant genetic material up to development of cropping systems would improve and help to meet their needs, while also sustaining food security and alleviating poverty. Plant breeding of major crops, however, often lacks this participation, neglecting marginal site conditions and fostering high input demanding improved varieties.

Genetic diversity is essential for improving crops already in use but also for developing potential novel crops. The successful use of plant genetic resources and their sustained production depend to a large degree on access to genetically diverse germplasm. Free international exchange of germplasm will contribute significantly to the worldwide development of new industrial crops [31]. This is another challenge which needs to be solved in an equitable and fair way. Often indigenous knowledge is highly esteemed by people but once it comes to payment for such services people are reluctant to do so. Contracts for compensating creativity of farmers and a framework for rewarding grass root creativity and innovation are possible solutions [32], while consumers' and traders' responsibility is fostering fair trade, supporting local people in their production of food, feed, fibre and fuel [33]. Four types of collaboration are considered vital for using plant genetic resources in a sustainable way: (i) a national regulatory framework for biodiversity prospecting, (ii) the development of infra-structure and technology; (iii) formal contractual relationships among biodiversity's sources, intermediaries and final users; and (iv) the moving of research and development into the source country so as to contribute to its gross national product [16].

There are knowledge gaps with regard to the world's ability to match both a bio-based energy production and maintaining food security at the same time [34]. The main challenge is the competition for arable land and limited fresh water resources associated with a fast growing demand for food, feed, fibre, and fuel worldwide. A solution requires higher crop yields and improving resource-use efficiencies, especially that of nitrogen, and water productivity in production systems over the next two or three decades which is only possible with high external inputs. Cropping systems adapted to climate change and improved stress tolerance of crops are key issues in this context. This can be achieved by genetic improvement of crops and establishing sustainable cropping systems in diverse environments. Integrated assessments of their impact on resources, environments, and people's welfare can help identifying management options, species and varieties well adopted or most appropriate for specific environments. This will largely depend on the added value regarding specific ambitions, i.e. food, feed, fibre or fuel [34].

Energy wealth in Latin America has so far contributed little to overcome poverty and foster development. The sometimes considerable oil and gas earnings are not used to improve general welfare but skimmed off by the elite. A major problem is that both, energy reserves and energy utilization, are unevenly distributed in Latin America [35]. Using bioenergy is an option for an improved participation of rural communities if political leaders set the right frame.

There is lack of proper research, training, and socio-economic information to produce biofuels in a sustainable way. Hence, research in agriculture has to set a focus on improved crop selection based on the local situation and on management options including cultivation, management of pests and diseases, mechanisation, and harvesting. Furthermore, it is necessary to adapt cropping systems to local soil conditions and use by-products of biofuel crops to increase the efficiency of nutrient use and decrease negative influences on the environment. This is essential for the sustainable production of bio-fuel crops [36].

There are two main approaches to conserve plant genetic resources:

- *In-situ* conservation which is the protection of biological resources in their native environments and within naturally established and evolving populations, e.g. networks of protected areas which are ecologically representative of the forest types present on the landscape; sustainable forest management practices, ensuring that harvesting practices are genetically sustainable and ecologically compatible with the natural regeneration of target species, maintaining locally adapted gene pools and their genetic diversity *in situ*, and conforming with the requirements of other forest-dependent species that affect forest regeneration and health.
- *Ex-situ* conservation, particularly where *in-situ* conservation cannot be practiced or will not be sufficient to ensure adequate protection for genetic resources including germplasm banks and common garden archives, seed banks, tissue and cell cultures, cryopreservation, and DNA banks [37].

Both approaches can also be applied to conserve agro-biodiversity where many land-races have vanished since the green revolution in the 1960ies. However, effectively conserving wild biodiversity in agricultural landscapes will require increased research, policy coordination, and strategic support to agricultural communities and conservationists [38]. Research needs to address open questions regarding the minimum size and level of area connectivity required to conserve biodiversity *in-situ* at landscape level. *Ex-situ* conservation is biased by human decisions. But where shall we set priorities for sampling? Who pays for the costs of collecting and sustaining such kind of environmental services? Can value be added by exploring options for development of bio-products? Identifying common priorities in shared natural resource systems, however, is a major step in sharing a common responsibility in addressing climate change and associated problems.

4. Examples for the potential of introducing underused genetic resources

Globally, we are facing a pressure on vegetable oil markets with an increasing demand for food, fuel and chemical applications of vegetable oils on the one hand, and a limited potential for a sustainable extension of vegetable oil production on the other hand. The increasing demand for vegetable oils has led to the steep increase of oil palm production area in South-East Asia, nearly all of it on the cost of rainforest area and dramatic losses of biodiversity. In Europe the production of rapeseed oil increased strongly, too, on the expense of high inputs of agrochemicals. Rapeseed is one of the most demanding crops, requiring high inputs of nitrogen fertilizer and up to a dozen of applications of pesticides and insecticides. A further

http://dx.doi.org/10.5772/59984

extension of rapeseed in Europe is limited by the availability of suitable land and narrow crop sequences.

All over the world, we find various activities on testing and promoting plant genetic resources for vegetable oil and biofuel production. For this purpose especially plant species which do not compete with food crops growing on less fertile land are of particular interest. So far, real success stories, if at all, are rare. *Jatropha curcas*, a species endemic to the Brazilian cerrados, nowadays widely spread in the tropical zone received strong public attention in the past but never fulfilled people's partly exaggerated expectations [39]. Many studies on this species are very enthusiastic on reclaiming wasteland while simultaneously producing high oil yields. This often contributes to hype these species, although sound fundamental research is lacking to backup and foster farmers' adaptation [40].

Jatropha has gained international recognition as feedstock for bio-diesel production in the early 1980s. Its properties convinced investors, policy makers and clean development mechanism (CDM) project developers to consider it as a promising substitute for fossil fuel. Its toxic compounds exclude jatropha from human consumption. The same is true for the protein-rich press cake remaining after oil extraction which, hence, cannot be used as animal feedstuff. Jatropha grows on poor soil but yields are also poor under such conditions. This species is open-pollinating which hampers selection of specific lines for developing non-toxic varieties by breeding. Another advantage, often mentioned when arguing for this species is that jatropha is drought-resistant and well adopted to erratic rainfall conditions. Propagated by seeds it develops a deep rooting system. This is not the case when propagated by woody stem cuttings. Then, for higher yields sufficient water needs to be supplied in semi-arid or sub-humid regions with erratic rainfall conditions, particularly during early growth [39].

Jatropha, however, is partly still a wild plant of which basic agronomic properties are not fully understood, while environmental effects have not been investigated yet. Main knowledge gaps are found in the cultivation of the crop, for both a description of best practice as for describing the potential environmental risks or benefits. Therefore, fueling the jatropha bio-diesel hype has to be handled with care, unless the before mentioned knowledge gaps are closed by sound research [40].

The process of introduction of jatropha was characterized by top-down approaches, often neglecting the needs and involvement of local farmers. This often led to non-acceptance or even resistance against jatropha plantations [41]. Another obstacle is the fact that jatropha products are non-edible. Many farmers that have been establishing jatropha in Africa, partially on land previously used for food production, and that did not find a market or processing facility for the jatropha nuts, cannot use the products in case food is needed. This questions the approach of planting crops that deliver non-edible products because there is no flexibility in use deciding for either food or fuel use.

Activities in the biofuel sector are also driven by external forces, e.g. environmental concerns or a growing worldwide demand for biofuel, which generates political action. Brazil's government initiated a national bio-diesel policy, promoting feedstock supply from family farms. Especially in semi-arid regions, farmers have been encouraged to grow castor beans; however farmers' uptake of improved varieties was poor as the majority of farmers face great challenges associated with limited market access, top-down trading conditions, and lack of farmers' association fostering their market position. A stronger policy impact could be achieved by promoting bio-diesel crops that have alternative markets and fit more easily into the current farming system, reducing trade-offs with current crop activities and allowing synergies between fuel and feed production. Better enforcement of resource providing contracts is critical to avoid default and to alleviate labour and land constraints, thereby improving farmers' ability to engage in bio-diesel crop production [42].

In this context, another example endemic to the neotropics - the oil-producing macaw palm (*Acrocomia aculeata*) - has to be mentioned. Macaw palm recently gained economic importance in Paraguay and Brazil. In contrast to the African oil palm (*Elaeis guineensis*), it is adapted to a much wider range of environmental conditions which allows its production outside of the humid tropical zone, reducing negative impact on tropical rain forests. Another advantage of macaw palm is that it does not contain toxic compounds. The palm is a non-domesticated species with a high yield potential of an estimated 2.5 to 10.9 tons oil per hectare and year [43-45] and a life time of 70 years [46]. It grows well under various soil and weather conditions, naturally occurring in tropical and subtropical environments from southern Mexico to northern Paraguay and Argentina [46, 47]. It is often found on degraded grasslands as single trees, providing some extra feed to cattle which eat both, the fruits and leaves. The palms sustain longer periods without rain, and dry periods may last up to several months. Macaw palm fruits have a wide range of market opportunities with local and international perspectives as they are able to provide food, feed, fibre, and fuel (Fig. 2) [45]. The production and use of macaw palm can, therefore, provide a good example for a bio-economy crop that can fulfil food and fuel demands at the same time. Macaw palms growing in the Brazilian cerrados show a huge variability in biomass production and oil yield within and across various sites which highlights the importance of protecting biodiversity hotspots as source of future crops and in view of their domestication potential [48].

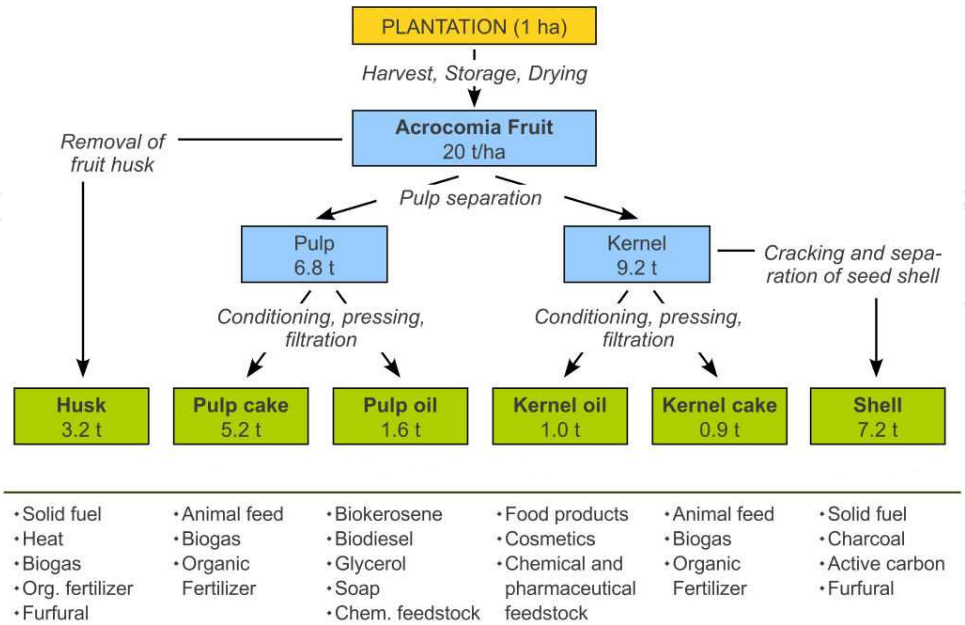

Figure 2. Processing, dry matter yield fractions and uses of macaw palm products [45]

http://dx.doi.org/10.5772/59984

5. Tools for the evaluation of impact assessment

The negative experiences of the large scale and partially forced introduction of the new crop jatropha [43] have shown that the introduction of a novel crop shall be guided by an *ex-ante* assessment of its ecological, economic and social impacts, including questions of local likelihood of acceptance.

Newcomers such as jatropha often lack proper long-term research on feasibility, trade-offs and environmental consequences, contributing to a better acceptance as well as public and private sector commitments for understanding needs of rural communities [39]. Macaw palms adapted to a wide range of environments are naturally occurring from Central America down to the north of Argentina and Paraguay [45], hence having potential for being cropped in many areas of South America or even outside of this continent, e.g. in Africa or Asia. Out-scaling of promising novel plants, however, also bears risks and requires an approach looking at all aspects of production from selection of genetic material and propagation, testing of cropping systems and crop management options to harvesting, transport, storage, and processing as well as considering development of new products. This needs an analysis of the entire value chain.

An *ex-ante* look at ecological and socio-economic aspects of macaw palm production or other novel crops allows identification of potential benefits, constraints and risks. Modelling is one approach in the portfolio of tools and techniques available to unravel dynamics of land use and their impact on the ecosystem associated with introduction of novel or alien species. Land use systems research addresses issues such as agricultural policy making, land use planning and integrated water management and involves for this purpose multiple stakeholders with various potential roles. Models are appreciated for both, their characteristic system research features and their integrative capacity [49]. Land use change models are tools for understanding and explaining causes and consequences of land use dynamics, The term land cover refers to the attributes of a part of the earth's land surface and immediate subsurface, including biota, soil, topography surface, groundwater and human structures. In that sense, modelling of land use changes provides insights into the extent and location of land use changes and its effects [50].

Especially important are arrangements regarding participation of stakeholders, and accountability in governance. Improving the ability of research programs to produce useful knowledge for sustainable development will require both greater and differentiated support for multiple forms of boundary work. Key issues are the use of knowledge for enlightenment, decision support, and negotiation support associated with boundaries between scientists and farmers, scientists and local policy-makers, and multiple knowledge sources and multiple users. Important determinants for their success are participation, accountability, and boundary objects to foster credibility and long-term success. Boundary objects are benchmark sites which allow studying human use of and impact on forest margins to gain knowledge for viable ways for a sustainable use of these sites. For decision support, joint creation of tangible products by scientists and farmers linking research with action, collaborative field trials, on-farm nurseries, and the production of training materials on effective land use practices are important. In terms of policy-makers, essential means are synoptic country reports, particularly when prepared as "policy briefs" on key issues and models focusing at regional scales. Moreover, it is important to note that context matters and challenges of boundary work need differentiation leading to strategies that follows context; however this is not possible without participation of all stakeholders [51].

Appropriate tools for that are:

- Participatory Landscape Analysis (PaLA),
- Rapid Carbon Stock Appraisal (RaCSA), and
- Integrated Renewable Energy Potential Assessment (IREPA).

PaLA was developed by the World Agroforestry Centre for agro-ecological analysis [52]. It captures local knowledge at relevant temporal and spatial scales, and provides insights on farmers' perception on the relationship between land use and landscape functioning: farmer's management options and the actual choices made, flows of water, sediment, nutrients and organisms, and internal filter functions that determine landscape functioning based on land use practices and interactions between landscape units. PaLA consists of the following eight steps [52]:

Step 1. Identification of ecological and administrative domains with clear boundaries.

Step 2. Sampling of representative stakeholders to be interviewed, using questionnaire and/or ranking methods. Criteria of representativeness are selected on the basis of specific project purposes.

Step 3. Formulation of the survey interdisciplinary group, planning and designing checklist and matching PRA tools.

Step 4. Making of a village sketch/model in order to identify the land use patterns and focus points in the landscape by using semi-structured interviews with male and female groups. The village sketch/model provides local names of area, distribution of land use, and main landscape features such as rivers, streams, mountains, roads.

Step 5. Transect walk are necessary to obtain an understanding of the soil-plant-water interactions along the landscape. Transects need to represent most of the land use types of the study area. The methods used are simultaneous transect walks and semi-structured interviews; delivered outputs are representative transects and sketches of the areas.

Step 6. A timeline for each land use type along transects or/and the fields located in the representative areas of the study catchment or village, is made to study land use changes over time, based on semi-structured interviews and timeline drawing.

Step 7. Feedback meeting in order to report findings to the farmers/stakeholders involved to get their feedback. The methods used are posters using visualising tools and group meetings.

Step 8. Data analysis: Qualitative data of each PRA tool, i.e. sketch transect, timeline, and secondary data is analyzed separately by the team. Thereafter, results are evaluated to identify landscape patterns and issues.

RaCSA also developed by the World Agroforestry Centre is a negotiation support tool that aims at providing reliable data on above and below ground carbon stocks in a defined landscape, its historical changes, the impact of on-going land-use change on projected emissions, and a framework for data generation on land-use options and their changes over time [52]. This approach assesses local ecological knowledge, explores its economic potential and uses carbon stocks as an indicator for the health or fertility status of soils. Furthermore, drivers of land use change and impact on environmental services such as biodiversity can be assessed. Simultaneously it provides knowledge on alternative land use options and mitigation strategies by means of mid- to long-term scenarios at landscape level using the Forest, Agroforest, Low value Landscape Or Wasteland (FALLOW) model. Finally, RaCSA was developed as negotiation support tool providing a basis for stakeholder discussions.

RaCSA consists of the following six steps [52]:

Step 1. Initial appraisal of landscape (see PaLA), focused on dynamics of tree cover.

Step 2. Explore Local Ecological Knowledge (LEK) and economics of local tree/forest management combined with a rapid household socio-economic survey.

Step 3. Plot-level C data of representative land cover units using an updated version of the ASB C_{stock} protocol provides time-averaged carbon stock data for above-ground vegetation and soils.

Step 4. Remote sensing and ground-truthing are used to provide spatial analysis of land cover change, based on a sufficiently sensitive 'legend'.

Step 5. The Public/Policy Ecological Knowledge (PEK) kit is used to obtain information on tree/forest management and existing spatial planning rules.

Step 6. Scenario studies of changes in C stocks and welfare through modelling land use and carbon stock dynamics in the landscape by using FALLOW.

FALLOW was developed by the World Agroforestry Centre for trade-off analysis [53, 54]. It allows a spatially explicit and dynamic modelling of land-use cover change (LUCC) in data-poor regions and merges bio-physical and socio-economic information to evaluate impacts of LUCC on food security, watershed functions, biodiversity, and carbon stocks. FALLOW was successfully applied in South-East Asia to assess local land use change dynamics without the need for long-term and data-intensive studies without the need for long-term and data-intensive studies based on farmers' knowledge [55], to explore livestock fodder options and their consequences for carbon stocks [56] and stakeholders' perceptions [57].

The introduction of new technologies, such as renewable energy technologies (RET) is comparable to the introduction of new plant species into local agricultural systems: new plant species as well as new technologies imply a change in the daily routine of local livelihoods. Traditionally, the planning of rural energy development projects took place in central government offices far away from rural communities [58]. The applied decision support tools aimed at the identification of the most efficient technology with the lowest costs [59]. The technologies selected in such 'top-down' approaches, were afterwards (involuntarily) imposed into rural communities [58]. Amigun *et al*. explored the community perspectives on the introduction of large-scale biodiesel production from canola (*Brassica napus*) and soybean (*Glycine max*) in South Africa [60]. The local population was overwhelmingly against the proposed biodiesel production. Their reasons for the rejection included a variety of especially social and environmental factors: land regarded as identity; competition with food security; distortion of the social community fabrics; doubts about the credibility of the developers and possible air and water pollution with respect to health risks of local population.

Several studies pointed out that the acceptance of RET depends on the complex interaction of social, institutional, environmental and techno-economic factors on a very local level [61, 62]. Smallholder agricultural systems are very diverse and therefore an assessment of these factors on individual basis is required that is based on public participation and pooled learning among the relevant stakeholders [60].

IREPA provides a people-centred, bottom-up approach for the assessment of the implementation potential of renewable energy technologies into smallholder agricultural systems [63]. This participatory approach explores the renewable resource base and the livelihoods of smallholder farmers to characterize the role of energy in the daily routine (social, institutional, environmental, technical, and economic factors) to select appropriate RET. The researcher acts as facilitator to guide the assessment while the local stakeholders become researchers who contribute knowledge and expertise. For that the IREPA approach comprises the following steps [63]:

- The assessment of local renewable resources based on a combination of statistical databases with global coverage and on-ground measurements for biogenic resources;
- The exploration of local social, institutional, environmental, technical and economic factors at household and community level by employing "participatory learning and action research methods" [64, 65].
- The combination of locally available resources and relevant factors to pre-select and design locally appropriate RETs;
- A participatory assessment of the impacts of these RETs on local livelihoods;
- A participatory identification of the most appropriate RET for implementation within a specific context using the multi-criteria decision analysis method "Analytical Hierarchy Process" (AHP) [66].

This participatory, bottom-up research structure provides a shift from the traditional top-down approaches to a holistic consideration of the local diversity. It aims to successfully induce changes into prevailing structures and behaviour patterns of smallholder agricultural systems in order to make sustainable use of the local natural resource base.

An important impact to the ecological and economic performance of land use systems is the productivity of these systems. To address this, the selected land-use systems and their performance can be modelled by using the **Wa**ter, **Nu**trient, **L**ight **C**apture in **A**groforestry **S**ystems model. This model deals with a wide range of agroforestry systems and annual single cropping systems with minimum parameter adjustments [67]. Hence, it is possible to explore the performance of various land-use systems under a wide range of management options and changing environmental conditions. In Brazil this model has already been used to assess the performance of sugar cane in agroforestry systems [68]. The model can be applied and adapted to various climate, soil, and cropping conditions [69, 70].

Agriculture is a major water consumer [71]. Furthermore, the semi-arid and arid areas of Brazil will suffer from a decrease of water resources due to climate change [72]. Brazil is a water rich country, for which the Amazon region is an example. But inappropriate land uses in Atlantic forest and cerrado ecoregions have led to a degradation of the soils which makes these resources scarcer in terms of biodiversity [73]. Different land use systems, small family farmers and industrial agriculture properties require different water quantities for their production processes. Therefore, water use efficiency will become an increasingly important sustainability indicator for land use systems. Water use in land use systems can be measured by evapotranspiration of crops. A water balance of the systems is an approach to quantify the water cycle. The water footprint is an indicator of water use, e.g. during agricultural processes, differentiating water use into three water categories: green, blue, and grey [74]. Green represents the volume of rainwater consumed during the production process and blue the natural run-off through groundwater and rivers minus environmental flow requirements, while grey is an indicator of freshwater pollution that can be associated with the production of a product over its full supply chain. The global water footprint in the period 1996-2005 was 9087 Gm^3 per year (74% green, 11% blue, and 15% grey) in which agricultural production contributed 92% [75].

We, therefore, propose linking and integrating the above mentioned methods once promising novel species or crops are identified to (i) develop and test land use options and model their agronomic performance; (ii) analyse, quantify and compare the ecological and socio-economic performance of land-use systems; and (iii) test options for developing new bioproducts. This procedure will help identifying optimised value chains, addresses trade-offs and consequences for environmental services, and looks at development of proper production systems for smallholder farmers. Using participatory approaches will foster farmers' participation and help identify options meeting their needs. It will also allow an exchange of ideas and information among all stakeholders.

6. Final consideration

More and more countries on all continents are developing bio-economy strategies striving for the sustainable use of renewable resources, especially biomass. Beginning with the development of bioenergy programs, bio-economic activities are growing rapidly in several countries and require an increasing supply of sustainably produced biomass. Here, the use of genetic resources to develop existing and new crops for a variety of applications in bio-based products can play an important role because bio-based products with new and improved properties also require a range of biomass properties. However, the development of bio-economies should not make the same mistakes that were observed in the development of modern bioenergies, such as transportation biofuels. The development of the modern bioenergy sector neglected the demands of smallholder farmers, who in the end did not benefit from the activities surrounding bioenergy but rather suffered the effects of land grabbing. Another much criticized effect of modern bioenergy development was the concentration on a few major crops only, such as maize or oil palm. Therefore we suggest that bio-economy strategies should ensure sustainable development of the biomass resource by:

a. *Ex-ante* assessment of the potential impacts of biomass production and supply systems

In section 5 of this chapter, various instruments were suggested for assessing the ecological and social impacts of biomass production systems which can be applied to *ex-ante* analysis and the planning of sustainable biomass production and supply systems.

b. Involving stakeholders and smallholder farmers

Acceptance of new technologies or crops and varieties is the pre-requisite for their implementation. Therefore their development should involve stakeholders, in particular smallholder farmers. Their involvement would not only improve the chances of implementation but also incorporate local or indigenous knowledge into developments.

c. Using genetic resources for developing new bio-economy crops or improved varieties

As discussed in this contribution there are many untapped genetic resources, most of them close to important agricultural centres. Demand for new crops and improved varieties for a bio-economy requires specific biomass properties on the one side, but also ecological requirements, such as nutrient- and water-use efficiency and stress resistance on the other. Therefore, in particular multi-purpose crops that integrate different land-use functions and biomass-use options appear most interesting for a future bio-economy. An example for such a multi-purpose crop was discussed in this contribution using the example of the macaw palm. This palm can grow under conditions of abiotic stresses, such as drought, and also contributes through its perennial character to soil carbon sequestration and erosion prevention. Its products are manifold allowing the integration of food, feed, fibre, and fuel production.

d. Development of sustainable biomass production concepts

The increasing demand for biomass leads to increasing pressure on land which can result in land-use changes, such as conversion from grassland to crop land. Recent findings from marginal grasslands show that increasing pressure on them can negatively influence ecosystem functioning, potentially compromising long-term production potentials. On the other hand, grassland communities in Europe suffer from mismanagement or under-management. In Europe many grasslands are no longer harvested due to the decreasing demand for roughage fodder. However, the maintenance of different grassland species requires cutting, but in regimes that are adapted to the ecological needs of grassland species. Therefore, biomass production concepts need to be developed that integrate production and ecological functions. Understanding the direct, indirect, and interactive effects of land-use changes on communities and ecosystems can help to better assess and balance such inherent trade-offs among multiple ecosystem functions [76].

There is need to prove such findings for other tropical environments such as rainforests on which a strong pressure lasts due to global interest on crops such as soybean and African oil

http://dx.doi.org/10.5772/59984

palm. The pressure on ecosystems resulting from the production of traded biomass, however, is highly variable between regions and products. Biomass consumption and trade are expected to surge over the next decades, suggesting a need to sustainably manage supply and demand of products of ecosystems on a global level [77].

There is need to find a way how to share and preserve biomes rich in species. Crops and other domesticated plants have a higher mobility than wild species and are already adapted to a wide range of environments due to anthropogenic influence in the past. Potentially new crops have undergone only little human selection if it all and are, hence, less well adapted to changes. In terms of gathered wild plants this may even be more severe. Recent studies indicate that under appropriate conditions, most native taxa may be sustainable within anthromes while at the same time increasing anthrome productivity in support of human populations [78]. The gaining economic interest on plant genetic resources for food and agriculture and their sustainable use will contribute to a better recognition and esteem of biomes hosting them. Proper rules for data and information exchange, for using plant genetic resources and indigenous knowledge are required. There is need for improving the south-north dialogue and creating the ground for south-south cooperation at international level to avoid further degradation, land grabbing and bio-piracy and foster local initiatives to safeguard locations rich in biodiversity and preserve land races *in-situ* on farmers' fields. As Robert Green Ingersoll, a British philosopher and ecologist of the 18th century, once said: "In nature there are neither rewards nor punishments – there are consequences" or in other words: Either we improve the conservation of plant genetic resources or we lose them forever without having had any opportunity to explore their potential.

Author details

Thomas Hilger[1*], Iris Lewandowski[2], Bastian Winkler[2], Barbara Ramsperger[3], Paulo Kageyama[4] and Carlos Colombo[5]

*Address all correspondence to: thomas.hilger@uni-hohenheim.de

1 Institute of Plant Production and Agroecology in the Tropics and Subtropics, Hohenheim University, Stuttgart, Germany

2 Institute of Crop Science, Hohenheim University, Stuttgart, Germany

3 Center for Agriculture in the Tropics and Subtropics, Hohenheim University, Stuttgart, Germany

4 Department of Forest Sciences, ESALQ, University of Sao Paulo, Piracicaba, Sao Paulo, Brazil

5 Instituto Agronômico de Campinas, Campinas, Sao Paulo, Brazil

References

[1] Hammer K, Arrowsmith N, Gladis T. Agrobiodiversity with emphasis on plant genetic resources. Naturwissenschaften 2003;90(6) 241-50.

[2] Tilman D, Cassman KG, Matson PA, Naylor R, Polasky S. Agricultural sustainability and intensive production practices. Nature 2002;418 671-677. http://www.nature.com/nature/journal/v418/n6898/pdf/nature01014.pdf (assessed September 26, 2014)

[3] Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). Farmers as breeders – Participatory plant breeding. Issue Papers – People and Biodiversity. Working Paper. Eschborn, Germany: GTZ Imprint. 2009. star-www.giz.de/dokumente/bib/04-5104a1.pdf (assessed on January 7, 2009).

[4] Food and Agriculture Organisation (FAO). The Second Report on the State of the World's Plant Genetic Resources for Food and Agriculture. Rome: FAO. 2010. http://www.fao.org/docrep/013/i1500e/i1500e00.htm (assessed September 26th, 2014)

[5] Ann Tutwiler. Agricultural biodiversity: the foundation of resilient family farms. Rural 2014;21(2) 24-6. http://www.rural21.com/uploads/media/rural2014_02-S24-26.pdf (assessed September 26th, 2014).

[6] Carter C, Finley W, Fry J, Jackson D, Willis L. Palm oil markets and future supply. European Journal of Lipid Science and Technology 2007;109(4) 307-14.

[7] Galluzzi G, Estrada R, Apaza V, Gamarra M, Pérez Á, Gamarra G, et al. Participatory breeding in the Peruvian highlands: Opportunities and challenges for promoting conservation and sustainable use of underutilized crops. Renewable Agriculture and Food Systems. 2014; 1-10. DOI: 10.1017/S1742170514000179 (in press).

[8] Lobell DB, Burke MB, Tebaldi C, Mastrandrea MD, Falcon WP, Naylor RL. Prioritizing Climate Change Adaptation Needs for Food Security in 2030. Science 2008;319(5863) 607-610. http://www.sciencemag.org/content/319/5863/607.full.pdf (assessed September 26, 2014)

[9] Barthlott W, Lauer W, Placke A. Global Distribution of Species Diversity in Vascular Plants: Towards A World Map Of Phytodiversity. Erdkunde 1996;50 317-27.

[10] Ford-Lloyd B, Jackson M. Plant genetic resources: an introduction to their conservation and use. Cambridge: Cambridge University Press 1992.

[11] Harlan JR. Crops and Man, 2nd Edition. Madison, Wisconsin, USA: American Society of Agronomy; 1992.

[12] Bolzani VdS, Valli M, Pivatto M, Viegas C. Natural products from Brazilian biodiversity as a source of new models for medicinal chemistry. Pure and Applied Chemistry. 2012;84(9) 1837-46.

[13] Manzi M, Coomes OT. Managing Amazonian palms for community use: A case of aguaje palm (Mauritia flexuosa) in Peru. Forest Ecology and Management 2009;257(2) 510-17.

[14] Schroth G, Da Mota M, Lopes R, De Freitas A. Extractive use, management and in situ domestication of a weedy palm, Astrocaryum tucuma, in the central Amazon. Forest Ecology and Management 2004;202(1) 161-79.

[15] Newman A. Tropical Rainforest. New York: Facts on File Publisher. 1990

[16] Reid WV, Laird SA, Meyer CA, Gámez R, Sittenfeld A, Janzen DH, et al. Biodiversity prospecting: using genetic resources for sustainable development. Washington (DC): World Resources Institute; 1993.

[17] Panik F. The use of biodiversity and implications for industrial production. A third millennium for humanity. In: Leihner DE, Mitschein TA. (Eds.) A Third Millennium for Humanity? The Search for Paths of Sustainable Development. Frankfurt: Lang Publisher.1998. p.59-73.

[18] Kübler E. Use of Natural Fibres as Reinforcement in Composites for Vehicles: Research Results and Experiences. In: Leihner DE, Mitschein TA. (Eds.) A Third Millennium for Humanity? The Search for Paths of Sustainable Development. Frankfurt: Lang Publisher. 1998. p.393-402.

[19] Zah R, Hischier R, Leão A, Braun I. Curauá fibers in the automobile industry–a sustainability assessment. Journal of Cleaner Production 2007;15(11) 1032-40.

[20] Berger N. Agronomische Optimierung des Anbaus von Curauá (Ananas lucidus Miller) in der östlichen Amazonas Region von Brasilien. Weikersheim, Germany: Margraf; 2004.

[21] Behrens D. Curaua-Faser - eine Pflanzenfaser als Konstruktionswerkstoff? Untersuchungen zum Anbau der brasilianischen Bromelien-Art Curaua (Ananas lucidus Miller) und Prüfung der Blattfasern im Hinblick auf ihre technologische Nutzbarkeit. Berlin, Germany: Köster; 1999.

[22] Tomich TP, Thomas DE, van Noordwijk M. Environmental services and land use change in Southeast Asia: From recognition to regulation or reward? Agriculture, Ecosystems and Environment 2004;104(1) 229-244.

[23] Food and Agriculture Organisation (FAO). The status of forests: the Global Forest Resources Assessment 2000 Part II. Key Issues in the Forest Sector Today. Rom: FAO, 2001, http://www.fao.org/docrep/003/y0900e/y0900e05.htm (assessed September 26, 2014).

[24] Top N, Mizoue N, Ito S, Kai S, Nakao T, Ty S. Effects of population density on forest structure and species richness and diversity of trees in Kampong Thom Province, Cambodia. Biodiversity and conservation 2009;18(3) 717-38.

[25] Lambin EF, Turner BL, Geist HJ, Agbola SB, Angelsen A, Bruce JW, et al. The causes of land-use and land-cover change: moving beyond the myths. Global environmental change 2001;11(4) 261-9.

[26] Pretty J. Agricultural sustainability: concepts, principles and evidence. Philosophical Transactions of the Royal Society B: Biological Sciences 2008;363(1491) 447-65.

[27] Pretty J, Sutherland WJ, Ashby J, Auburn J, Baulcombe D, Bell M, et al. The top 100 questions of importance to the future of global agriculture. International journal of agricultural sustainability 2010;8(4) 219-36.

[28] Rockström J, Steffen W, Noone K, Persson Å, Chapin III FS, Lambin E, et al. Planetary boundaries: exploring the safe operating space for humanity. Ecology and Society 2009;14(2). http://www.ecologyandsociety.org/vol14/iss2/art32/ (assessed September 26, 2014)

[29] Warren R, Price J, Fischlin A, de la Nava Santos S, Midgley G. Increasing impacts of climate change upon ecosystems with increasing global mean temperature rise. Climatic Change 2011;106(2) 141-77.

[30] Sonwa DJ, Nkem JN, Idinoba ME, Bele MY, Jum C. Building regional priorities in forests for development and adaptation to climate change in the Congo Basin. Mitigation and Adaptation Strategies for Global Change 2012;17(4) 441-50.

[31] White G, Gardner J, Cook C. Biodiversity for industrial crop development in the United States. Industrial Crops and Products 1994;2(4) 259-72.

[32] Chand VS, Patel KK, Murali Krishna S, Gupta AK. Contracts for 'Compensating' Creativity: Framework for Rewarding Grassroot Creativity and Innovation. In: Leihner D. and MitscheinTA (Eds.) A Third Millennium for Humanity? The Search for Paths of Sustainable Development. Frankfurt: Lang Publisher. 1998. p201-217.

[33] Leatherman P. Fair Trade Organisations: Is This the Fairest Trade of All? In: Leihner DE. and Mitschein TA. (Eds.) A Third Millennium for Humanity? The Search for Paths of Sustainable Development. Frankfurt: Lang Publisher. 1998. p219-224.

[34] Spiertz J, Ewert F. Crop production and resource use to meet the growing demand for food, feed and fuel: opportunities and constraints. NJAS-Wageningen Journal of Life Sciences 2009;56(4) 281-300.

[35] Linkohr R. Latin America's energy policy between state and market. Internationale Politik und Gesellschaft 2006;4 105-119+191.

[36] Morgan K, Gilbert R, Helsel Z, Buacum L, Leon R, Perret J. White paper report from working groups attending the international conference on research and educational opportunities in bio-fuel crop production. Biomass and Bioenergy 2010;34(12) 1968-72.

[37] Rajora OP, Mosseler A. Challenges and opportunities for conservation of forest genetic resources. Euphytica. 2001;118(2):197-212.

[38] Scherr SJ, McNeely JA. Biodiversity conservation and agricultural sustainability: towards a new paradigm of 'ecoagriculture'landscapes. Philosophical Transactions of the Royal Society B: Biological Sciences. 2008;363(1491):477-94.

[39] Jongschaap R, Corré W, Bindraban P, Brandenburg W. Claims and Facts on Jatropha curcas L. Global Jatropha curcas evaluation, breeding and propagation programme. Wageningen, the Netherlands: Plant Research International BV, Report 158, 42 pp+ annexes. 2007.

[40] Achten W, Verchot L, Franken YJ, Mathijs E, Singh VP, Aerts R, Muys B. Jatropha bio-diesel production and use. Biomass and bioenergy 2008;32(12) 1063-84.

[41] Burnod P, Gingembre M, Andrianirina Ratsialonana R. Competition over Authority and Access: International Land Deals in Madagascar. Development and Change 2013;44 357-79.

[42] Leite JGDB, Bijman J, Giller K, Slingerland M. Biodiesel policy for family farms in Brazil: One-size-fits-all? Environmental Science and Policy 201327 195-205.

[43] Berton LHC, Azevedo JA, Filho CRL, Carvalho WJ, Siqueira RM, Coelho, and Colombo C A. Teor de óleo do fruto da macaúba (Acrocomia aculeata) nos Estados de São Paulo e Minas Gerais. Paper presented at 5th Congresso da Rede Brasileira de Tecnologia de Biodiesel. Held at Salvador de Bahia, Brazil, April 16-19, 2012. http://oleo.ufla.br/site/trabalhos/buscar-trabalhos/#!/codigo/80f50668946acd05603f935cb597db22 (assessed September 26, 2014)

[44] Pires TP, dos Santos Souza E, Kuki KN, Motoike SY. Ecophysiological traits of the macaw palm: a contribution towards the domestication of a novel oil crop. Industrial Crops and Products 2013;44 200-10.

[45] Poetsch J, Haupenthal D, Lewandowski I, Oberländer D, Hilger T. Acrocomia aculeata - a sustainable oil crop. Rural 21 2012;21(03) 41-4. http://www.rural21.com/uploads/media/rural2012_03-S41-44.pdf (assessed September 26, 2014)

[46] Agroenergías. "South American oil palm (Acrocomia aculeata Jacq.) as a new multipurpose crop." Acrocomia Solutions. http:// www.acrocomiasolutions.com/en/ (assessed September 15, 2014).

[47] Teles HdF, Pires LL, Garcia J, Rosa JQS, Farias JG, Naves RV. "Ambientes de ocorrência naural de macaúba." Pesquisa Agropecuária Tropical 2011;41 595-601.

[48] Ciconini G, Favaro S, Roscoe R, Miranda C, Tapeti C, Miyahira M. Biometry and oil contents of *Acrocomia aculeata* fruits from the Cerrados and Pantanal biomes in Mato Grosso do Sul, Brazil. Industrial Crops and Products 2013;45 208-14.

[49] Sterk B, Leeuwis C, van Ittersum MK. Land use models in complex societal problem solving: Plug and play or networking? Environmental Modelling & Software 2009;24(2) 165-72.

[50] Verburg PH, Schot PP, Dijst MJ, Veldkamp A. Land use change modelling: current practice and research priorities. GeoJournal 2004;61(4) 309-24.

[51] Clark WC, Tomich TP, van Noordwijk M, Guston D, Catacutan D, Dickson NM, et al. Boundary work for sustainable development: Natural resource management at the Consultative Group on International Agricultural Research (CGIAR). Proceedings of the National Academy of Sciences 2011. doi: 10.1073/pnas.0900231108. www.pnas.org/content/early/2011/08/11/0900231108.full.pdf+html (assessed September 26, 2014)

[52] Van Noordwijk M, Lusiana B, Leimona B, Dewi S, Wulandari D, eds. Negotiation-support toolkit for learning landscapes. Volume II. Bogor, Indonesia: World Agroforestry Centre (ICRAF) Southeast Asia Regional Program. http://www.asb.cgiar.org/Publications%202014/ Books/Negotiation%20support%20tool%20kit.pdf (assessed September 26, 2014).

[53] van Noordwijk M. Scaling trade-offs between crop productivity, carbon stocks and biodiversity in shifting cultivation landscape mosaics: the FALLOW model. Ecological Modelling 2002;149(1) 113-26.

[54] van Noordwijk M, Poulsen JG, Ericksen PJ. Quantifying off-site effects of land use change: filters, flows and fallacies. Agriculture, Ecosystems & Environment 2004;104(1) 19-34.

[55] Lippe M, Thai Minh T, Neef A, Hilger T, Hoffmann V, Lam N, et al. Building on qualitative datasets and participatory processes to simulate land use change in a mountain watershed of Northwest Vietnam. Environmental Modelling & Software 2011;26(12) 1454-66.

[56] Lusiana B, van Noordwijk M, Cadisch G. Land sparing or sharing? Exploring livestock fodder options in combination with land use zoning and consequences for livelihoods and net carbon stocks using the FALLOW model. Agriculture, Ecosystems & Environment 2012;159 145-60.

[57] Lusiana B, van Noordwijk M, Suyamto D, Mulia R, Joshi L, Cadisch G. Users' perspectives on validity of a simulation model for natural resource management. International Journal of Agricultural Sustainability 2011;9(2) 364-78.

[58] Dalal-Clayton B, Dent D, Dubois O. Rural Planning in Developing Countries: supporting natural resource management and sustainable livelihoods. London: Earthscan; 2003.

[59] Wang J-J, Jing Y-Y, Zhang C-F, Zhao J-H. Review on multi-criteria decision analysis aid in sustainable energy decision-making. Renewable and Sustainable Energy Reviews 2009;13(9) 2263-78.

[60] Amigun B, Musango J, Brent A. Community perspectives on the introduction of biodiesel production in the Eastern Cape Province of South Africa. Energy 2011;36(5) : 2502-8.

[61] García V. G., Bartolomé M. M. Rural electrification systems based on renewable energy: The social dimensions of an innovative technology. Technology in Society 2010;32 303-11.

[62] Barry M-L, Steyn H, Brent A. Selection of renewable energy technologies for Africa: Eight case studies in Rwanda, Tanzania and Malawi. Renewable Energy 2011;36(11) 2845-52.

[63] Winkler, B. Monitoring and Evaluation of the Integrated Renewable Energy Potential Assessment - A case study in Mgwenyana, rural Eastern Cape, South Africa. MSc Thesis University of Hohenheim. Department for Biobased Products and Energy Crops and the Department for Gender and Nutrition Stuttgart, Germany; 2013.

[64] Chambers R. The origins and practice of participatory rural appraisal. World development 1994;22(7) 953-69.

[65] Hart T. Demystifying participatory research and its role in development. Occasional Paper No. 21. Department of Sociology and Social Anthropology, University of Stellenbosch, South Africa 2008. http://hdl.handle.net/10019.1/45891 (assessed April 7, 2012).

[66] Saaty TL. How to make a decision: the analytic hierarchy process. European journal of operational research 1990;48(1) 9-26.

[67] van Noordwijk M, Lusiana B van Noordwijk M., Lusiana, B. WaNulCAS, a model of water, nutrient and light capture in agroforestry systems. Agroforestry Systems 1999;43 217-42.

[68] Pinto LFG., Bernardes MS., van Noordwijk M., Pereira AR., Lusiana B., Mulia R. Simulation of agroforestry systems with sugarcane in Piracicaba, Brazil. Agricultural Systems 2005;86 275-92.

[69] Pansak W, Hilger T, Lusiana B, Kongkaew T, Marohn C, Cadisch G. Assessing soil conservation strategies for upland cropping in Northeast Thailand with the WaNuLCAS model. Agroforestry Systems 2010;79(2) 123-44.

[70] Walker A, Mutuo P, van Noordwijk M, Albrecht A, Cadisch G. Modelling of planted legume fallows in Western Kenya using WaNuLCAS.(I) Model calibration and validation. Agroforestry Systems 2007;70(3) 197-209.

[71] Leflaive X, Witmer M, Martin-Hurtado R, Bakker M, Kram T, Bouwman L, et al. Water. In: OECD Environmental Outlook to 2050. OECD Publishing; 2012: 207-274, DOI: dx.doi.org/10.1787/9789264122246-en.

[72] IPCC. Climate Change: Synthesis Report 2007 - Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.2008. www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_synthesis_report.html (assesed September 26, 2014).

[73] Kageyama PY, Gandara FB. A Biodiversidade Brasileira e a Questão das Mudanças Globais. Brasília: UNESCO, IBECC; 2008.

[74] Hoekstra A., editor. Virtual water trade: Proceedings of the international expert meeting on virtual water trade. Delft, the Netherlands: IHE; 2003. http://www.waterfootprint.org/Reports/Report12.pdf (assessed September 26, 2014)

[75] Mekonnen M, Hoekstra A. The green, blue and grey water footprint of crops and derived crop products. Hydrology and Earth System Sciences Discussions 2011;8(1): 763-809.

[76] Haberl H, Erb K-H, Krausmann F. Human Appropriation of Net Primary Production: Patterns, Trends, and Planetary Boundaries. Annual Review of Environment and Resources 2014;39(1) 363-91. http://www.annualreviews.org/doi/pdf/10.1146/annurev-environ-121912-094620

[77] Erb K-H, Krausmann F, Lucht W, Haberl H. Embodied HANPP: Mapping the spatial disconnect between global biomass production and consumption. Ecological Economics 2009;69(2) 328-34.

[78] Ellis EC. Sustaining biodiversity and people in the world's anthropogenic biomes. Current Opinion in Environmental Sustainability 2013;5(3) 368-72.