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Life Cycle Assessment of agri-food systems

An operational guide dedicated to developing and emerging economies

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Table of contents

Part 3
Overcoming the challenges for robust agri-food LCA in developing and emerging economies

Part 4
Conclusions and moving forward

Part 5
Appendices

Preface

The application of LCA to agri-food systems in developing and emerging contexts remains limited, but the approach has considerable potential to support and guide their transition towards sustainable practices. The demand for LCA studies of agri-food systems in these contexts is increasing rapidly, and relates both to agri-food systems for export and for local markets. Agri-food systems in developing and emerging economies present key particularities combining socio-economic, pedoclimatic and environmental aspects, which can be summed up according to three main characteristics: a great diversity of production systems with little reliable data; highly specific natural contexts with little data, knowledge and tools for informing the inventory and impact assessment phases (especially for tropical systems); and varying awareness and capacities among stakeholders in relation to environment and environmental assessment.

These specificities pose important challenges for a reliable application of the LCA methodology, which will require a comprehensive answer. This guide takes the opposite view of the studies historically carried out remotely by Western consultancies on tropical agri-food systems in developing and emerging countries by promoting an approach based on fieldwork, designed with and for all stakeholders associated with the study.

Another original feature of this guide consists of its elaboration process based on a participatory and consensus-building approach to formalize actual field experiences from a panel of senior international experts on LCA in these contexts. This elaboration process included a web-based questionnaire covering all considerations of LCA studies completed by nearly 30 identified experts from around the world and supported a consistent formalization of their practices. Best practices were then discussed and agreed-upon through four dedicated workshops.

Unlike existing and numerous guidelines which are complementary to this guide, the present guide focuses on collaborative, ethical and operational aspects of LCA. It aims to help LCA practitioners successfully engage in this exciting adventure of undertaking LCA studies for agri-food systems in developing and emerging contexts. The guide also presents the most up-to-date and appropriate models to perform the inventory and impact assessment in these contexts and make clear recommendations on all components of the study.

The core content of this guide is complemented by a substantial corpus of appendices to provide LCA practitioners with more detailed information.

Part 1

Introduction

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1

LCA within developing and emerging economies

Developing and emerging economies are defined by Ghemawat and Altman (2016) as countries, regions and economies that are not fully industrialized, in socio-economic terms, generally showing an average low to middle income and high inequality of income distribution. According to various international references (UN, FAO, etc.), those countries may include least developed countries (LDC) and low and middle-income countries (LMIC[1]). The application of life cycle assessment (LCA) for environmental assessment in these contexts is still very limited (Hou *et al.* 2015), especially in Africa (Karkour *et al.* 2021). The scarce existing studies were generally commissioned by international or developed country-based institutions, or were carried out in the context of research activities financed from abroad. Recently, a growing interest is exemplified by some locally driven initiatives and emerging LCA networks (Bjørn *et al.* 2013).

Political and social conditions influence the capacity of agri-food stakeholders – i.e. in agriculture (including livestock), aquaculture, fisheries and food processing – to adopt new social or technical innovations. Such conditions may affect both the implementation of LCA and the use of final LCA results. Some specificities of developing and emerging contexts embedding potential consequences on LCA implementation and uptake are briefly presented in the following sections.

Land tenure issues

Land tenure issues have strong implications on the possibility of improving agricultural systems. Land ownership and decision-making processes on communal or private land use do not have the same implications; thus, land tenure issues should be identified before further analysis. Several governance rules were set since

1. The list of LDC and LMIC is regularly updated: https://www.oecd.org/dac/financing-sustainable-development/development-finance-standards/daclist.htm. The transition criteria across OECD country categories are described here: https://www.oecd.org/dac/transition-finance-toolkit/LMIC-to-UMIC.pdf

the end of colonialism (Focus on land in Africa (FOLA) 2018), but they are still failing to adequately consider property rights and customary land (Veit 2013). The FOLA website (https://www.wri.org/data/rights-resources-interactive-map) provides an overview of property rights issues and an interactive map of national experiences pertaining to land and natural resource rights.

In many developing countries, national land reforms have generated inequality of access, with poor land access for women under state laws and customary arrangements. Encroachment onto indigenous peoples' territories and common property resources such as protected areas are increasing due to economic and commercial pressures (UN-Habitat 2019). The Global Land Tool Network (https://gltn.net/) presents land access initiatives, while the World Database on Protected Areas (https://www.protectedplanet.net/) lists and classifies protected areas; both address these issues on the global scale.

In Asia-Pacific, around 80% of farming households are small-scale farmers. The main challenges in this region (where 13 of the world's 23 megacities are located) regarding land access include economic transformation with growing inequality (increasing level of urbanization, private large-scale land acquisitions), vulnerability of women and indigenous people, and environmental degradation (UN-Habitat 2015).

Latin America has the highest inequality of land distribution compared with the rest of the world, and this remains a key unresolved historical issue on the continent (OXFAM 2016). The concentration of land ownership and land-grabbing are strongest in Argentina, Brazil, Dominican Republic, Mexico, Chile, Colombia, Nicaragua and Uruguay (Jarroud 2016). For instance, in Dominican Republic, the agrarian revolution has not been completed, leaving a considerable part of agricultural land with no formal property titles. In 1997, about 36% of private land was used by owners with no official title. In countries where public investment is low, this lack of clear land tenure rights may prevent investments for better agricultural development (Tejada de Walter and Peralta Bidó 2000).

Other issues related to secure land access may hamper sustainable land use development. In Colombia, for instance, conflicts between the government and armed groups, which have driven refugee migrations between regions, have had a major impact on Amazonian agriculture. Raising cattle has been considered a valuable option within uncertain contexts, since livestock is a "mobile" agricultural asset. Now, improving livestock systems, e.g. with enhanced permanent pasture quality or silvo-pastoralism, could only be developed under peace conditions and with substantial support from companies, universities and research centres (Estrada and Holmann 2008).

Environmental vs. economic development concerns

In contexts where the economy is becoming increasingly industrialized, and sometimes quickly, another key aspect relates to the potential trade-offs between economic development and environmental protection[2]. Growth-oriented strategies usually focus first on increasing production, often through conventional systems rather than more environmental-friendly practices. A related aspect may be the low environmental awareness of local populations, due to low levels of education and knowledge about the environmental pressures of socio-economic activities. Additionally, sometimes the lack of proper law enforcement may lead to misappropriation of funds allocated to development priorities due to corruption or insufficient field control when dealing with environmental protection laws (e.g. legislation protecting natural reserves). The environmental Kuznets curve highlights that environmental degradation increases with economic development until a difficult-to-predict (Bernard *et al.* 2015) tipping point is reached, and then starts to decrease (Du and Xie 2020). However, this model has been challenged based on evidence that some developing economies are also addressing environmental issues, and that the prevalence of conflicts and the quality of institutions are more important drivers (Stern 2004; Kinda 2015; Sarkodie and Strezov 2018).

Most developing and emerging countries are located in the tropical zone

Most developing and emerging countries are located in the tropical zone (in-between the two tropics), although not exclusively. The tropical zone can host extreme climate conditions, from humid to very arid climates. The history of those very contrasted climates has led to highly contrasted pedoclimatic conditions, with sometimes heavily weathered soils, very arid areas or areas facing regular floods, etc. In most extreme contexts, the development of agricultural activities has long been hampered by extreme events and the lack of proper infrastructure to enable resilient development. Nonetheless in some humid tropical zones, soil and climate conditions may also provide optimal conditions for faster crop rotations and even more frequent harvests per year on the same field compared to temperate climates (Table 1.1). Such diversity in natural conditions has obviously led to a unique range of adaptation strategies and broad diversification of practices. In such optimal conditions, where the soil has been protected by the natural vegetation, there is also critical competition for land between agri-food systems and still pristine environments with a high biodiversity (e.g. the agricultural and livestock frontier expands in the South American Amazonia at the

2. In Africa and Asia, for instance, the increase in cocoa production for export is based on expanding surfaces, whereas in Latin America it is based on increasing yields driven by management improvements (Arvelo Sánchez *et al.* 2017).

expense of rainforest and Pantanal biomes; the cotton-growing frontier expands in Sahel areas at the expense of savannah systems). Such competition has led to land conflicts, imbalances in ecosystems and support for the development of more resilient agricultural development pathways.

Table 1.1. Pedoclimatic factors influencing temperate and tropical agriculture.

Factors	Temperate agriculture systems	Tropical agriculture systems
Climate	Four seasons with winter rains Lower humidity Lower temperature	Dry vs. wet season(s) with heavy rainfall events Higher humidity Higher temperature
Soil	Higher natural fertility Higher organic matter Lower decomposition rate Lower leaching	Lower natural fertility Lower organic matter Higher decomposition rate Higher leaching

Sources: Hartemink (2002); Six *et al.* (2002).

The specific soil and climate conditions, combined with the diverging long-term evolution of socio-technical agricultural systems, have led to a wide range of agri-food systems, both in terms of practices in fields (as well as in ponds and seas for fish and seafood products i.e. "blue foods", Gephart *et al.* 2021) and in terms of food processing and value chain organization. The evolving socio-technical systems have been influenced by many factors, including colonialism, governmental instability, development funds, population growth rates, etc. Compared to more industrialized contexts, the combination of complex tropical conditions and precarious socio-economic contexts – with no safety net such as mutualized risk management within Europe – has led to a lack of standardization of agri-food systems such as that observed today in many countries (e.g. among European countries). From past shifting cultivation to sedentary intensive systems, very diversified agri-food systems co-exist still today in tropical and emerging countries, which will have implications for the application of LCA.

Inadequate input issues

The environmental impacts of agri-food systems in developing and emerging contexts are often influenced by underperforming or inadequate inputs (e.g. homemade aquafeed, over-fertilization, pesticides designed for another crop, highly polluting fuels, etc.). In many cases, producers use these inputs because there are no suitable or economically interesting alternatives, or because they do not have enough knowledge on available and feasible alternatives. For instance, African small-scale horticulture farmers often use pesticides designed for cotton or other cash crops (Avadí *et al.* 2020b). Many Peruvian fishmeal producers use heavy residual fuels instead of natural gas, because the gas pipelines simply do not reach them or are overloaded (Fréon *et al.* 2017). Many Zambian and Peruvian

small-scale fish producers cannot afford commercial aquafeed, or its transportation to remote locations, and thus rely on homemade feed (Avadí *et al.* 2015, 2021). Most market vegetable producers in Benin over-fertilize their plots with manure and compost, mainly due to ignorance on the nutrient content of these organic inputs (Avadí *et al.* 2021a).

Moreover, benefiting from economies of scale is less widespread, especially in developing contexts, due to gaps in infrastructure (e.g. poor roads impede efficient transport, sparse irrigation infrastructure hinders controlled irrigation, and poor landing facilities increase vessels' fuel consumption and generate product losses).

Research and development priorities and capacities

Finally, in developing and emerging contexts, research and development priorities vary regionally depending on the development levels and invested resources, while globally, agri-food systems face new or tougher challenges related to worldwide trends and changes (Table 1.2).

Table 1.2. Trends and challenges in food and agriculture in developing contexts.

Trends	Challenges
– Population growth, urbanization and ageing – Global economic growth, investment, trade and food prices – Competition for natural resources – Climate change – Agricultural productivity and innovation – Transboundary pests and diseases – Conflicts, crises and natural disasters – Poverty, inequality and food insecurity – Nutrition and health, including the connections among environment, agriculture and infectious diseases of poverty – Structural change and employment – Migration and agriculture – Changing food systems – Food losses and waste – Governance for food and nutrition security – Development finance	– Sustainably improving agricultural productivity to meet increasing demand – Ensuring a sustainable natural resource base – Addressing climate change and intensification of natural hazards – Eradicating extreme poverty and reducing inequality – Ending hunger and all forms of malnutrition – Making food systems more efficient, inclusive and resilient – Improving income earning opportunities in rural areas and addressing the root causes of migration – Building resilience to protracted crises, disasters and conflicts – Preventing transboundary and emerging agriculture and food system threats – Addressing the need for coherent and effective national and international governance

Sources: WHO 2013; FAO 2017a.

National agricultural research systems in developing countries in particular are usually understaffed and underfunded, thus a large proportion of agri-food research is carried out in cooperation with, or directly by, international institutions. For instance, the main global agricultural development research institution, the Consultative Group on International Agricultural Research (CGIAR),

devoted 11% of its expenditure in 2008 to strengthening national agricultural research centres across the world, 8% to environmental protection, and under 50% to increasing productivity, plant enhancement and breeding, and research on production systems (Lele *et al.* 2010). Public agricultural research and development investment has increased worldwide in the last 40 years, notably in Latin America, Asia-Pacific and China. However, West Asian and African public investment has remained relatively low. The relevance of extension services (i.e. agri-food advisory) proved valuable in improving both agronomic performances and environmental protection (Lele *et al.* 2010). Unfortunately, these services show uneven coverage and efficiency, and often farmers remain isolated with no access to technical advice or capacity-building support.

2
The purpose of this operational guide

This operational guide focuses on applying LCA to agri-food systems in a range of socio-economic contexts, from least developed to emerging economies, mainly within the tropics. Agri-food systems are defined as all systems providing food, fibre and bioenergy products based on agriculture, livestock, aquaculture and fisheries. This guide aims to provide solutions to overcome the specific issues found by LCA practitioners in developing and emerging contexts, by consolidating the knowledge from the literature and formalizing LCA practitioners' experience in these contexts. Feasible and practical solutions are preferred, namely those that are useful under severe resource constraints, but more sophisticated and resource-intensive solutions are also discussed.

Over the last two decades, LCA has become an essential framework for the environmental assessment of agri-food systems at various scales, from the cropping system to the rest of the value chain and even entire agricultural regions. Applying LCA to agri-food systems, is supported by a number of methodological developments and resources. These include dedicated guidelines for direct emission models, life cycle inventory (LCI) databases, life cycle impact assessment (LCIA) methods, sets of characterization and normalization factors, and multiple research initiatives aimed at overcoming unresolved issues[3]. Existing LCA resources, such as background inventory databases on technologies and practices or emissions models, are generally tailored to developed and temperate contexts, where LCA was first developed. Hence, the vast majority of LCA resources available nowadays represent production systems operating mostly in temperate and developed contexts, where large statistical and field measurement datasets were available to develop various models.

Putting LCA into practice for agri-food systems in developing and emerging economies is more recent and faces specific challenges, related to both the socio-economic and biophysical specificities of these contexts. As already mentioned, tropical agricultural systems can be highly diversified and complex (e.g. tropical

3. See a list of unresolved issues in LCA in Reap *et al.* (2008a,b). Some of these issues have been successfully addressed to date, but not all.

agroforestry systems), while data is often missing to characterize this diversity and calibrate existing models, which have been calibrated for temperate conditions. Moreover, in the tropics some environmental issues may be particularly severe such as water deprivation, salinization, soil quality and biodiversity losses. They may require specific parameters in LCA (e.g. regional characterization factors (CFs) that are thus far mostly lacking for tropical zones).