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Review

Revolutionizing Towards Sustainable Agricultural Systems: The Role of Energy

Ilaria Zambon [1,*], Massimo Cecchini [1], Enrico Maria Mosconi [2] and Andrea Colantoni [1]

[1] Department of Agricultural and Forestry Sciences (DAFNE), Tuscia University, Via San Camillo de Lellis, I-01100 Viterbo, Italy; cecchini@unitus.it (M.C.); colantoni@unitus.it (A.C.)

[2] Department of Economics Engineering, Society and Business Organization, Tuscia University, Via del Paradiso 47, I-01100 Viterbo, Italy; enrico.mosconi@unitus.it

* Correspondence: ilaria.zambon@unitus.it

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Abstract: Innovations play a significant role in the primary sector (i.e., agriculture, fisheries and forestry), ensuring a greater performance towards bioeconomy and sustainability. Innovation is being progressively applied to examining the organization of joint technological, social, and institutional modernizations in the primary sector. Exploring the governance of actor relations, potential policies, and support structures is crucial in the phase of innovation, e.g., during research activities, often applied at the national or sectorial scale. However, when opposing normative guidelines for alternative systems of agriculture arise (e.g., the industrial agriculture paradigm), modernizations in agricultural and forestry may contribute to outlining more sustainable systems. To date, innovations in the primary sector do not seem as advanced as in other sectors, apart from industrial agriculture, which sometimes appears to be the most encouraged. The present review aims to shed light on innovations that have been identified and promoted in recent years in the primary sector, including agriculture and forestry. The need to pursue sustainable development in this sector requires the inclusion of a fourth dimension, namely energy. In fact, energy sustainability is an issue that has been much discussed in recent years. However, the need for progressive technological progress is indispensable to ensure long-lasting energy efficiency. The aim is to understand what innovations have been implemented recently, highlighting opportunities and limitations for the primary sector.

Keywords: innovation; agriculture; forestry; energy; sustainability

1. Introduction

Innovations play a significant role in the primary sector (i.e., agriculture, fisheries and forestry), ensuring a greater performance towards bioeconomy and sustainability [1–3]. Innovation has been progressively applied to examine the organization of joint technological, social and institutional modernizations in the primary sector [4–6]. Exploring the governance of actor relations, potential policies, and support structures is crucial in the phase of innovation, e.g., during research activities [7], often applied at the national or sectorial scale [5,7]. However, when opposing normative guidelines for alternative systems of agriculture arise (e.g., the industrial agriculture paradigm), modernizations in agriculture and forestry may contribute to outlining more sustainable systems [5,8–12]. To date, innovations in the primary sector do not seem as advanced as in other sectors, apart from industrial agriculture, which sometimes appears to be the most encouraged nowadays [10]. This leads to the need (i) to adopt a multifunctional approach to agriculture, (ii) to focus explicitly on ecological aspects, and (iii) to take on technological advances that involve different disciplines [5,13,14].

Innovations in the primary sector can enable a cooperative achievement emerging from different actors (frequently in new mixtures), providing innovative modes of production and new organizational structures and activities to better support widespread learning, adapting, and adjusting [5,15]. By permitting relations across different stakeholders (e.g., professional, sectoral, organizational, or cultural), the involved actors can (i) experiment together, (ii) propose new technologies, practices, and institutions, and (iii) support evolution towards a more sustainable agriculture [5,15]. Thanks to the interactions among different actors, changes to more sustainable agriculture comprise the development of modernization [15,16].

Complex challenges facing an evolution towards more sustainable agricultural and forestry systems are often connected to resource competition (e.g., energy, water, land, biodiversity), socio-economic apprehensions (e.g., community development, rural livelihoods, emerging markets), and environmental integrity (e.g., climate change) [17–20]. Such challenges characteristically span numerous natural resource management systems (e.g., agriculture and forestry, but also water, conservation and energy) and related ecosystem services (including the provision, regulatory, cultural and support services) [5,21,22]. Agriculture-related fields identify the requirement for better adoptive relationships across scales and sectors to report multifaceted sustainability trials [13,23]. Consequently, more networked methods are required to move toward innovation and sustainable agriculture, with the aim to simplify the boundary crossing and to coordinate actors across different spatial scales [5]. With reference to crossing scales, changes toward sustainability require the skill to move innovation processes ahead by working across scales [14,24]. Correspondingly, landscape approaches have the latent character to mature more combined approaches for sustainable agriculture and to enable the compulsory connections among the systems, services and, sectors interested in agricultural and forestry areas [16,25,26]. For instance, multifunctionality and circular economies are some of the main ideas in sustainable agricultural and forestry systems [5]. Multifunctionality includes production, environmental, and human features of agriculture, which are crucial to sustainability [19,27,28]. Sectoral divisions (e.g., agriculture versus energy) or sub-sectoral divides within agriculture owing to specialization (e.g., separation of crop and livestock sectors) have long delayed endorsing multifunctional methods in agriculture and practical crossovers with non-agricultural sectors [5,27,29–31].

The present review aims to shed light on innovations that have been identified and promoted in recent years in the primary sector, including agriculture and forestry. The need to pursue sustainable development in this sector perceives the requirement to include a fourth dimension, namely energy [32]. Examining one of the recent notions of 'sustainability', energy can be assumed as the fourth dimension of sustainability. With the four sustainable dimensions (energy, economy, society and environment), rural districts can provide greater maintainable growth, also focusing on a sustainable (energy) future, which in literature is perceived by the "agro-energy districts" [32–36]. However, very often such innovative realities present their intrinsic limits. For this reason, today, the need for progressive technological progress is indispensable to ensure long-lasting energy efficiency. The general aim of the present review is to understand what innovations have been carried out recently, highlighting opportunities and limitations for the primary sector.

2. Energy for a Sustainable Development in the Primary Sector

Agriculture is one of the most significant sectors, which is characterized by the greatest potential for sustainable economic development [5,7,9,16,28–39]. Specifically, renewable sources represent good alternatives to fossil resources in the primary sector, which are inadequate in quantity and are prone to exhaustion [31,38,40–43]. Development of renewable energy as a main global resource of clean energy is one of the main global purposes of current policies, which, in the overall outline of sustainable development, is intended to reduce energy consumption and increase the security of supply, environmental protection, and maintainable technology development [38].

Forest and agricultural resources are conspicuous sources of energy that may be indispensable for greater local and technological development [23,41,44–47]. For this reason, recent scientific and technical research has sought to mature innovations that allow the larger reuse of resources with clean energy and low environmental impact [2,3,6,12,14,17].

To become economically sustainable, undeveloped renewable resource-based technologies must progress along the learning curve, finally influencing competitiveness with fossil resource-based options [8,48,49]. Furthermore, innovations are fundamental for ensuring environmental sustainability that decreases the potential impacts of renewable resource use on ecosystems [49,50]. The employment of a circular flow economy needs original technological, organizational and product solutions, and improved resource efficiency [1,47]. On the supply side, innovations should focus on technologies and products, while from the user side, main concern should be given to consumption and waste generation patterns [49,51].

The innovation lies in the fact that the advancement of energy efficiency is achieved through a gradual move from fossil energy sources to more environmentally friendly and renewable energy sources, endorsing energy efficiency through improved performance technologies and schemes [8,52,53] and affording a combined method reliable with the expansion of the liberalized market. For this purpose, today, a scheme that can assimilate advanced and innovative essentials of tariff control and direct control of the market should be implemented [43].

With the regards a prospective future changeover towards a sustainable bioeconomy, today, policy interventions, technology and product markets results are inadequate in offering suitable encouragements [49,54,55]. Furthermore, compulsory fossil resource-based technologies profit from past learning properties, increasing returns, and network externalities, all of which interrelate with the dedicated nature of investments to produce a technological path reliance [49]. Such a framework can be strengthened by a co-evolutionary growth of fossil resource-based organizations, codependent industries, consumption patterns, and private and public institutions ensuing in a "carbon lock-in" [4,7,9].

Research on the relationship among innovation systems, sustainability, and policies focused on energy system transitions [56–59]. Literature offers significant insights concerning appropriate policies, innovation economics, and systems [49,58]. Therefore, an inclusive and well-coordinated policy asset is compulsory to support a well-developed innovation system, which is in turn helpful in providing a sociotechnical path change [56,59].

In the last decade, climate and energy strategy was emphasized by the European declaration towards the achievement of definite environmental goals of energy strategy and advancement of agriculture-based bioenergy and biofuels [41,60–62]. Several global challenges require innovative approaches to knowledge discussion, e.g., those predicted in the European Innovation Partnership "Agricultural Productivity and Sustainability", which are of greatest importance to foster the application of explanations [52]. The change toward agriculture-based bioenergy has also been supported in reply to structural variations in agriculture that involve an examination of new endurance approaches [60].

2.1. Conjugating Innovation with Biomass

Climate change, scarcity of resources and materials, increasing population, and environmental pressures have encouraged a revaluation and assessment of the current fossil-based economy [3,63]. The bioeconomy concept has been given numerous descriptions and its conceptualization is still developing [64–66]. However, two main features can be shared. Firstly, bioeconomy will depend on renewable biomass in place of finite fossil inputs to produce an extensive variety of value-added products, e.g., bio-based products and bioenergy [3,32,64,67–70]. Secondly, these products will be formed in biorefineries succeeding a cascade principle with the intention of extremely valorizing the obtainable biomass [71,72]. Biomass is originally processed into high value products and the relative residues are used for lower value applications until the smallest amount of waste remains at the conclusion of the process [73–75]. Bioeconomy can therefore be considered an assortment of sectors and subsectors (e.g., agriculture and energy), employed in combination to derive products from renewable biological resources from the primary sector [3,71,72].

According to [3], innovation can develop following specific processes within the bioeconomy based on a four-staged literature research: innovation process, network management, stakeholder groups, and bioeconomy contextual factors. Idea development, invention, and commercialization are the three fundamental phases for activating an iterative process. During the latter process, the three fundamental phases are interconnected via learning cycles, enabling repetition of confident process steps to adjust to unexpected progresses and errors (Figure 1).

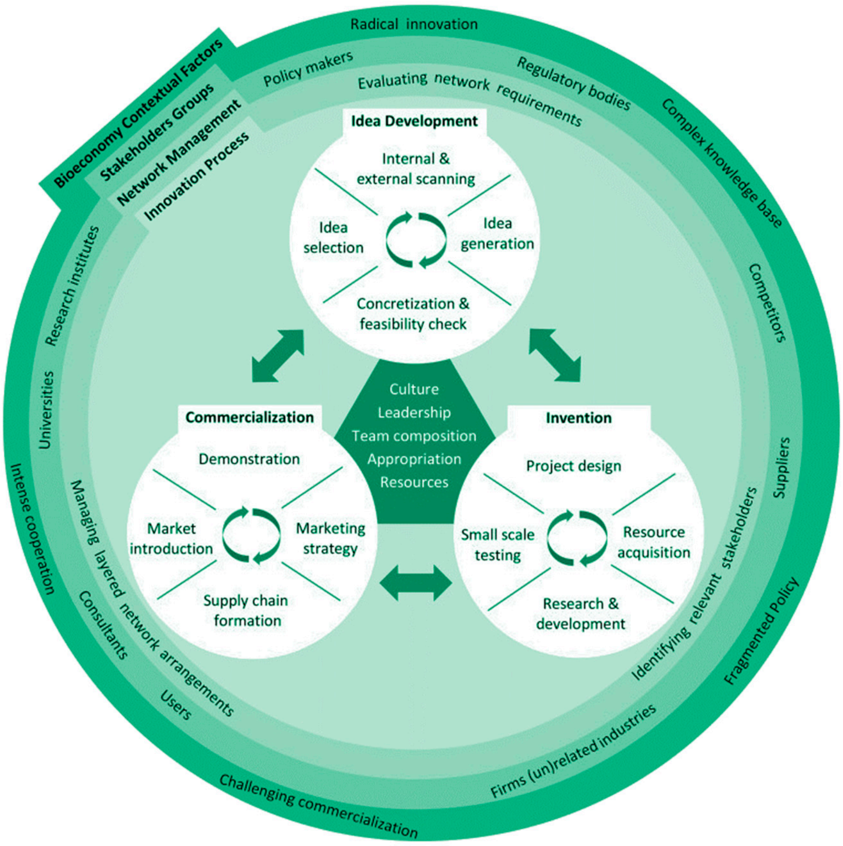

Figure 1. A schematic depiction of innovation in the bioeconomy framework (source: our elaboration with a reproduction with permission from [3], 2016).

Biomass feedstock are energy sources in the primary sector, which are derived from wastes associated with their processing (e.g., agricultural residues) [6,67,68,70,76]. However, natural resources for energy purpose expose contrasting opinions. Following some researchers, land-use change for the cultivation of energy crops can have important consequences on global food security, employment, the income of regional populations, and the biodiversity of ecological societies [37,76,77]. Land accessibility, land-use practices, and water availability are some of the main key factors for the large-scale production of biofuels [76,78–80]. A negative perspective has exposed that the future availability of arable land, using existing farming areas for energy crop cultivation, might result in food deficiency [76]. However, it may be practicable to convert abandoned and marginal areas into cultivated land for energy crop cultivation [32,55,67,69,77]. Global biofuel programs will usually subsidize the sustainable livelihood of agricultural employees by growing employment rates in most rural contexts since a large portion of feedstock cultivation and plant processing includes manual work [76].

Following a more optimistic perspective, biomass supply may be protected and extended using advanced management procedures and strategies [40,81]. For instance, new sources of cheap biomass for energy production can be selected by using lignocellulosic material that is inappropriate for common forestry and agricultural usage [82].

Investigation into innovations and technologies that can decrease land use and decrease accidents from renewable energy sources and the risk of resource competition have been carried out [83,84]. For instance, with bioenergy, food for consumption competes in the same areas as those for energy production [42].

2.2. Conjugating Innovation with Solar Energy

Innovation in the primary sector also benefits from solar energy [85–89]. Many studies have deepened understanding of this issue since the installation of solar systems on greenhouse structures became one of the recent strategies to allow both agricultural production and energy production [39,46,86,89–91]. However, the installation of photovoltaic panels on greenhouses involves certain limitations, which have been solved through specific studies [39,92]. Shading represents one of the main limitations for photovoltaic installation on the rooves of greenhouses [39,93–96]. The spatial shading variations in a greenhouse during a year can be supposed an appropriate factor for picking out the greatest combination of photovoltaic panels and crops present, guaranteeing both energy and production activities [52,88]. The choice of the covering shading on the spectral distribution of solar radiation incoming to greenhouses, the kind of material, and further properties of the greenhouse are crucial for defining pertinent technical structural details, environmental influences, and internal climatic settings [87,97–99].

The question of shade due to the presence of photovoltaic panels on greenhouse rooves, though, is related to the possible reduction of cultivation that is carried out within the greenhouse [52,100]. Nevertheless, several studies have already promoted different methods and strategies and projects of innovative greenhouses with the intention of limiting the shadow percentage and ensuring optimal agricultural production [39,46,85].

3. Discussion

Innovation is indispensable to reply to the critical apprehensions and challenges related to, for example, climate change, environmental trials, energy scarcity, and food security [1,13,21,22,27,37,50,76,77,99]. Numerous novelties will be in the form of products, processes, and services which can improve the success and efficiency of answering to these socioeconomic challenges and dealing with the measurement and mitigation of negative externalities [63].

Greater sustainability in the primary sector can be guaranteed through (i) the use of agricultural residues, i.e., biomass from agricultural and forestry wastes [16,39,67,68,70,82,101], and (ii) renewable energy, e.g., solar energy [39]. The importance of having adequate structures as solar systems installed on greenhouses helping to produce agricultural products is fundamental to maximize space and optimize both agricultural and energy production [32,39].

Agricultural innovation can be considered as a co-evolutionary process where technological, socioeconomic, and institutional changes are combined [4,7,102]. With production and technical knowledge, numerous factors play a crucial role as prerequisites for innovation, for instance, policy, legislation, funding, infrastructure, and market progresses [7]. However, a limited quantity of research is available concerning current technologies and innovations within the primary sector, such as in developed countries [102–104]. The latter countries are mainly vulnerable to environmental influences, e.g., related to climate change [34,42]. Such current challenges usually have an explicit influence on the agricultural and forestry sector [103].

Addressing the current complex and uncontrolled sustainability matters facing the primary sector, innovations must ensure continuous progress by (i) facilitating the development of rural and forestry economic realities, (ii) pursuing greater environmental mitigation, and (iii) bringing the political sphere into line with the more practical one [5,15,16]. However, dealing with such current challenges is progressively significant (i) bearing in mind mission-oriented innovation strategies and (ii) underscoring the requirement for innovation systems to achieve specific determinations for a sustainability changeover [5,10,105].

Agricultural innovation is no longer just about approving new technologies, technical practices, and alternative customs of organization [7]. Additionally, agricultural innovation is usually driven by different visions exposing different development directions, e.g., sustainable developments and energy efficiency [7,8,16,52,53,104]. However, soil should play a major role in food production in view of another fundamental issue today, namely the increase of both food requirements and the reduction in soil availability and fertility due to population growth and the growing phenomena of desertification and soil degradation [106–111]. In this requirement, the sustainability of agricultural practices can make sense of the reduction of waste and the agronomic energy reuse of by-products [75,82,101]. The role of energy is decisive in this framework also in view of a sustainable development in which the needs of fossil fuels (to produce energy biomass) must assess and reflect on the proper use of agricultural areas and in the recovery of abandoned and marginal areas, even where energy crops are grown [8,43].

4. Conclusion

Energy can assume a key role in current innovations, highlighting chances and limitations for sustainable development [32,33,38,39,76,82,83,112–115]. In this review, the primary sector is investigated due to different issues, e.g., alternative systems of agriculture, more sustainable modernizations in agricultural and forestry [116], reuse of rural land [75,77,82,101,107,116], environmental respect avoiding stress on natural resources, e.g., soil, which can lead to degenerative phenomena, e.g., soil degradation, which are especially severe if they relate to the loss of high-quality soils [37,80,106–111]. Innovation has become increasingly applied to survey the organization of joint technological, social, and institutional modernizations in the primary sector [6,99,103,106,113]. Sightseeing the governance of actor relations, latent policies, and support structures is critical to the stage of innovation, e.g., during research activities, at different spatial scales [117,118]. Modernizations in agriculture and forestry may contribute to planning more sustainable systems, even including energy as a fourth dimension together with economy, society, and environment [32,33,116]. In fact, energy sustainability has become a crucial question in recent years, especially where progressive technological progress is necessary to ensure long-lasting energy efficiency.

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