



Circular economy and sustainable agri-food systems

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A B S T R A C T

In recent times, scientists and economic policy authorities have been promoting viable solutions to address global emergencies related to human-caused climate change. In particular, there is a growing demand for renewable energy sources, technological innovation and energy-saving systems, and ecological and environmental sustainability of natural resources and the territory. At the center of this global effort, an increasingly significant role seems to be destined for the agricultural sector and agro-energy production systems due to the potential benefits in terms of production costs. However, the interest in non-conventional and low-impact energy sources requires an in-depth investigation not only of the advantages, in terms of availability and economic efficiency, but also of the impact on the environment and the quality of the landscape, as well as on the aspects of the overall intervention that must be adopted to allow the supply of agricultural products to the market. Given this scenario, the broad agro-energy issue would be incomplete without exhaustive economic sustainability analyses, which serve as operational decision support tools to measure the cost-effectiveness of investments in agro-energy production and its use. This study presents a methodological proposal to evaluate the economic convenience of energy investments for the production of renewable energy which represents a trade-off between food and non-food production to promote effective and efficient solutions for the allocation of resources. The results of the research must be read to make the agricultural company competitive, not forgetting that it is called upon to produce agricultural products for the market.

1. Introduction

Sustainability in all its aspects (economic, environmental, and social) is one of the most debated topics by the scientific community and by government bodies at an international and national level. In recent years, an increase in the demand for energy from renewable sources has begun to be expected [1]. This aspect derives both from legislative constraints imposed by the various economic policy authorities and from a greater sensitivity to issues concerning the protection of resources in a long-term perspective and the protection of agricultural landscapes resulting from a systemic interaction between man and the environment external. Within the European Union, among the main causes of the current energy crisis, is certainly the war in Ukraine and the cut in Russian gas exports to Europe, decided as retaliation by Moscow for the sanctions imposed by the West [2]. However, Russia's behavior in energy markets has exacerbated an already negative situation [3]. The economic recovery and the return of production to pre-pandemic levels, unfavorable climatic conditions in some parts of the world, the reduction of investments in the gas and oil sectors by producing countries, and the maintenance works of gas and oil pipelines postponed due to the pandemic, these are all factors that – well before the Russian invasion – were already putting a strain on the stability of the global energy market. Fortunately, however, this crisis is not jeopardizing the energy transition in the long run [4]. The decisions on the energy front that states are adopting today include above all emergency

measures, aimed at containing the increase in electricity and gas prices, and ensuring that the supply of energy corresponds to the demand. For the long term, the climate commitments signed to contain global warming remain unchanged, as demonstrated by the European RePowerEU plan (which even proposes to slightly accelerate the transition), the package of US measures contained in the Inflation Reduction Act or the Chinese target to increase the share of non-fossil energy in its energy mix to 25% by 2030 [5]. India also aims to produce 500 GW of energy from renewable sources by 2030, while Japan has approved an investment plan to increase the production of nuclear energy and from low-emission sources – such as green hydrogen and ammonia. South Korea and many other states are moving along the same lines. Just as the 1979 energy crisis accelerated energy efficiency processes and the development of technologies in the wind and solar sector, the current crisis could stimulate the use of renewable and low-emission energy sources. The report of the International Energy Agency published in December 2022 predicts that by 2027 the installed capacity of non-fossil energy will grow by about 2400 GW, 75% more than the current value [6]. According to estimates, 60% of the growth will be driven by the extension of renewable generation plants from photovoltaic panels and the most virtuous state will be China (which will install half of the additional clean energy production capacity). In addition to the willingness of states to limit global warming (less than 20% of the energy mix should come from fossil sources to avoid exceeding the 1.5 °C warming threshold), the increase in the share of renewable energy is due

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to two other factors: 1) the increase in the price of energy from fossil sources has made solar and wind energy more competitive. This is true even though the costs of the raw materials underlying clean energy technologies have increased (one of the consequences of the global supply chain crisis, but also the very increase in demand for new renewable energy installations). According to Bloomberg, for the same amount of energy produced, building a new solar or wind power plant would cost 40% less than a coal or gas plant; 2) the impact of the Russian invasion of Ukraine on energy supply has made evident - in terms of national energy security - the disadvantages of dependence on a few and large suppliers [7]. On the contrary, relying on renewable sources means being able to differentiate one's sources of supply (resources such as the sun and wind are more widespread on a global scale), as well as making oneself more autonomous (it is easier to find sun and wind within one's borders rather than oil and gas). To reduce energy dependence on Russia, in May 2022 the European Commission announced the launch of RePowerEU: a plan to improve the efficiency and decarbonization of the European energy system. By 2027, the European Union has set itself the goal of increasing the share of renewable energy in the transport, heating, and electricity generation sectors. This plan includes, for example, the recent agreement between the EU and the governments of Belgium, Denmark, the Netherlands, and Germany ('Esbjerg Declaration') to develop wind energy production capacities in the North Sea. The goal of the agreement is to produce 260 GW of wind energy by 2050: a value equal to what 24,000 of the largest existing wind turbines, or just under 260 medium-sized nuclear power plants, would produce today. 260 GW is just over a third of the world's current wind power generation. Equally important is the Solar Energy Strategy which aims to produce almost 600 GW of energy from photovoltaics by 2030. However, despite the commitments and agreements made, at the moment the European Union is not keeping up with the achievement of the RePowerEU objectives. By 2027, renewable sources will support 54% of energy production in the electricity sector, 16% in transport, and 32% in heating, against targets of 69%, 32%, and 60% respectively. Among the main stumbling blocks are the subsidies that Member State governments still give to the fossil fuel sector, administrative hurdles to install and expand plants, and opaque and uncompetitive procurement procedures. A further barrier is the outdated state of the energy infrastructure, unsuitable to support the deployment of solar and/or wind energy on a large scale. Finally, the wind and solar energy market in Europe faces the instability of material supply chains and high material costs. Steel and rare earth are the basis for the operation of turbines and photovoltaic panels, as well as for the production of batteries and storage systems (necessary to guarantee the continuity of the energy supply given the intrinsic discontinuity of sources such as wind and Sun). Currently, China produces more than 70% of batteries while the European Union only has 7%. To increase the European battery production capacity, and strengthen the independence of a sector considered strategic, the European Commission launched the European Battery Alliance in 2017 and then in 2022 concluded a collaboration agreement between it and the US Li-Bridge Alliance, US counterpart. The premises for an acceleration of the renewable energy market in the European Union are there but, to achieve the RePowerEU objectives and carbon neutrality by 2050, the Member States will have to remove economic, infrastructural, and bureaucratic obstacles [8]. It is also certain that barring a joint effort at the European level in all sectors and among all regions, regardless of whether the objectives are ambitious or not, the future of a decarbonized Europe remains a chimera. In this scenario, an increasingly significant role has been assigned to the agricultural sector and the production of energy from renewable sources (such as photovoltaic systems). The availability of land allows for the installation of very large parks for the production of this type of energy [9]. However, we must not forget that farms are called upon to produce food products for the market to be used as human nutrition. Therefore, within rural areas, it is necessary to think about the economic convenience of investments for the production of energy from renewable sources without forgetting the objectives of

protection and enhancement of natural resources in an eco-systemic vision of multifunctionality and sustainability of production activities [10,11]. In the face of these challenges, the conclusion is that a reciprocal virtuous coexistence between the production of food and energy production, with respect for nature and the landscape and economic and social problems, does not appear to be taken for granted. Speaking about sustainability in the literature we find several studies. The regionalized environmental damage and life cycle cost of chickpea production have been examined in the literature using the LC-IMPACT assessment [12], this aspect is very important in the context of sustainable food production. Still, others have dealt with a comparison between modeling and life cycle assessment techniques for predicting the energy produced, economic profit, and global warming potential for wheat farms [13]; Still others have highlighted the energy consumption and economic and environmental impacts in conventional tunnels and vertical systems equipped with LEDs in the healing and acclimation of grafted watermelon seedlings [14]; Furthermore, the potential for optimizing energy consumption and costs in saffron production in central Iran has been highlighted in the literature through data envelopment analysis and a multi-objective genetic algorithm [15]; Furthermore, in this context, a combined life cycle assessment and data envelopment analysis was carried out to optimize energy consumption and mitigate environmental impacts in agricultural production [16]. Again, the literature has addressed the life cycle assessment, life cycle cost, and exergoeconomic analysis of different tillage systems in safflower production using micronutrients [17]; Furthermore, machine learning models of exergo-environmental damage and social costs of mushroom production emissions were examined [18] and enlightening sustainability: a comprehensive review of the environmental life cycle and exergy impacts of solar systems on the sector agri-food [19]. In all this research, the importance of the circular economy and its sustainability as a successful strategic variable in agri-food systems is highlighted. Fig. 1 presents a synthesis of the sustainable agri-food system and circular economy. At the center, we find agriculture, the farms where the entrepreneur must decide how much to allocate to food and how much to no food. In this choice from a circular economy perspective, the mission of the agricultural company which is the production of agricultural products for the market must not be distorted. Diversification for the production of energy from renewable sources in a sustainable agri-food system must respect the natural balance of the mission of the agricultural enterprise, the destination of agricultural products to the market.

2. Materials and methods

Therefore, any serious assessment of the possibilities of spreading agro-energy must necessarily involve an in-depth assessment of all the aspects mentioned above, including an in-depth analysis in terms of

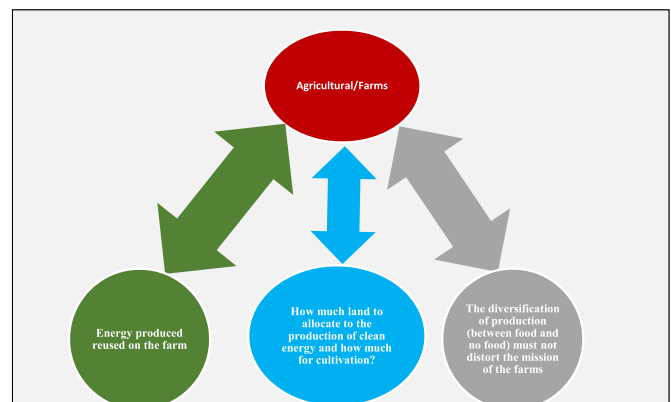


Fig. 1. Sustainable agri-food system and circular economy.

economic feasibility, as a basis for becoming aware of the profitability margins of these margins of profitability of such investments, whether subsidized or not, from the point of view of the renewable energy producer and the user, as an opportunity for agricultural enterprises to diversify their sources of income [20]. In economic Theory, the rational behavior of the entrepreneur is to minimize costs given the level of production and constant prices, put another way the entrepreneur will try to maximize profit by lowering costs (for the same revenue minimize costs). And again given the price level he will try to maximize the quantity of total product to increase total revenue [21,22]. Suppose that the entrepreneur has to decide based on his funds (limited endowment) the combination of production that maximizes the company's profit and that he has to decide whether to produce good Y_1 (corn) or good Y_2 (wheat) whose prices are given (P_1 and P_2) in a given competitive market, therefore the agricultural enterprise cannot change prices, and that the endowment of resources is limited. In other words, the firm cannot increase the level of output Y_1 (corn) without reducing that of Y_2 (wheat) and vice versa. In economic terms, the solution to the problem of the economic profitability of the investment for the entrepreneur who seeks to maximize profit with a given set of production factors [20]. As we know from economic theory, the possible combinations of the two products are arranged along the technical transformation curve, and along the curve, all the combinations of the two products have the same cost since one uses the same assigned amount of resources; in other words, they vary according to the allocation of the factors, i.e. as a consequence of their distribution between the two production processes [23]. Since the total cost along the curve remains constant, then for infinitesimal variations it can be said that:

$$\delta Y_1 C_{m1} = \delta Y_2 C_{m2} \quad (1)$$

The reduction in production of Y_1 (corn) implies a decrease in cost exactly compensated by the increase generated by the increase in production of Y_2 (wheat). Since total cost is given this allows us to carry out profit maximization in terms of total revenue:

$$R = P_1 Y_1 + P_2 Y_2 \quad (2)$$

Which can be written as the same revenue line:

$$Y_1 = (R/P_1) - (P_2/P_1) Y_2 \quad (3)$$

In analytical terms, the condition is expressed as equality between the marginal rate of transformation between products and the inverse ratio between the prices of the products:

$$SMT = \delta Y_1 / \delta Y_2 = - P_2 / P_1 \quad (4)$$

From the combination of (1) and (4) we have that:

$$P_1 / C_{m1} = P_2 / C_{m2} \quad (5)$$

The two terms of (5) represent the weighted marginal returns of the two products. In particular, (5) represents the optimal combination of the two products. If for Y_1 (corn) the marginal return were higher than that of Y_2 (wheat), there would be the possibility of increasing the total revenue and therefore the profit by changing the allocation of resources; conversely, once equality is reached, any change in the distribution of resources between the two processes would imply a loss of profit.

3. Results and discussion

The agricultural entrepreneur today is forced to choose between food and non-food production. How does he choose? This choice depends on several variables, first of all, his profit objective function. with the proposed methodology, a new method of calculating the economic convenience between food and non-food production is proposed to entrepreneurs. The agricultural sector is destined to play a strategic role in the production of energy from renewable sources. We can produce

biomass from the use of the soil and we can always install photovoltaic panels through the soil the economic policy of the European Union seems to be oriented precisely in this direction. The orientation that emerges from the Common Agricultural Policy (CAP) sees the promotion of specific policies aimed at the production of energy from renewable sources which in a certain sense aim at diversifying farmers' income. However, here we ask ourselves what role energy from renewable sources should play in the context of agricultural companies [24]. We believe that the role that the production of renewable energy must have within the farm must lower production costs or diversify farmers' income. The production of energy from renewable sources therefore represents a concrete means for farms to broaden the scope of their activities, beyond the mere production of quality food. However, it should not be underestimated that the production of agricultural products remains the *raison d'être* of the farm. Therefore, even if, depending on the climate emergency, the production of energy from renewable sources represents a main road to achieving objectives with a lower impact on the environment, we believe that the agricultural company must take care of producing products for human consumption mainly and the production of energy can represent a way to increase the company's competitive advantage based on lower costs (linked to the reuse of the energy produced in the production process) or to the diversification of income based on the higher revenues deriving from a possible sale of the energy produced [25]. Therefore, flexible agro-energy supply chains must be created, through the commitment to systematize the different ways of sustainable use of agricultural land, while the biomass plants that produce and use these forms of energy must be built, within a reorganized local territorial system. The proposed model makes it possible to evaluate the profitability of the production of energy from renewable sources both for use on the farm and for destinations on the market. In addition, the model allows for taking into account national and EU agricultural policy subsidies for energy crop producers. It must be said that the model illustrated here is somewhat lacking in terms of the representativeness of real farms according to the assumed constraints as we have assumed that prices remain constant and that the technique is constant. Be that as it may, we believe that it is a tool that we believe is an exceptional operational tool and far better than traditional analytical crop accounts [26]. Finally, it should be noted that, in the current scenario, for there to be real profitability in the production of energy from renewable sources, Italian agricultural enterprises should first overcome some weaknesses due to business fragmentation and the fragmentation of land bodies [27]. Therefore, and reality demonstrates it in the current production scenario in Italy but also the rest of the world, the production of energy from renewable sources in most cases is carried out by large farms which, among other things, sell the energy produced to the grid and they do not reuse, if not minimally, the energy produced in the corporate structure. The method finds application in those farms where they have to decide between food and non-food crops, and how much to invest in one crop or the other crop. The method presents itself as an innovation to the traditional analytical crop accounting methods widely used among agricultural companies to make choices.

4. Conclusions

The changing climate and international competition impose new scenarios for farms. If on the one hand, the economic policy authorities adopt policies aimed at the production of energy from renewable sources, on the other hand, the choice between the production of food and that of no food is imposed. In industrialized countries, as we know, agriculture contributes in a low way to the formation of the Gross Domestic Product of a country. In this scenario, for the farms operating in these industrialized countries, there are problems of choice that are influenced by the structural conditions. The production of energy from renewable sources such as photovoltaic certainly represents an opportunity for the community, however, the installation of panels on the

ground involves the loss of soil. The need to invest in the production and use of renewable energy sources has become a pillar of the broad debate involving public opinion around the world, so much so that it is universally perceived as an urgent issue that significantly contributes to a disturbing vision of our collective future. In this work, we have proposed a methodology that can guide the entrepreneur's choices given a set of fixed factors such as how he chooses between food and non-food production. It is in this context that the issues related to the further development of agro-energy sources must be addressed, even if agro-energy sources take due account of their specificity. For such a successful development, from an operational point of view, there must be a farmer's perception of tangible profitability, beyond incentives and subsidies, as a solid and economically viable investment. A crucial contribution in this sense can come from research, conducted at the scale of the single farm, aimed at highlighting both the territorial specificities and the possible benefits of the single farm. In the primary sector, perhaps more than elsewhere, the choice of productive investments must take into account the (often irreversible) changes induced by alternative management and use options of alternative management and use options of the territory and natural spaces. From the entrepreneur's point of view, these are high-risk transformations, the repercussions of which transcend the local scale of the single company. The growing demand for agricultural land intended for the cultivation of energy crops in the primary sector and the installation of photovoltaic panels also requires reliable assessments that take into account the interrelationships between the need to preserve the environment/landscape and the foreseeable trends of the agricultural and energy, while ensuring an interdisciplinary approach to macro and microeconomic analyses. The objective of converting the agricultural sector towards new production lines, therefore, appears difficult to pursue without a sector strategy that also protects agricultural production. In economically advanced countries, the creation of territorial agro-food systems appears to be a strategy to be pursued. The solutions are not simple but it is necessary to evaluate the territorial context by territorial context as well as by individual farm. For the future, we believe that agricultural companies, also due to their economic and social role, must remain such, i.e. companies that produce for the market. In his objective function, the entrepreneur must keep in mind his mission and the introduction of renewable energy must represent a way of ensuring that the agricultural company remains competitive without distorting its orientation towards the market of agricultural products where there is demand.

Declaration of competing interest

I have submitted the manuscript entitled "Circular economy and sustainable agri-food systems" to Journal of agriculture and food research. Special issue: "Perspectives on the emerging and trending science and technology in agriculture and food research".

I declare not to be in a conflict of interest Journal of agriculture and food research.

We hope that this manuscript can be taken into consideration for publication in to Journal of agriculture and food research.

Data availability

Data will be made available on request.

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