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Caroline Lejars, Koladé Akakpo, Magalie Bourblanc, Emeline Hassenforder,
Pierre-Louis Mayaux

► To cite this version:

Caroline Lejars, Koladé Akakpo, Magalie Bourblanc, Emeline Hassenforder, Pierre-Louis Mayaux. What solutions for agricultural water management in the face of climate change?. Blanfort Vincent (ed.); Hrabanski Marie (ed.); Demenois Julien (ed.). Climate impacts and challenges in agriculture, forests and food systems. Perspectives on the Global South, Springer; Ed. Quae, pp.283-293, 2026, 978-3-032-04331-3. <10.1007/978-3-032-04331-3_18>. <hal-05578443>

HAL Id: hal-05578443

<https://hal.science/hal-05578443v1>

Submitted on 3 Apr 2026

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Vincent Blanford · Marie Hrabanski
Julien Demenois *Editors*

Climate Impacts and Challenges in Agriculture, Forests and Food Systems

Perspectives on the Global South

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 **Springer**

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Second Edition

 Springer

Editors

Vincent Blanfort
Cirad joint research unit Selmet “Tropical
and Mediterranean Animal Production
Systems”, Montpellier Univ, Inrae
Institut Agro
Montpellier, France

Marie Hrabanski
Cirad UMR Actors Resources
Territories & Development (ART-Dev)
Montpellier, France

Julien Demenois
CIRAD UPR Agroecology and sustainable
intensification of annual crops (Aïda)
Montpellier, France



ISBN 978-3-032-04330-6 ISBN 978-3-032-04331-3 (eBook)
<https://doi.org/10.1007/978-3-032-04331-3>

Translation from the French language edition: “L’agriculture et les systèmes alimentaires du monde face au changement climatique” by Vincent Blanfort et al., © Éditions Quæ 2025. Published by Éditions Quæ. All Rights Reserved.

Jointly published with Éditions Quæ, Versailles, France

The original submitted manuscript has been translated into English. The translation was done using artificial intelligence. A subsequent revision was performed by the author(s) to further refine the work and to ensure that the translation is appropriate concerning content and scientific correctness. It may, however, read stylistically different from a conventional translation.

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Chapter 18

What Solutions for Agricultural Water Management in the Face of Climate Change?



Caroline Lejars, Koladé Akakpo, Magalie Bourblanc, Emeline Hassenforder, and Pierre-Louis Mayaux

Abstract Growing food demand and competing land and water uses exert intense pressure on agricultural systems, which are further stressed by climate change. Water availability is declining and unevenly affected, with surface waters impacted faster than groundwater, creating local adaptation challenges. Agriculture competes with other sectors like energy and drinking water during shortages, especially in dry seasons. Adaptation strategies must be locally tailored, combining efficient water use, new resources, and flexible management. This chapter highlights various technical and governance-based solutions, including participatory approaches to improve coordination.

The increasing food needs, coupled with the demand for other competitive uses, exert unprecedented pressure on many agricultural production systems worldwide. Current production systems, defined as “systems at breaking points” by the FAO (2021), thus face increased competition for land and water resources, which is exacerbated by climate change (see Chap. 7).

In this context, adapting to climate change, whether it manifests as droughts or other extreme events, proves extremely complex. The impacts of climate change on water resources are poorly known at local scales, as the number of empirical studies remains limited (Moore et al. 2017). Climate change affects available resources differently: surface waters, for example, are affected more rapidly than groundwater, which often serves as “buffer” to meet the needs of irrigated crops when rain is lacking. The impacts of declining water availability also vary depending on local uses, types and diversity of available resources, and the period of reduced rainfalls. They depend on local needs which are variable: the demand for drinking water can vary seasonally in tourist cities, the needs for hydroelectricity also vary according

C. Lejars (✉) · K. Akakpo · M. Bourblanc · P.-L. Mayaux
Cirad, UMR Gestion de l’Eau, Acteurs, Usages (G-EAU), Montpellier, France
e-mail: caroline.lejars@cirad.fr

E. Hassenforder
Cirad, UMR G-EAU, Institut national agronomique de Tunisie (INAT), Tunis, Tunisie

to the seasons, crop needs are generally greater in summer when water is lacking. More generally, water is at the intersection of several issues: energy, food, drinking water, industrial needs and ecosystem health. When water is lacking, agriculture finds itself in competition with other sectors and the difficulties vary depending on the type of agriculture and irrigation practiced.

The mechanisms for adapting to climate change in agriculture are therefore highly dependent on contexts and local situations. Managing seasonal variations, consuming less water or more efficiently, finding new resources require the implementation of panels of locally adapted solutions that can rely on technical solutions, as well as management and governance solutions. We describe here these panels of solutions and the promising experiences of participatory approaches that would allow them to be coordinated.

18.1 Diverse Technical and Agroecological Solutions, but Poorly Evaluated and Sometimes with Unintended Impacts

In recent years, the observation of the increasing scarcity of water resources has prompted governments to turn to technical solutions and to massively reinvest in large infrastructures, particularly for irrigation (see Chap. 7). The infrastructures put in place to cope with water shortages cover both the classic works of “large-scale hydraulic systems” (large dams, inter-basin transfers, supply canals, distribution networks), but also solutions presented as innovative around wastewater reuse or desalination. These latter, which locally increase water supply, are however in many cases (such as reuse) simple mechanisms for reallocating water and in others (such as desalination) very energy-intensive solutions with potentially damaging effects on ecosystems and water quality (Williams et al. 2023). Massive investments in irrigation, while they have increased food production, have also come at the cost of growing inequalities (Mayaux et al. 2022). Beyond investments in large infrastructures, technical solutions intended to be developed at the farm and plot level have also been promoted and subsidised in many countries to optimise irrigation and best meet crop needs. Drip irrigation, a localised and water-saving irrigation system, is an emblematic example. Developed and funded in many countries, it theoretically reduces the amount of water used at the plot level. However, in the absence of control over the expansion of irrigated areas, it has led to a global increase in resource exploitation at territorial levels (Venot et al. 2017).

In parallel, the agroecological transition is gradually promoted as a solution for developing sustainable agricultural systems. The general principle is that such a transition would facilitate water retention and infiltration on plots. However, the place of water and irrigation in the agroecological transition is still little studied. To

ensure sustainable food and nutritional security, many authors highlight the interest of judicious use of water available for agriculture through micro-irrigation technologies and water-saving, through conservation and climate-smart agriculture (see Chap. 3), through the development of multiple cultivars and stress-tolerant crop biotypes using biotechnological tools (see Chap. 21), and through the restoration of degraded soils (Jat et al. 2016). Agroforestry, conservation agriculture, crop diversification, climate information services are also highlighted as new climate-smart agricultural options to improve agricultural productivity, rural livelihoods and the adaptive capacity of farmers and production systems (Zougmore et al. 2018; Partey et al. 2018). Even though these practices theoretically allow for an increase in water use efficiency (the ratio between the amount of water supplied and that actually used by the crops), it is challenging to quantify water savings, whether at the plot or territorial scale. For instance, the water savings achievable through drip irrigation or practices such as soil conservation are intrinsically linked to farmers' irrigation strategies (amounts supplied, irrigation frequency). However, these practices are not always effectively adapted or optimised on farms. Similarly, the complex interactions between trees and crops in agroforestry systems, for example, make it difficult to accurately assess their impact on available water.

In some regions, particularly in France and Europe, access to new water resources is increasingly conditioned by the adoption of agroecological practices such as soil conservation agriculture, legume-based cover crops, or organic farming, without a precise understanding of the impact of these practices on water use. The development of organic or low-input certified productions, currently promoted by several countries, could nevertheless lead to an increase in irrigation demands, as the management of irrigation schedules is a means of ensuring yields and in the absence of herbicides, can become a means of controlling weed growth. Therefore, there is a significant need for research in this area to provide solutions for farmers, while assessing their final impact on water at the plot or territorial scale (Torquebiau et al. 2018).

Regardless, the close links between agroecology and climate change are promising and provide some successful technical examples, both in the North and the South. In India, for example, the Andhra Pradesh Community Natural Farming (APCNF)—which promotes a set of agricultural practices designed to significantly reduce farmers' direct costs while increasing yields and farm health—is one of the major examples of large-scale agroecological transition in the world in terms of the number of participating farmers and involved institutions, and with interesting impacts in terms of plot-level water savings (Bharucha et al. 2020; Landy and Dorin 2022). Unfortunately, agroecology is still rarely explicitly mentioned in the nationally determined contributions (NDCs) presented by countries at the Paris Agreement in 2015 (COP21) (see Chap. 2), and some of its components are not explicitly mentioned, such as water conservation management (Torquebiau et al. 2019).

18.2 Governance Solutions Around Water Sharing Are Proving More and More Ineffective

18.2.1 Integrated Water Resources Management: A Global Diffusion with Mixed Results

During the 1990s, integrated water resources management (IWRM) gradually became a panacea in the world of water resources (Mayaux et al. 2022). It accompanied the implementation of a range of programmes and institutional tools worldwide, such as the creation of basin agencies, local management plans, and aquifer contracts. Participation is one of its key concepts, with the aim of including relevant stakeholders in the formal decision-making process. The concept of integration is multidimensional. Besides the very general integration between resource preservation, economic efficiency, and social well-being, it also needs to be operated (1) among all waters, surface and underground, and among all environments; (2) among all actors and sectors of public action related to water, namely the environment, energy, agriculture, planning, urban planning, etc.; (3) from a spatial point of view, at the watershed scale.

Ultimately, its global diffusion has, however, had mixed results (Barone and Mayaux 2019). It has undoubtedly promoted knowledge production, problem identification, and institutional capacity building. On the other hand, many basin agencies still struggle to access the human, financial, and logistical resources necessary to function properly. In South Africa, and in Africa more generally, numerous obstacles and limitations in terms of financial capacities, lack of skills, institutional conflicts, and rigidity have hindered the successful establishment of water management agencies following the decentralisation principles of IWRM. In France, limitations related to the institutional layering and financial capacities led the Court of Auditors to describe the country's water governance as "ineffective" in 2022 (Court of Auditors 2022).

More broadly, there is a glaring gap in the water sector between the complexity of the issues and the weakness of the resources allocated to the sector's management, particularly regarding the staffing of the water police (as in the case of countries as different as Morocco, Mexico, Brazil, or France). Besides the lack of technical and financial resources, water policy projects often relegate environmental issues to the background, behind economic and social issues. Water institutions are often marginalised in the system. Decision-making. Finally, the effectiveness of water policies (are they really implemented?) and their efficiency (do they achieve their objectives?) are rarely evaluated. Such evaluations of policy impact could strengthen trust between authorities and citizens.

18.2.2 Regulatory Restrictions and Tools in Response to Droughts

In the context of climate change, water restrictions, particularly in the agricultural sector, are increasingly being used as emergency regulatory measures to prevent water supply disruptions in stressed areas, whether in the Northern or the Southern countries. While these scarcity management issues are well known in the South, they are now becoming increasingly acute in Northern countries, as evidenced by the drought episode in the summer of 2022 when nearly 350 municipalities in France had to be supplied with water by tanker trucks. It is important to note here, the significance of not using this regulatory tool in a reactive manner only once the crisis is well established, but to anticipate the shortage and implement usage restrictions early enough. Indeed, in France (as in other countries), the systematic triggering of crisis tools in many departments during the summer, when they should in principle be used only two years out of ten at most, indicates deficiencies in the ordinary management of water (Barone and Mayaux 2019). The case of South Africa also illustrates how delays in making decisions about politically unpopular restriction measures inevitably lead to more drastic measures *in the end* when the crisis is established and to the promotion of new hydraulic structures to remedy it (Bourblanc 2022).

18.2.3 Incorporating Climate Change into Water Governance Instruments

From the mid-2000s, many countries or provinces began to adopt climate change adaptation (CCA) strategies including agriculture (for example France, Spain and Senegal in 2006, California and the Western Cape province in South Africa in 2008). Some innovative instruments for climate change adaptation have been implemented in several countries. Many are information instruments, which support research and innovation, through information systems, promoting the regular publication of reports at different levels (national and subnational, for example by the countries of the European Union) (see Chap. 7). Regulatory instruments are also gaining significantly. For example, a policy of quotas and restrictions on irrigation water has been implemented in France for several years (Loubier et al. 2021). These policies are sometimes accompanied by public interventions to encourage new agricultural models. Incentives have been designed to restructure certain production areas, such as subsidies for the restructuring of vineyards in Spain and southern France, but dedicated funding remains limited so far. In Spain for example, some measures, included in rural development plans and adopted by the different provinces and largely funded by the European Union, are now striving to limit water consumption in a long-term climate change adaptation perspective. In Andalusia, irrigation communities can only apply for certain grants if they demonstrate that the project they

wish to fund will reduce total water consumption by at least 5% compared to the current situation. This commitment must then be regularly verified by the Andalusian agricultural administration, for a period of at least 5 years. While many controls have been developed, none of them has so far led to any penalty, despite numerous reports of unfulfilled commitments. Moreover, the farmers of this province have successfully mobilised against a much more ambitious project, that of a permanent reduction in their water rights (Boutroue et al. 2022).

Thus, political innovation towards effective climate change adaptations has so far remained limited. For example, many planning documents (for water or agriculture) do not yet consider the expected effects of climate change. Moreover, in many cases, traditional policy instruments have simply been re-labelled as instruments for climate change adaptation (Barone and Mayaux 2019). This is the case for crop yield insurance against natural disasters, subsidies for agroecological practices, drip irrigation, or inter-basin transfers in Spain, Brazil and North Africa.

18.3 The Need to Develop Territorial Approaches Towards an Agroecological Transition Incorporating the Issue of Water

18.3.1 Developing More Coherent Intersectoral and Territorialised Policies

The challenges of coordination between sectoral policies are perceived as more complex than ever with the emergence of the WELF (water, energy, land and food) nexus paradigm. Policies in the fields of water, food, land and energy are mostly developed in silos, even though the interdependencies between them are numerous and substantial. These interdependencies prove (1) complex to understand, (2) highly variable from one territory to another and (3) often not recognised in policy development. Some recent conceptual frameworks put these interdependencies at the forefront (for example, virtual water¹, ecosystem services, etc.), but they are still not very operational.

More than a decade after the introduction of Integrated Water Resources Management (IWRM), the need for territorial approaches has given rise to the new rural paradigm (OECD 2006). The OECD has shown that governments are increasingly aware of the need to improve, and sometimes even abandon, traditional sectoral policies and replace them with more appropriate instruments. OECD governments (but also some countries outside OECD) have shown increasing interest in territorial approaches to rural policy, allowing for the integration of different sectoral policies and improving the coherence and efficiency of public spending in

¹This terminology refers to the water used to produce exportable goods in one location and consumed “virtually” in another space.

rural areas. . For example, in France or Tunisia, such policies have created spaces for involving local communities in decision-making and policy development (such as local water commissions, territory committees, etc.). Local planning authorities are becoming more autonomous and can promote a territorial and participatory approach. These experiences have had positive results, as shown by several experiments conducted over the past decade (Hassenforder and Ferrand 2024). However, important questions remain regarding the appropriate level of public intervention, its legitimacy, and the ability of local planning authorities to implement adequate planning processes.

18.3.2 Improving Participation and Territorial Dialogue Around Water

Participatory approaches to planning and integrated use of natural resources have been widely encouraged over the past few decades, whether in the context of IWRM, but also Sustainable Development Goals (SDGs) (public participation is target 16.7 among others). Public participation is advocated by international donors, governments, and various stakeholders themselves. Public participation is increasingly necessary to obtain funding for development projects . The last decade has also witnessed the rise of civic technologies and citizen science. In Kenya, for example, citizens can lodge complaints or provide feedback on water services through a website, MajiVoice. Citizen science initiatives are research programmes involving individuals—many of whom are not qualified scientists—in the collection, categorisation, transcription or analysis of scientific data. These trends present both opportunities and risks. On the one hand, they allow for more participatory approaches with more numerous and diversified participants, as well as greater transparency of public policies and greater accountability of decision-makers. But these trends also present risks of exclusion, marginalisation and corruption if participation is not implemented efficiently.

Even though participatory approaches have delivered on their promises in many cases, obstacles remain that can limit their implementation and impact.

- The results from participatory processes are not always taken into account in political decisions: many decision-makers still pay little attention to farmers' knowledge and do not understand the added value of public participation.
- Governments rarely have the means to involve the most marginal and disadvantaged people, especially in rural areas, as this requires individual outreach and the implementation of adapted participatory methods. Governments therefore often rely on associations or representatives of different categories of actors (whose interests are not always aligned with those of the poorest). There is also often a lack of political will to implement participatory approaches.
- The evaluation of participatory approaches is fundamentally deficient in most countries. While it sometimes includes a procedural evaluation (number of

participants, representativeness, etc.), it rarely includes the evaluation of social impacts (learning, change of practices, etc.) or environmental performance. Moreover, evaluations 5 or 10 years after the end of processes are anecdotal, and we therefore lack perspective on the impact of these approaches.

- Large-scale participation, particularly in a rural context, raises questions of data storage, aggregation and sharing (Bright and Margetts 2016; Karim et al. 2020; Tang and Liao 2019)
- There is often a gap between the participatory process and investment timelines. A participatory diagnosis must be able to proceed at its own pace, while there is often pressure to quickly spend an annual budget or a project budget.
- It remains difficult to integrate plurality, conflicts and hybridity into participatory planning approaches (Brown et al. 2017; Murray et al. 2004).

To overcome these obstacles, a set of recommendations is proposed in the literature and would allow for the implementation of coherent combinations of technical and institutional solutions. Here are a few of these recommendations.

- Implementing multi-level participatory approaches, that is, approaches that do not only transfer responsibilities at the local level, but also strengthen and support public participation in regional and national decision-making, and create links between different levels (Daniell and Barreteau 2014; Newig et al. 2017). Some participatory methods — such as role-playing games or strategic planning — can enhance interactions between several levels of governance (Hassenforder et al. 2020), particularly by involving stakeholders early in the process. In Tunisia, the Climate Change Adaptation Programme for Vulnerable Territories (2018–2022) has strengthened multi-level participatory planning, through the creation of multi-party platforms and the enhancement of the capacities of territorial facilitators (Hassenforder and Ferrand 2024).
- Developing a culture of participation, within governments and administrations, among elected officials, territorial managers and technicians. The aim is for the various actors to see participation as an opportunity to build more transparent public policies, based on more diverse and closer opinions of citizens, farmers and users. Participation must adapt to the cultural context, but the context must also adapt to the requirements of participation.
- Implementing participation charters that contribute to the transparency and accountability of public policies. Increasingly, participatory processes are designed jointly with the participants themselves. This means that the participants decide who will participate, when, with which methods and with which roles (Daniell et al. 2010; Hassenforder et al. 2020).
- Adopting more systemic approaches to participation, taking into account the complexity of the socio-environmental system within which participation takes place (Chilvers et al. 2018; Jager et al. 2020), particularly temporal inconsistencies, as very distinct temporalities (those of the participatory devices themselves, those of political decision-makers, farmers, researchers and funders) are often poorly articulated.

- Establishing meaningful systems of monitoring, evaluation and decision support, which include qualitative and quantitative data, which assess the multiple impacts of participation (learning, institutional and relational changes, justice and equity, behaviour change, etc.) and which are used to support the steering of processes and decision-making. Various approaches have been developed for such systems (Blundo Canto et al. 2018; Hassenforder and Ferrand 2024). These approaches promote the involvement of different stakeholders in the design of the evaluation process, in the collection and analysis of data and in the sharing of results.

The aim would be to move from a vision of evaluation as a control tool to an evaluation contributing to the impact of the participatory approach.

18.4 Conclusion

To cope with the pressures and decreases in water availability affecting our agri-food systems, many technical or governance solutions exist and have been partially implemented in several countries, both in the Northern and the Southern countries. But if these solutions are not made coherent with each other, they often lead to perverse effects or a form of inefficiency. Governments and the private sector, including farmers, could embrace a more proactive and participatory approach to advance the widespread adoption of sustainable and coherent land and water management practices. These solutions must be adapted and discussed at the territorial level, and their impacts must be evaluated. The implementation of sustainable, equitable and poverty-reducing land and water policies is possible, but it is a long-term effort that requires strong state capacities and citizen engagement, particularly at the territorial level. Adapting to climate change, like any public action, cannot be perfectly consensual: it will necessarily involve that some will lose more than others, at least in the short term, hence growing tensions. These tensions are not to be feared: they can be fruitful and productive, provided they can be expressed in inclusive, relatively transparent and accountable debate and decision-making spaces.

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Chapter 19

Energy Production in Agriculture to Tackle Climate Change



François Pinta, Antoine Ducastel, Patrice Dumas, Marie Hrabanski, and Grâce Chidikofan

Abstract Agriculture heavily relies on energy, especially fossil fuels, which played a key role in the Green Revolution but also contribute significantly to greenhouse gas emissions. Agri-food systems account for about 30% of global energy use, with most consumed after harvest in transport, processing, and distribution. However, agriculture also has strong potential to produce renewable energy. This chapter examines energy generation from biomass and the integration of electricity production into farming. Special attention is given to agrivoltaics as a promising solution.

Energy is a major input in agricultural production. Historically, the green revolution which began in the 1950s was the result of the widespread use of fossil fuels and electricity in agriculture, through extensive mechanization, and the intensive use of fertilizers, and pesticides, to address global food security. As a result, agricultural production levels and the fulfilment of human food needs are closely linked to energy availability and use. However, when this energy is of fossil origin, it leads to significant greenhouse gas emissions. Agri-food systems currently account for

F. Pinta (✉)

Cirad, UPR BioWooEB (Biomass, Wood, Energy, Bioproducts) University of Montpellier, Montpellier, France
e-mail: francois.pinta@cirad.fr

A. Ducastel

Cirad, UMR Actors Resources Territories & Development (ART-Dev), FAO, Rome, Italy

P. Dumas

Cirad, UMR Cired, Montpellier, France

M. Hrabanski

Cirad, UMR Actors Resources Territories & Development (ART-Dev), Montpellier, France

G. Chidikofan

National University of Sciences, Technologies, Engineering and Mathematics of Abomey (ENSGEP/UNSTIM), Abomey, Benin

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V. Blanfort et al. (eds.), *Climate Impacts and Challenges in Agriculture, Forests and Food Systems*, https://doi.org/10.1007/978-3-032-04331-3_19

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about 30% of global energy consumption¹ with about 70% of that energy used during post-harvest stages such as transport, processing, packaging, storage, marketing, and distribution.

At the same time, agriculture is also a source of renewable energy and has the potential to contribute significantly to energy production.

This chapter analyses the challenges and opportunities related to the increasing role of agriculture in green energy production. The first part focuses on energy generation from biomass (in the form of solid fuels, biogas, and liquid biofuels), while the second part explores the integration of electricity production units into agricultural systems, with particular emphasis on agrivoltaics.

19.1 Energy Production from Agricultural Biomass

Agriculture today plays a role in energy production, through various categories of biomass that can be used to generate different forms of energy. This energy can be utilized within the agricultural sector itself or externally to meet other societal needs. The three forms of energy that can be derived from agricultural biomass are: solid biomass fuels (from lignocellulosic waste), biogas (from wet agricultural waste via anaerobic digestion), and liquid biofuels (from energy crops).

The following Table 19.1 presents the main forms of energy that can be generated from agricultural biomass, whether on farms or in industrial facilities within the energy sectors.

Table 19.1 Main forms of energy produced from agricultural biomass

Biomass resource	Form of energy produced			
	Heat	Electricity	Biogas	Biofuel
Dry residues from agri-food processing	+++	+		
Lignocellulosic crop residues (e.g. straw)	+++	+		
Oilseed or carbohydrate-rich energy crops (palm, maize, rapeseed, etc.)				+++
Wood residues (pruning, hedgerows, roadside maintenance, etc.)	+++	+		
Wet biomass: livestock manure and intermediate energy crop (Cive)	+	+	++++	

¹FAO, 2015: <https://openknowledge.fao.org/server/api/core/bitstreams/1b142e0d-de8b-4043-9900-6d8b7c088726/content>

19.1.1 Energy and Fuel Generation from Lignocellulosic Waste

This section addresses agricultural biomass, including tree pruning from agroforestry systems and arboriculture (e.g. fruit orchards), as well as wood from wooded plots of agricultural operations (Box 19.1). These resources represent significant supplies of woody biomass, also known as “dry biomass”. Please note that forestry activities based on forest exploitation are not considered in this paper.

Box 19.1 Availability of agricultural residues for energy production: examples in West Africa (according to BOAD 2023)

In Benin, Ivory Coast and Senegal, significant deposits of agricultural and Agri-food waste have been identified, which were estimated in 2023 to be 5 Mt./year per country.

Large Agri-food processing units generate cotton husks, rice husks, sugarcane bagasse, cashew nut shells, etc., of which only a small portion is currently used. For example, cashew processing plants use around 15% of the shells to fuel their boilers, leaving 85% as lignocellulosic residue available for other purposes, such as energy production.

Lignocellulosic biomass from the agricultural sector is typically too dispersed geographically, and of insufficient technological quality to be used as construction materials. The same applies to straws, husks (the outer layers of cereal grains, such as rice for example), and nut shells (e.g. hazelnuts, cashew, etc.). These materials are most effectively used as fuels for heat production via controlled combustion appropriate boilers.

When biomass must be transported, it is advantageous to convert it into pellets or compressed briquettes to ease logistics and reduce storage and transport costs. When territorial conditions are favorable, thanks to abundant resources and appropriate infrastructure, these fuels can be used in power plants (possibly with cogeneration of heat) that supply electricity to local or national grids, thereby serving both the population and local industries. Finally, in cases requiring thermal energy (e.g. drying agricultural products, or heating greenhouses), it’s possible to replace fossil-derived gas (propane, butane, natural gas) with syngas. Syngas, or synthetic gas, is produced by gasifying dry biomass at high temperatures (900–1000 °C), in a gasification reactor.

The main challenges lie in mobilizing available biomass residues and overcoming economic, technical or organizational barriers. These include:

- High dispersion of biomass sources,
- High mobilization costs,
- Storage needs (due to the mismatch between residue availability and energy demand),
- Intense logistical demands and costs, etc.

Regarding the GHG emissions, the combustion or gasification of lignocellulosic residues reduces both CO₂ and CH₄ emissions that would otherwise result from natural decomposition. Even if natural decomposition can take years (depending on environmental conditions). The Life Cycle Analysis (LCA) method shows that when biomass transport distances are limited, the overall emissions balance is clearly positive. This is due to avoided emissions from natural decomposition and the substitution of fossil carbon with renewable sources.

19.1.2 Production of Biogas Through Anaerobic Digestion of Wet Biomass

Biogas is a renewable gas composed primarily of methane (CH₄) and carbon dioxide (CO₂) produced by the anaerobic digestion of organic matter in a methanisation reactor. Biogas can be used directly, or upgraded to biomethane (by removing CO₂), which can be injected into natural gas networks. Like syngas, biogas can be used to produce heat and/or electricity depending on the configuration of the facilities and energy needs. The co-product of methanisation, known as digestate, is typically used as an organic soil amendment returning organic matter and nutrients to the soil.

The raw material for biogas can include various types of wastes or dedicated agricultural crops. These may consist of energy-oriented intermediate crops (EIC) or other biomass specifically cultivated for this purpose. The waste used is diverse and includes: animal excreta, manure, slaughterhouse waste, cereal sorting waste, green waste from recycling centres, and more. Each batch of biomass has a specific methanogenic power depending on its intrinsic characteristics and the process implemented. Biogas can be used on site as seen in family farming systems in India, China, and to a lesser extent in some African countries. In these cases, biogas is used as a domestic fuel for cooking, replacing firewood or fossil fuels.

In several European Union (EU) countries, including France, methane is separated from CO₂ and injected into the natural gas grid, enabling transport to distant locations and easier storage. The EU has actively supported the development of the biogas sector through its “biogas roadmap,” which helps member states implement national strategies. In Latin America, Brazil has seen the most significant growth in the methanisation sector in recent years. In Africa, several countries have launched biogas initiatives—such as the Biogas Africa program started in 2005—with South Africa, Kenya, and Nigeria leading in development.

From a GHG emissions perspective, the methanisation of agricultural waste contributes to a reduction of CO₂, methane, and nitrous oxide emissions that would otherwise result from the natural degradation of residual wet biomass. Therefore, despite the infrastructure and logistical demands, the overall balance of methanisation activities is generally very positive thanks to the significantly avoided emissions (Couturier et al. 2019). However, some conflicts and controversies persist around the use of methanisation. Experts have raised concerns about the long-term

sustainability of agricultural systems integrating EICs. Additionally, some argue that biogas production can contribute to land use conflicts, with land being continuously cultivated solely for energy production. A territorialized assessment may therefore be useful to evaluate the local relevance and sustainability of biogas projects.

19.1.3 Biofuels Production

There are currently different modes of biofuel production, classified by generation, from the first to the third generation. Current biofuels are predominantly produced through the transformation of agricultural products such as sugar beet, wheat, corn, rapeseed, sunflower, these are known as first-generation biofuels.

The main advantage of first-generation biofuels lies in their technological maturity: production methods and costs are well established on a large scale in various regions of the world, including the European Union, Brazil and the United States. Bioethanol is primarily produced from corn (two-thirds) and sugarcane (over one quarter). It is blended with gasoline and used in the internal combustion engines of motor vehicles. Global production is close to 100 million cubic meters of ethanol in 2022, representing approximately 5–10% of total gasoline consumption worldwide. The United States is the leading producer, followed by Brazil: together, they account for 82% of the global market. However, the Asia-Pacific has shown the highest growth in ethanol production with an annual increase of over 10% in 2022. India, China and Thailand are major producers in this region.

Biodiesel, on the other hand, is derived from various sources of fatty acids, particularly soybean, rapeseed, palm and other vegetable oils. Three-quarters of biodiesel production comes from the processing of vegetable oils, especially rapeseed oil.

However, the agricultural origins of first-generation biofuels raise significant concerns and controversies, due to their competition with food crops. This mode of production can directly compete with food production, as they are produced from cereal or oilseed grains, or from the sucrose of sugar beets or sugar canes. Their large-scale cultivation may contribute to rising agricultural commodities prices and to an increased use of synthetic pesticides to maintain crop yields. For these reasons, the EU has limited the share of biofuels to an average incorporation rate of 7% at most. According to the World Bank, between 2002 and 2008, increased demand for biofuels accounted for approximately 75% of the rise in food prices and was partially blamed for the global food crisis affecting vulnerable populations, particularly in countries of warm regions.

Second-generation biofuels are produced from the nonedible parts of plants. These include lignocellulose materials from agricultural residues (e.g. straw) and forestry residues (e.g. wood), purpose-grown energy crops (e.g. fast-growing coppice), and industrial waste. These biofuels avoid direct competition with food production. Furthermore, they rely on more diverse and often lower-cost biomass

resources, and they offer a better environmental production balance. However, industrial-scale production technologies for second-generation biofuels are still in the early stages of deployment and remain costly. Nevertheless, their development is supported by the EU, whose renewable energy Directive (directive 2018/2001 known as EnR2, published on 21 December 2018) sets a target of 14% in transport fuels by 2030, half of which should come from second-generation sources.

Third-generation biofuels refer to fuels produced from algae cultivated in off-ground basins. However, this technology is still at the research and development stage and lacks commercial maturity. In 2020, biofuels production remains largely dominated by first-generation sources.

Finally, it is important to note that some experts have raised concerns about land-use conflicts related to both the biogas and biofuels sectors specifically when dedicated energy crops are involved. When considering the replacement of the pre-existing vegetation on the lands used to grow energy crops, the greenhouse gas emission balances often appear negative in the short to medium term. The benefits generally emerge only in the long term (Searchinger et al. 2018).

19.2 Energy Production and Land-Use Conflicts Associated to Agrivoltaics

The second part of this chapter discusses the use of agricultural land for the installation of photovoltaic panels. Today, the decarbonisation of energy in the agricultural sector is reflected in the figures. In 2019, only 3% of global electricity demand was met by photovoltaic energy, but by 2023 this figure had risen to 6.2%. This trend is expected to continue, highlighting the global surge in photovoltaic installations, particularly in China. A difficult-to-quantify portion of these panels is installed on agricultural land, but the development of these renewable energies (RE) since the 2010s has highlighted a growing issue: competition over land use, suitable for both agricultural production and photovoltaic electricity generation. To reconcile these two objectives, the concept of ‘agrivoltaics’ has gradually emerged, particularly following the seminal scientific publication in 2011 (Dupraz et al. 2011). One of the stated objectives of agrivoltaic systems is to preserve agricultural land. Agricultural production is generally considered the primary objective of these systems, even if energy production proves more profitable. Solar panels, sometimes adjustable or installed at varying heights, can be integrated into a variety of agricultural practices, including horticulture, market gardening, viticulture, pasture management, and large-scale crop farming. Constraints on agricultural production vary from one country to another depending on climate, current legislation, crop type and the specific goals of the agrivoltaic system (e.g. maximizing crop yield, improving product quality, optimizing electricity generation). By extension, greenhouses equipped with solar panels may also be considered agrivoltaic systems, especially if they enhance crop production through improved climate control and water management.

Agrivoltaics is therefore presented both as a technique to prevent soil sealing due to photovoltaics and as a solution for adapting to climate change. For example, the panels can provide protection during periods of extreme heat and/or hail (Dinesh and Pearce 2016). In terms of productivity and energy efficiency, proponents of agrivoltaics emphasise that one hectare of agrivoltaic land can enable an electric car to travel a distance roughly hundred times greater than a biofuel crop (e.g. wheat or rapeseed converted into biofuel) can achieve for a combustion engine vehicle (Dupraz et al. 2011).

There are also economic benefits (Al Mamun et al. 2022), as often landowners or farmers can receive an annual lease payment for hosting panels, albeit at the risk that they may no longer be incentivised to continue agricultural activity. The development of agrivoltaics therefore also gives rise to numerous controversies or reinforces those that already existed on photovoltaics (Hrabanski et al. 2024).

This new international market is expanding rapidly in Asia, and its growth is also significant in Europe and North and South America. The African continent is for the time being still little affected by this enthusiasm (Fig. 19.1).

The development potential of the sector is considered immense by some experts, who estimate that just 1% of global agricultural surface would be enough to meet the world's entire electricity production (Barron-Gafford et al. 2019). However, this potential raises questions about the future use of agricultural land. Given the particularly high economic returns from photovoltaic installations, many stakeholders in the agricultural sector—alongside citizen collectives and some environmental

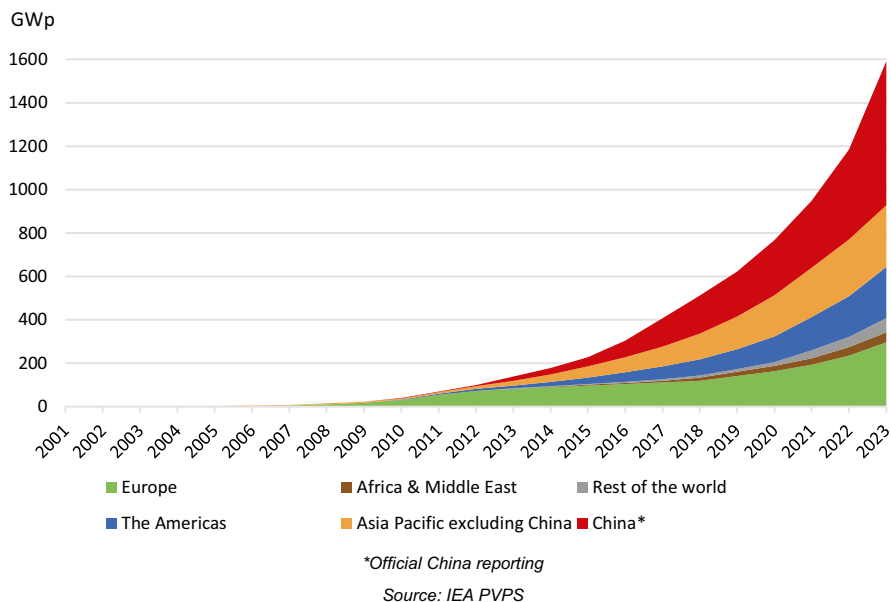


Fig. 19.1 Regional growth of photovoltaic installation capacities between 2001 and 2023 (in gigawatts) according to IEA (Source: IEA Photovoltaic Power Systems Programme 2023—Snapshot of Global PV Markets. https://iea-pvps.org/wp-content/uploads/2023/04/IEA_PVPS_Snapshot_2023.pdf)

organizations—fear that the balance may increasingly shift away from food production toward energy generation. In China and India, some authors estimate that this form of “Solar extractivism” (Hu 2023) or solar capitalism primarily benefits large industrial energy corporations, which are acquiring agricultural land on a large scale to the detriment of local socio-ecological systems. Climate change and the greening of political agendas could legitimise a particularly alarming land-grabbing process threatening global food security and the rights of local farmers (Singh 2022; Hu 2023).

19.3 Conclusion: Growing Competition Between Food and Energy Production

Climate change has brought to the forefront the need for agricultural energy consumption, particularly in the Global North. In the Global South, however, access to energy and electricity remains a major challenge for improving living conditions.

According to the FAO, every energy-consuming activity in agriculture holds potential for savings, provided stakeholders adopt a rigorous approach to identifying and implementing effective reduction strategies. The aim is to reduce energy consumption without compromising agricultural productivity. Based on an energy efficiency criterion, measured in kilowatt-hours consumed per unit of food delivered “to the plate”, experts consistently highlight that reducing post-harvest losses in agri-food systems is one of the most effective strategies (see Chap. 23), while also improving global food availability.

The use of renewable energy sources such as the valorisation of residual biomass which remains abundant especially in some Southern countries, should help reduce GHG emissions in the sector, improve productivity (through enhanced local energy access) and manage feeding a rapidly growing population, particularly in sub-Saharan Africa.

However, energy production in and by agriculture, whether through lignocellulosic biomass, methanisation, agrivoltaics or wind power, can create competition between food and non-food (energy) uses.

The use of biomass or agricultural land for energy purposes also competes with other critical priorities such as preserving carbon sinks, biodiversity, and sustainable soil fertility, especially in a context where biomass availability is increasingly constrained. While renewable, biomass is not inexhaustible, and its main sources (forests and agriculture) are weakened by global warming.

Agrivoltaic installations, while capitalising on solar energy are drastically changing access to farmland in many regions. The development of renewable energy sources in agriculture also has the potential to significantly redistribute economic value within the sector, sometimes increasing existing socio-economic disparities among farmers.

Finally, these renewable energy sources may also lead to numerous conflicts over land use and impact soil quality. Their development should not, therefore, be solely driven by large industrial groups seeking short-term profitability but rather be guided by principles of social and environmental justice (Demenois et al. 2022; Demenois 2023).

At the geopolitical level, the development of agricultural energy production reinforces the issues surrounding land control. The emergence of China, as the main producer of renewable energy, associated with its growing demand for agricultural land, is likely to shift global balances of influence.

At the territorial scale, agricultural-energy projects must be integrated into broader territorial planning. These projects mobilise local resources—agricultural land, biomass, co-products, waste—and can become levers for local economic and social development.

It is therefore essential that in both the global North and South, these issues be carefully framed and regulated to prevent the destabilization of three key pillars: (1) food security, (2) farmers' rights, and (3) integrity of local ecosystems.

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